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

Murray hydrological studies: surface water, groundwater and environmental water

Land development, drainage and climate scenario report

Looking after all our water needs

Water*Science*
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Cover photograph: Aerial photograph of the Murray flowing into the Peel Inlet, facing east, J Hall (2010)

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Summary

This *land development, drainage and climate scenario report* is the final of three reports that comprise the 'groundwater studies' component of the *Murray drainage and water management plan* (DWMP). The objective was to use the numerical model for the Murray DWMP region to develop a suite of predictive runs and determine changes to water budgets and groundwater levels under various land development, drainage and climate scenarios. The report includes modelled regional scenarios and finer-scaled wetland scenarios. The wetland scenarios supported development of the wetland ecological water requirements (EWRs).

Scenarios for the Murray regional model included:

- **Land development scenarios** based on mapping from the *Draft south metropolitan and Peel structure plan – urban growth management strategy* (WAPC 2009). Development scenarios included 'current development', areas identified for 'immediate detailed investigation', and areas identified for 'further investigation'. Domestic bore abstraction was investigated in these regions.
- **Drainage scenarios** including depths of subsurface drains at ground level with 1.0 m clean-fill, drainage at 1.0 m below ground level (bgl) with no extra clean-fill and drainage at average annual maximum groundwater level.
- **Climate scenarios** were based on Intergovernmental Panel on Climate Change (IPCC) predictions, and included predictive changes in rainfall, evapotranspiration and sea-level rise. Sea-level rise scenarios included a 0.2 m increase for the 2031 climate scenarios, and a worst-case increase of 0.9 m for the year 2100. For the Murray DWMP project, the following climate scenarios were chosen, with respect to rainfall and evaporation:
  - future wet: -1.4% change in mean annual rainfall from 1975 – 2007
  - future medium: -8.7% change in mean annual rainfall from 1975 – 2007
  - future dry: -16.2% change in mean annual rainfall from 1975 – 2007
  - historical wet: +14.3% change in mean annual rainfall from 1975 – 2007

  The future wet, medium and dry scenarios represented the 10th, 50th and 90th percentile average annual rainfall for a suite of 45 scenarios generated from global climate models, predicted for a rainfall sequence for 2030. As such, the future wet climate scenario had marginally less rainfall than the current climate scenario.

Regional model scenarios

Fifteen regional model scenarios were simulated, which were a combination of the climate, drainage and development options. The results of the scenarios were presented both spatially and quantitatively (changes in water balance).

Climate scenarios predicted the following changes in average annual maximum and minimum groundwater levels (AAMaxGL and AAMinGL) for the Murray DWMP area, compared with the current climate scenario:

- future wet (S09): -0.04 m for AAMaxGL, -0.01 m for AAMinGL
- future medium (S18): -0.27 m for AAMaxGL, -0.09 m for AAMinGL
- future dry (S27): -0.56 m for AAMaxGL, -0.20 m for AAMinGL
- historical wet (S36): +0.42 m for AAMaxGL, +0.18 m for AAMinGL

Subsurface drainage was modelled in 11 development areas of the Murray DWMP region at a range of drainage depths. The quantity of subsurface drainage predicted for the developments ranged from 5 ML/year in the South Yunderup subregion, with drains at maximum groundwater level and a future medium climate scenario; to over 5000 ML/year for the Carcoola development for the future wet climate scenario and drains at 1.0 m bgl. The total drainage volume from all development areas was predicted to increase from 4.2 GL/year (base-case scenario with no development) to between 12 GL/year (dry climate, drains at ground level) and 22 GL/year (wet climate with the drains at 1.0 m bgl).

The drainage quantities listed in this report do not necessarily represent the quantity of water drained away from the development areas; rather they represent the water required for management at the development scale.

The effects of a 0.9 m sea-level rise are confined to the western coastal corridor and the region surrounding the Murray River to Pinjarra, where groundwater levels are predicted to rise by approximately 0.2 m by 2030. Most of the development areas are largely unaffected. The developments close to the Murray River (apart from Buchanans and Yunderup) are unlikely to be affected by the rise in groundwater because large depths to groundwater already exist in these areas.

Waterlogging (groundwater inundation) is predicted to be extensive throughout the DWMP area, and is most severe in the low-lying coastal plain, away from major rivers and sand dune systems.

Domestic bore abstraction was modelled for the development areas (at 800 kL/house/year, with 600 m^2 house blocks and 20% of houses using domestic bores). The use of domestic bores was predicted to have significant effects on subsurface drainage quantities and on minimum groundwater levels. Average annual minimum groundwater levels were predicted to decrease by approximately 0.6 – 0.9 m compared with a similar scenario without garden bores, increasing the potential of acid sulfate soil issues. The use of domestic bores was predicted to significantly decrease the subsurface drainage quantity – a decrease from 12.4 – 5.4 GL/year was predicted for the future medium climate scenario. The domestic bore abstraction quantities and installation rates are associated with high degrees of uncertainty. Results of the drainage and abstraction values for the domestic bore abstraction scenario are therefore indicative, because uncertainty in the model inputs is too large to have a high level of confidence in the absolute values.

Wetland scenarios

A suite of wetland scenarios was developed for the wetland EWR component of the Murray DWMP project. The wetland scenarios included climate change, subsurface drainage, hydrological zone analysis and an analysis of fringing sand dunes with respect to wetland hydrology. Future wet and future dry climate scenario inputs were identical to the Murray regional model.

The scenario involving analysis of the effect of removing fringing sand dunes was undertaken for the Scott Road, Benden Road, Greyhound Road and Airfield wetlands. All wetlands had predicted decreases in average maximum wetland water depth of less than 4% when the fringing sand dunes were removed. Greyhound Road wetland had the smallest change in average annual maximum wetland depth (less than 0.01 m or 1%); however, in this wetland the maximum depth was likely to be limited by the outflow drain invert level. Benden Road wetland had the largest proportion of dunes removed from its fringes, resulting in the largest decrease in average wetland depth (0.04 m or 3.1%).

The wetland hydrological zone analysis explored the effects of various drainage levels and zone radii on the wetland water regimes. The objective was to quantify the effect of various zone sizes on each wetland’s hydrological regime, for a range of subsurface drainage levels. For drains modelled at 1.0 m bgl, a hydrological zone radius of larger than 400 m was generally required for a minimum of 10% change in maximum wetland water level. At 0.5 m bgl, the zone requirements were much smaller than for drainage at 1.0 m bgl, however the results varied from wetland to wetland. For three of the eight wetlands analysed, a hydrological zone radius of 200 m was required for a decline in average annual water level of less than 10% and when drainage was modelled at AAMaxGL, six out of the eight wetlands modelled required a 200 m zone radius.

The future wet climate scenario predicted changes in average annual wetland depth ranging from a 1% increase (Barragup Swamp) to a 9% decrease (Airfield South) when compared with the current climate. The 1% increase in Barragup Swamp was likely to be due to the 0.2 m sea-level rise implemented for the future climate scenarios. The future dry climate scenario predicted decreases in average annual wetland depth ranging from 21% (Greyhound Road wetland) to 71% (Phillips Road wetland). The historical wet climate (1945 – 1974) predicted increases in maximum wetland depth ranging from 11% (Scott Road wetland and Greyhound Road wetland) to 42% (Airfield South wetland). Sea-level rise of 0.9m is predicted to influence one of the eight wetlands (Barragup Swamp): increasing the average annual wetland water level by approximately 0.21 m.

1 Introduction

The Western Australian Planning Commission, and local government authorities, have prioritised the development of structure plans for areas experiencing urban growth pressure. Structure plans provide a guide to the future development of the area and management of key environmental issues (WAPC 2007). A key step is the creation of a Drainage and Water Management Plan (DWMP) that sets the standard for total water cycle management in an area and provides a framework for more site-specific water management plans. A DWMP addresses the following aspects of the total water cycle:

- protection of significant environmental assets within the structure plan area, including meeting their water requirements and managing potential impacts from development
- water demands, supply options, opportunities for conservation and demand management measures and wastewater management
- surface runoff, including both peak event (flood) management and WSUD principles to be applied to frequent events
- groundwater, including the impact of urbanisation, variation in climate, installation of drainage to manage maximum annual groundwater levels, potential impacts on the environment and the potential to use groundwater as a resource
- water quality management, which includes source control of pollution inputs by catchment management, acid sulfate soil management, control of contaminated discharges from industrial areas and management of nutrient exports from surface runoff and groundwater through structural measures.

As part of the Murray region DWMP, the Department of Water's Drainage and Waterways Branch has instigated the following projects:

1. a floodplain development study including inundation and local catchment stormwater modelling
2. groundwater studies including regional pre-development groundwater levels, water balance modelling, climate impacts and extent of current waterlogged areas
3. ecological water requirements (EWRs) for wetlands within the study area
4. groundwater and surface water nutrient studies
5. preparation of a DWMP for the DWMP study area.

GHD Pty Ltd was contracted to prepare the DWMP for the Murray region, which integrates the results of the other studies. The Department of Water's Water Science Branch was commissioned to deliver the 'groundwater studies' project, as well as to provide the hydrological deliverables of the 'ecological water requirements and ecological study' component of the project.

The DWMP area includes a portion of the Swan Coastal Plain centred on Ravenswood, where there is flat terrain, significant waterlogging, wetlands of significance, and risk of riverine flooding. The study area extends from the Nambeelup Brook catchment in the north, Lower Serpentine River and Peel Inlet/Harvey Estuary in the west, Fauntleroy Drain catchment in the south and the Murray River/Darling Range foothills in the east.

The area specified for the groundwater studies, designated 'modelling boundary' in Figure 1-1, is larger than the DWMP area, and comprises the Murray regional model domain. The Murray model domain extends east to the Darling Fault, west to the Indian Ocean and Peel-Harvey estuary and approximately 5 km north and south of the DWMP study area to the boundary of Dirk Brook and Caris Drain.

1.1 Project objective

Groundwater studies

The purpose of the groundwater studies was to develop and calibrate a regional-scale groundwater model, and to use the model to run various climate and land-use change scenarios. The groundwater studies were re-named *Murray hydrological studies: surface water, groundwater and environmental water*, due to the region's high degree of surface water/groundwater interaction, the need to study both parts of its water regime, and the requirement to determine EWRs (environmental water) for wetlands. The model, referred to as the 'Murray regional model', is thus an integrated surface water/groundwater model, that reflects the nature of the local environment which has wetlands of significant size and value.

The primary objectives of the groundwater studies were to:

- deliver a calibrated regional-scale groundwater model
- develop and run a suite of scenarios
- deliver associated maps and ESRI shapefiles.

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

- maximum, minimum, average annual maximum and average annual minimum groundwater levels (MaxGL, MinGL, AAMaxGL and AAMinGL)
- water balance modelling including changes in groundwater discharges, interaction with surface water and environmental water
- likely impacts of acid sulfate soils (ASS)
- re-use opportunities such as community bores and surface detention
- likely areas of waterlogging
- flows in drains and tributaries
- flood, drought, wet, dry, average year and climate change impacts
- impacts on water-dependent ecosystems (wetlands) and ecology
- guidance for drainage design (surface water and groundwater infrastructure).

Ecological water requirements and ecological study

The purpose of the project's EWR component was to provide a detailed hydrological assessment of key wetlands within the study area, which was used to predict wetland water levels under various climate and land-use conditions. EWRs are defined as the water regimes needed to maintain the ecological values of water-dependent ecosystems at a low level of risk. It is necessary that EWRs are primarily based on the water requirements of wetland vegetation, with limited consideration of other factors. This EWR study required a detailed vegetation survey, analysis and subsequent report. GHD was contracted to conduct the vegetation study, analyse the hydrological regimes and prepare the report.

For this EWR study, the delivery of the hydrological components included the estimated surface water and groundwater inflows, outflows, and water levels from the modelling of the key wetlands identified by an EWR technical advisory group. The vegetation science component, drilling, monitoring, analysis and reporting will be delivered by GHD.

Integration

The Murray regional model primarily provides groundwater levels and flows, but also information on surface water flows, groundwater interactions, waterlogging, and groundwater summaries including MinGL, MaxGL, AAMaxGL and AAMinGL for all modelled scenarios. This allows for a controlled groundwater level (CGL) to be developed, taking into account the wetland EWRs.

The Water Science Branch's specific deliverables for the EWR study were to describe the current and predicted hydrology for each of the wetlands, taking into account land use and climate change. The ecological team from GHD then assessed the potential impacts on the wetlands and specified an EWR for each wetland.

The groundwater and EWR components of the project have been guided by their respective technical advisory groups. The groundwater studies group comprised members of the Drainage and Waterways, Water Allocation Planning, Water Science and Water Resource Assessment branches of the Department of Water. The EWR group included staff from the Department of Environment and Conservation (DEC), Department of Water and GHD.

1.2 Scope of work

The scope of the Murray hydrological studies was broadly divided to three phases. Each phase produced its own detailed scientific report, which was reviewed before the subsequent phase was undertaken. The three phases of the groundwater/surface water component of the study include:

1. Developing a conceptual groundwater/surface water model and steady-state water balance model for the Murray study area including:
    - a review of relevant literature
    - description of the study area
    - description of the climate and hydrology

- interpretation and development of a three-dimensional conceptual model of the geology
- definition of all aquifers and major hydrogeological processes
- a description of the hydrological and hydrogeological processes and parameters
- a numerical steady-state water balance conceptual model that includes surface water, groundwater and the interaction between them.

This project phase was described in the *conceptual model report* (Hall et al. 2010a).

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

   The Murray regional model was constructed using the modelling software package Mike SHE, and was based on the conceptual hydrogeology and hydrology described in the *conceptual model report*. The model was constructed using available geological, hydrogeological, hydrological, soil and land-use information. The Murray regional model consisted of unsaturated zone, saturated zone, channel flow and overland flow components. It had a constant grid spacing of 200 m, and covered an area of approximately 720 km^2.

   The calibration period was from 1985 – 2000 and validation was from 2000 – 2009. The model's calibration was adequate for relative assessment of changes in groundwater levels in the model due to changes in climate, land use and drainage. A sensitivity analysis was undertaken for the model's major parameters. A detailed description of the numerical model is outlined in the *construction and calibration report* (Hall et al. 2010b).

3. A suite of scenarios were implemented to determine the change to water budgets and groundwater levels under various land-use and climate scenarios. The technical advisory group presented the scenarios to the Water Science Branch, which included:

   - **Land development scenarios:** using mapping from the *Draft south metropolitan and Peel structure plan – urban growth management strategy* (WAPC 2009). The future development scenarios included regions identified for 'immediate detailed investigation' and those for 'further investigation'. Domestic bore use was investigated in these regions.
   - **Drainage scenarios:** a range of depths of subsurface drainage were simulated for the development areas to determine the effect on the regional aquifer and to determine drainage quantities. Drainage levels included drains at surface level with 1.0 m fill, drainage at 1.0 m bgl with no extra clean-fill, and drainage at AAMaxGL.
   - **Climate scenarios:** a range of future climate scenarios were simulated to account for various possibilities in changing rainfall and evapotranspiration. The climate scenarios were based on IPCC predictions, and included predictive changes in rainfall, evapotranspiration and sea-level rise.

The results of the scenarios are presented both spatially and quantitatively (changes in water balance) in this report. An analysis of catchment waterlogging was undertaken for each climate scenario, and water balances were undertaken to determine drainage quantities for various subsurface drainage depths and development scenarios.

The three phases of the EWR hydrological studies component of the project have the following scope:

1. Characterisation and conceptualisation of the wetlands included in the EWR. This involved the determination of the appropriate drivers for wetland water levels, based on available literature and data gathered from hydrogeological measurements and stratigraphy interpretation from GHD's recent drilling program. This project phase was described in the *conceptual model report* (Hall et al. 2010a).
2. Construction and calibration of finer-grid-scale wetland models using modelling results from phase 2 of the surface water and groundwater studies. Detailed calibration of fine-scaled models were completed using data collected during the 2009 winter by Department of Water staff. Boundary conditions for wetland models were taken from the Murray regional model. Five separate wetland models were used to model the eight key wetlands. Scott Road wetland and Benden Road wetland were included in the same model, as were Lakes Road wetland Greyhound Road wetland and Airfield wetland. The five models were set up with grids ranging between 30 and 50 m, and calibrated over the period 2000 – 2009. This phase was described in the *construction and calibration report* (Hall et al. 2010b).
3. A suite of predictive runs to determine the change to water budgets and wetland water levels under various land use, climate and drainage scenarios. The technical advisory group together with GHD presented the scenarios to the Water Science Branch. The scenarios were approved by the Murray DWMP technical advisory group and included:
    - **Climate scenarios:** these were equivalent to those undertaken for the regional model (in the surface water and groundwater component of the study). The climate scenarios were based on IPCC research, and included predictive changes in rainfall, evapotranspiration and sea-level rise where relevant.
    - **Sand dunes analysis:** the effect of removing fringing sand dunes was undertaken to determine the change in water levels and periods of inundation for the relevant key wetlands.
    - **Hydrological zone analysis:** a suite of wetland hydrological zones (zones around wetlands where abstraction or drainage is not allowed) and subsurface drainage depths were used to determine the effect of wetland hydrological zone radii and drainage depths on wetland water regimes. Drainage levels included drains at 0.5 m bgl, drainage at 1.0 m bgl and drainage at AAMaxGL.

    The results of the wetland scenarios were extracted for pre-defined vegetation transects within the wetlands, and delivered to GHD to develop EWRs for the wetlands.

2 Murray regional model scenarios: background and model implementation

2.1 Land development scenarios

Development scenarios were undertaken using mapping from the draft *South metropolitan and Peel structure plan – urban growth management strategy* (WAPC 2009). The structure plan is a strategic document (non-statutory) to guide the planning and management of growth and development in these regions until 2031, through a broad set of policy principles and responsibilities. The plan informs and guides the following:

- the preparation of strategic and statutory plans and policies: by landowners, land and infrastructure developers, and by certain state government agencies
- the 'consideration for approval process' of district and local structure plans by the state government agencies, local governments and the WAPC.

The structure plan is the culmination of three years' work including a land capability and suitability assessment, traffic and transport modelling, and stakeholder consultation. Associated with this process was preparation of a policy statement that identified specific land areas (designated as 'urban growth management policy areas'), where land and infrastructure development was either encouraged or discouraged. The plan identifies three distinct areas:

- areas under 'immediate detailed investigation' for development and/or protection
- areas under 'further investigation'
- areas not under consideration for urban development.

The areas under 'immediate detailed investigation' and those under 'further investigation' within the Murray region determined the development scenario areas for the Murray DWMP (Figure 2-1). The combined development areas cover 84.1 km^2, with 38 km^2 identified for 'immediate detailed investigation'. The Department of Water's Drainage and Waterways Branch further subdivided the development areas into 11 development subareas for the purposes of reporting based on catchments (Figure 2-2). Water balance fluxes for each of the simulations are reported specifically for each of the 11 development subareas.

Domestic bores are used extensively on the Swan Coastal Plain to water urban gardens and lawns. Table 2-1 shows the indicative water use from domestic bores (DoW 2009). The average bore installation rate indicates the percentage of properties that may install a bore. The figures provided are generic for the Perth metropolitan region, and do not account for the considerable variation that occurs between areas.

Table 2-1: *Indicative water use from domestic bores (DoW 2009)*

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

Modelling implementation of development scenarios

Urban development was implemented in the Murray regional Mike SHE model by changing the land-use properties of the development areas. The values of leaf area index (LAI) and root-depth were set to replicate recharge rates of approximately 40 – 50% in the new land-use areas. This rate reflected urban recharge rates that were studied in detail during the Swan Coastal Plain PRAMS modelling project (Davidson & Yu 2006), and corresponded to values used in the PRAMS vertical flux model (Xu et al. 2009). The 'development' land class had a LAI of 0.8 and a root-depth of 500 mm, which corresponded to a gross recharge rate of between 40 and 50% for the development areas in the current climate rainfall and evapotranspiration regime.

Domestic garden bore abstraction was implemented by adding abstraction bores to each cell of the Mike SHE model that had urban development land use. The technical advisory group requested an average lot size of 600 m^2 be used in the modelling exercise. 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's policy document (DoW 2009), and 600 m^2 blocks corresponded to a rate of 20%. A bore installation rate of 20% was therefore used in the modelling scenario. The following technique was used to determine abstraction quantities for each of the domestic bores:

- the total area of the development scenarios was calculated (84.1 km^2): 65% of this area was assumed to be urban lots (55.7 km^2)
- the urban area was divided into 600 m^2 lots, and 20% of the lots (one in five) were assumed to have a domestic bore (the assumed abstraction at each of them was 800 kL/year)
- the total abstraction quantity was divided equally into each of the grid cells in the model, at a constant rate of abstraction between October and May.

2.2 Drainage scenarios

To protect infrastructure and assets from flooding and damage from groundwater, sufficient clearance from maximum groundwater levels must be provided and maintained by groundwater drainage, earthworks, innovative 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 sustained seasonal inundation and the needs of the underlying aquifers, water-dependent ecosystems and waterbodies – while considering the mobilised groundwater as a resource and ensuring that the outlets of the system are free-draining.

To explore the effect of a variety of possible groundwater drainage levels, the technical advisory group requested four drainage scenarios be modelled as part of the Murray DWMP regional model scenarios:

- drainage at 1.0 m bgl
- drainage at ground level, with 1.0 m of fill placed on top of the ground surface
- drainage at AAMaxGL with at least 1.0 m of fill above the phreatic line, noting that more than 1.0 m of soil will be above the phreatic line when the distance to AAMaxGL is greater than 1.0 m (the AAMaxGL used in the drainage layer was the modelled AAMaxGL for the years 1978 – 2007)
- drainage at maximum groundwater level (MGL), with at least 1.0 m of fill above the phreatic line (the MGL used in the drainage layer was the modelled MGL for the years 1978 – 2007).

Modelling implementation of drainage scenarios

Drainage was implemented by use of the subsurface drainage module in Mike SHE. In Mike SHE, saturated zone drainage is a special condition used to define natural and artificial drainage that cannot be defined in Mike 11. Drain-flow is simulated using an empirical formula. Each cell requires a drain level and a time constant (leakage factor). Both drain levels and time constants can be spatially defined, and drain levels were defined only for regions where development was taking place. When groundwater reaches the level of the drains, Mike SHE gives the following options:

1. drainage can be routed downhill based on adjacent drain levels
2. drainage can be forced to a certain region of the model (using grid codes)
3. drainage not routed, but removed from the model.

For the purpose of the urban subsurface drainage scenarios, option 3 was selected. Therefore any subsurface drainage was removed from the model, allowing the quantity of drainage water to be calculated for each scenario (the quantity removed from the model). The changes to the base-case model to account for the 1.0 m bgl drainage scenario were as follows:

- For scenarios with drainage at ground level with 1.0 m of fill, the topography was adjusted. Then 1.0 m was added to the development areas to create a new topography layer. The hydraulic properties of the fill were assumed to be the same as Bassendean Sand. It should be noted that 1.0 m of fill is an approximate yet arbitrary figure and does not directly relate to the actual fill amount that individual site designs or other organisations might require.
- A subsurface drainage layer was developed and implemented 1.0 m below the topography. The drainage layer is shown in Figure 2-3.

- The drainage time-constant was set to ensure that all groundwater coming into contact with the drains was removed before the following time-step.

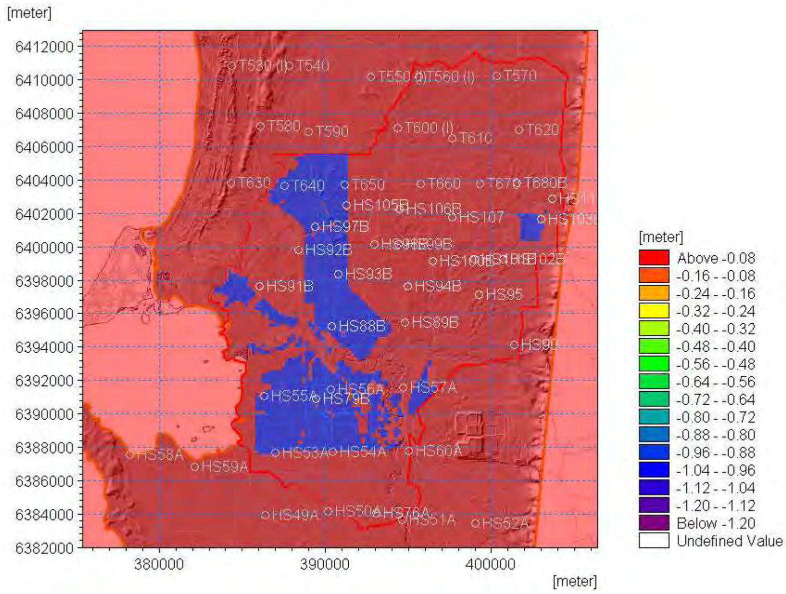


Figure 2-3: *Model drainage layer, for drainage at 1.0 m bgl*

Changes to the base-case scenario to account for drainage at AAMaxGL and MaxGL were as follows:

- the AAMaxGL (or MaxGL) was abstracted from the base-case scenario (the technical advisory group requested the AAMaxGL for drainage be based on the current climate regime) for the development areas
- the topography was compared with the AAMaxGL layer, and where there was less than 1.0 m of soil above the AAMaxGL, the topography was adjusted to 1.0 m above the AAMaxGL
- the drainage layer was created by subtracting the new topography from the AAMaxGL for the development areas, to give a drainage depth below ground level
- the drainage time-constant was set to ensure that all groundwater coming into contact with the drains was removed before the following time-step.

The reported drainage volume indicates the quantity of water requiring management for each of the development areas. It includes the sum of the surface water drainage (channel flow), overland flow, and subsurface drainage produced within the development areas, and does not include inflows from upstream. It does not necessarily represent the volume of water that is lost from the development area to downstream waterways. For example, the drainage volume can be directed internally in development areas, and can be used by constructed lakes, wetlands or raingardens. It may then be available for re-use, or if the residence time in these regions is large, a significant quantity of the water is likely to evaporate.

Scenarios involving internal drainage and water management practices at a development scale are outside the Murray DWMP project's scope (the model grid-size of 200 m is prohibitive for a more detailed drainage design). The drainage presented in the Murray DWMP Mike SHE model is conceptual: the regional model is not designed to be used as a detailed drainage tool. However, the regional model does provide first-pass estimates of drainage quantities that are likely arise in the various development areas for a range of subsurface drainage levels and climate scenarios.

In practice there is likely to be marginally less drainage than predicted in the modelling. The modelling assumes the entire catchment is underlain with subsurface drains, because structure plans are not available to define drainage at a finer scale. In reality, significant areas within developments will not require subsurface drainage (where there is no infrastructure or assets that require protection). As such, a less extensive subsurface drainage network would be likely to result in lower drainage quantities.

2.3 Climate scenarios

International research reviewed by the IPCC indicates a warming world is leading to significant changes in regional climates. Evidence for global climate change includes:

- 11 of the last 12 years rank among the 12 warmest years in the post-1850 instrumental record of global surface temperature
- a linear global warming trend over the past 50 years of about 0.13℃ per decade increasing to 0.18℃ per decade since the mid-1970s
- widespread warming of the atmosphere and ocean, and ice mass loss.

The IPCC (2007) concludes that most of the observed increase in global average temperature since the mid-20th century is very likely attributable to the observed increase in anthropogenic greenhouse gas concentrations.

To estimate future climate change, scientists have developed emission scenarios for greenhouse gases and aerosols that account for future human activities such as energy generation, transport, agriculture, land clearing and industrial processes. The IPCC *Special Report on Emission Scenarios* (SRES) (IPCC 2000) prepared 40 greenhouse gas and sulfate aerosol emission scenarios for the 21st century that combine a variety of assumptions about demographic, economic and technological factors likely to influence future emissions. Each scenario represents a variation within one of four ‘storylines’ giving projected carbon dioxide, methane, nitrous oxide and sulfate aerosol emissions until 2100.

The ‘storylines’ predicted by the IPCC were used to derive three projections of the temperature change by ~2030 relative to ~1990: a low global warming of 0.7℃ (low end of SRES scenario B1), medium global warming of 1℃ (av erage of the low and high global warming scenarios), and high global warming of 1.3°C (high end of SRES scenario A1T).

Regional climate change resulting from global warming (including predictions in rainfall and evaporation) is best assessed by global climate model (GCM) simulations. Despite rapid improvements in climate modelling during the past few decades, different GCMs will produce a range of future projections, which commonly form a large source of prediction uncertainty at a regional scale. The other main form of uncertainty in future climate prediction is that associated with the magnitude of global warming (the uncertainty of the ‘storyline’ predicted by the IPCC).

The future climate scenarios for the Murray DWMP were selected using the methodology and data from the South-West Western Australia Sustainable Yields (SWSY) project (CSIRO 2009). The SWSY project produced a series of reports examining the likely water yield of surface water and groundwater catchments in the state's south-west as a result of future climate changes and possible land management changes.

The methodology used in the SWSY project accounted for both forms of uncertainty mentioned above. To account for uncertainty in GCM simulation for future climate scenarios, the project used 15 GCMs (shown in Table 2-2). To account for uncertainty in global warming, each of the GCMs was simulated for low (0.7℃), medium (1.0℃) and high (1.3℃) global warming scenarios for ~2030 relative to ~1990.

Table 2-2: *Global climate models used in analysis*

Global climate model	Modelling group, country
CCCMA T47	Canadian Climate Centre, Canada
CCCMA T63	Canadian Climate Centre, Canada
CNRM	Meteo-France, France
CSIRO-MK3.0	CSIRO, Australia
GFDL 2.0	Geophysical Fluid, Dynamics Lab, USA
GISS-AOM	NASA/Goddard Institute for Space Studies, USA
IAP	LASG/Institute of Atmospheric Physics, China
INMCM	Institute of Numerical Mathematics, Russia
IPSL	Institut Pierre Simon Laplace, France
MIROC-M	Centre for Climate Research, Japan
MIUB	Meteorological Institute of the University of Bonn, Germany
	Meteorological Research Institute of KMA, Korea
MPI-ECHAM5	Max Planck Institute for Meteorology DKRZ, Germany
MRI	Meteorological Research Institute, Japan
NCAR-CCSM	National Center for Atmospheric Research, USA
NCAR-PCM1	National Center for Atmospheric Research, USA

The steps involved in producing 45 (15 GCMs by 3 global warming scenarios) future climate series of daily rainfall and potential evapotranspiration (APET) were as follows:

1. GCM daily rainfall time-series data was extracted and processed for 1981 – 2000 and 2046 – 2065 and monthly climate time-series for 1870 – 2100 for the 15 GCMs.
2. The monthly climate time-series data was used to calculate 'seasonal scaling' factors for changes in mean seasonal rainfall and other climate variables per degree global warming. This was achieved by regressing the mean seasonal climate variables against global average temperature simulated by the GCM, where the gradient of the linear relationship gives the change in the climate variable per degree global warming. The seasonal scaling factor was expressed as a percentage change (except for temperature where an absolute change is used) per degree global warming by dividing the absolute change by the mean value of the variable over 1981 – 2000. These seasonal scaling factors were calculated for the four seasons for each GCM grid cell overlying the region for rainfall, temperature, relative humidity, and incoming solar radiation.

3. For rainfall, distributional differences between 2046 – 2065 and 1981 – 2000 GCM daily rainfall were used to calculate ‘daily scaling’ factors (percentage change in daily rainfall percentile per degree of global warming) for each rainfall percentile class on a seasonal basis. To obtain smooth transitions in the daily scaling factors, the percentage changes per degree global warming were estimated by averaging the rainfall amounts over percentile ranges: 1st percentile (all points smaller than 2nd percentile), 5th percentile (all points between 2.5th and 7.5th percentiles), 10th percentile (all points between 7.5th – 12.5th percentiles), and every five-percentile range upwards to a highest category, where all the small rainfall amounts were considered together. The highest category bound was defined by the percentile at which the observed rainfall was less than 1 mm, or the 30th percentile if the percentile at which the observed rainfall was less than 1 mm was above the 30th percentile. Therefore, if the highest category bound was the 30th percentile, all rainfall amounts above the 30th percentile were lumped together and used to determine the single value of percentage change per degree of global warming for rainfall amounts above the 30th percentile.
4. For each of the 15 GCMs and each of the three global warming scenarios, the daily scaling factors were used to scale the different daily rainfall amounts in the current-climate daily rainfall series to obtain 33 years of daily rainfall series for a ~2030 relative to ~1990 climate. This daily scaling approach accounts for different changes in the different rainfall amounts, but assumes the future daily rainfall sequence of rain days is the same as the current climate sequence. The entire series was then re-scaled, using the seasonal scaling factors, to ensure the mean rainfalls in the four seasons were the same as those resulting from seasonal scaling. This was done because the seasonal scaling factors were determined using a large amount of data (1871 – 2100) from several ensemble runs, while the GCM simulations used to estimate the daily scaling factors were only available for two 20-year time slices (2046 – 2065 and 1981 – 2000) from limited modelling runs.

The consideration of changes in the daily rainfall distribution was important because many GCMs indicate that future extreme rainfall in an enhanced greenhouse climate could be more intense, even in regions where a decrease in mean seasonal or annual rainfall is projected.

As the future climate series were obtained by scaling the historical daily climate series from 1975 – 2007, the daily climate series for the two series (~1990 and ~2030) had the same length of data (33 years) and the same sequence of daily climate (e.g. potential changes in the frequency and timing of daily rainfall are not considered). The future climate series were therefore not a forecast climate at 2030, but a 33-year daily climate series based on 1975 – 2007 data scaled for projected global temperature at ~2030 relative to ~1990.

Figure 2-4 shows the percentage change in mean annual rainfall of the 45 future climate scenarios relative to the 1975 – 2007 climate. The future wet, future medium and future dry climate scenarios represent the 10th, 50th and 90th percentile of the change in average annual rainfall for all 45 GCM scenarios, predicted for a rainfall sequence for the year 2030. As such, the future wet climate scenario had marginally less rainfall than the current climate scenario. For the Murray modelling domain (the Murray Basin) the scenarios selected for future climate were:

- future wet: -1.4% change in mean annual rainfall from 1975 – 2007 (Parallel Climate Model from National Centre for Atmospheric Research, USA [NCAR PCM], warming scenario 1℃)
- future medium: -8.7% change in mean annual rainfall from 1975 – 2007 (Meteorological Research Institute, Japan [MRI], warming scenario 0.7℃)
- future dry: -16.2% change in mean annual rainfall from 1975 – 2007 (MRI, warming scenario 1.3℃).

A summary of the seasonal and annual percentage changes in rainfall and evapotranspiration for the future wet, medium and dry climate scenarios are shown in Table 2-3. Seasonally, most GCMs display trends in decreased winter rainfall. MRI predicts a 10 – 20% decrease in winter rainfall for the 1℃ temperat ure rise, whereas NCAR PCM predicts very little change in winter rainfall. Most GCMs predict a decrease in autumn rainfall, and MRI predicts a 5 – 20% decrease in autumn rainfall. In contrast, NCAR PCM predicts a 2 – 5% increase in autumn rainfall. Summer rainfall predictions vary between GCMs: MRI shows very little change in average annual summer rainfall, and NCAR PCM predicts a 2 – 5% increase in summer rainfall for the 1℃ temperature rise. All GCMs predict a decrease in spring rainfall: MRI predicts a 10 – 20% decrease and NCAR PCM predicts a 5 – 10% decrease for the 1℃ scenario in the Murray Basin. Evapotranspiration values increased by between 2 – 3%, and were consistent for most GCMs.

Table 2-3: *Percentage changes in seasonal and annual rainfall and evapotranspiration for future dry, medium and wet climate scenarios*

Climate	**Future dry climate**		**Future medium climate**		**Future wet climate**	
GCM	**MRI +1.3°C**		**MRI +0.7°C**		**NCAR PCM +1°C**	
% change	**Rainfall**	**EVT**	**Rainfall**	**EVT**	**Rainfall**	**EVT**
Summer	2.3	2.5	1.0	1.3	4.5	2.1
Autumn	-12.7	3.3	-7.0	1.8	3.3	2.8
Winter	-19.5	3.9	-10.6	2.1	-1.6	3.4
Spring	-15.2	2.7	-8.2	1.5	-7.8	2.3
Annual	-16.2	3.1	-8.7	1.7	-1.4	2.7

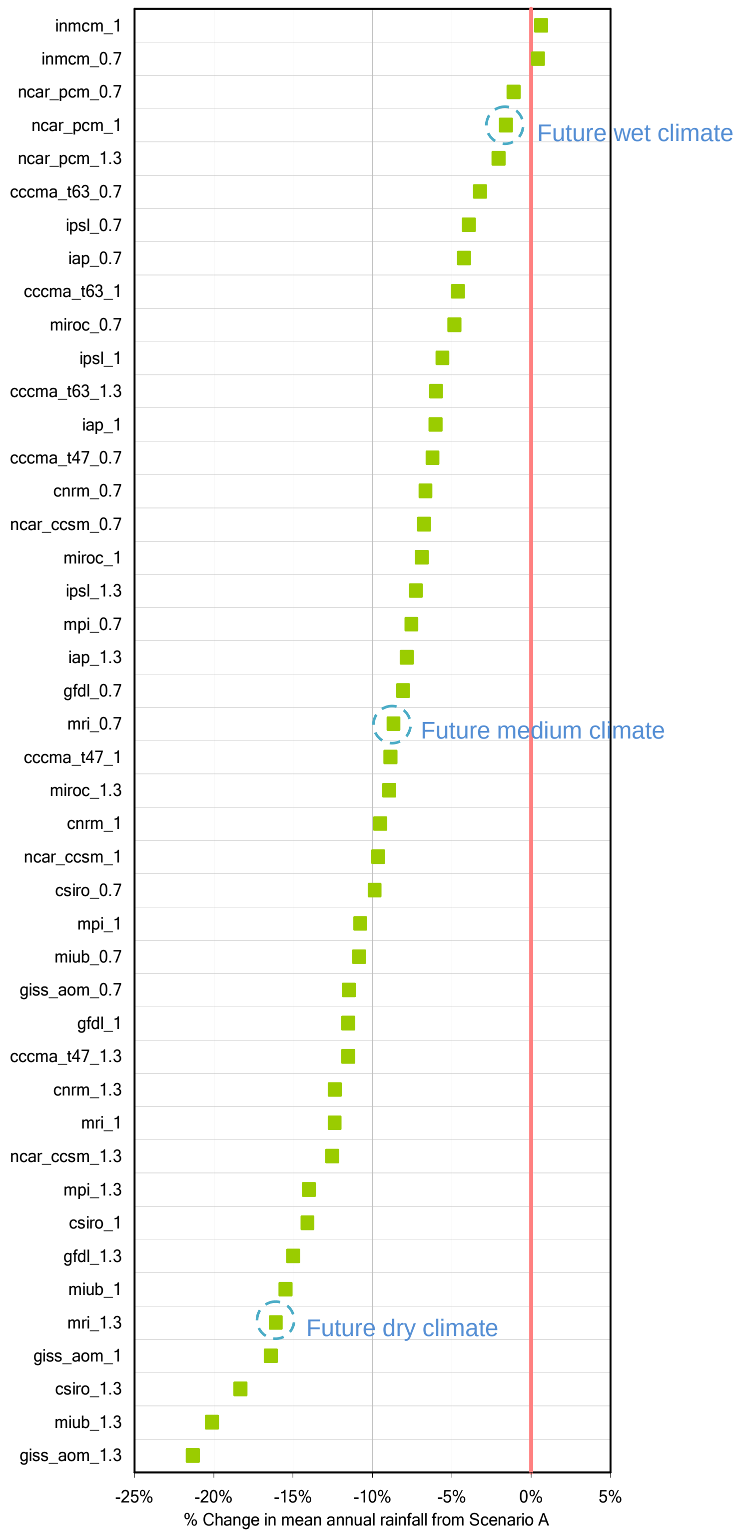


***Figure 2-4**: 45 GCM scenarios versus change in mean annual rainfall from current scenario. Future wet, medium and dry scenarios represent 10th, 50th and 90th percentile of change in annual rainfall.*

In addition to the future climate scenarios, the technical advisory group requested that the Water Science Branch simulate a historical 30 years of rainfall from the past century. The 30-year period for the simulation was 1945 –1974, which experienced significantly more precipitation than for the past 30 years. The SILO data was used to derive the 'historical wet' scenario. See Table 2-4 for seasonal changes in rainfall and evapotranspiration for the 'historical wet' period compared with the base-case period (1978 – 2007).

***Table 2-4**: Change in seasonal and annual rainfall and evapotranspiration for the 'historical wet' scenario*

Season	Rainfall (mm)			Evapotranspiration (mm)		
	Current 1978 - 2007	Historical wet 1945 - 1974	Change (%)	Current 1978 - 2007	Historical wet 1945 - 1974	Change (%)
Autumn	177	205	16.1	302	287	-4.8
Spring	167	165	-1.0	356	340	-4.6
Summer	42	37	-11.7	530	516	-2.8
Winter	456	560	22.7	158	150	-4.9
Total	841	967	14.9	1347	1293	-4.0

Modelling implementation of future climate data

Daily rainfall for each of the 45 GCM scenarios developed as part of the SWSY project were processed as described above, and extracted at each of the SILO data-drill locations. For the Murray regional model, 1978 – 2007 was the climate sequence used for current climate predictive scenarios, and 2010 – 2039 for future climate scenarios. Both periods contained 30 years of daily rainfall and evapotranspiration data, so statistics and results for each could be compared directly. The evapotranspiration was adjusted from the current SILO Penman-Montieth evapotranspiration seasonally, according to the values shown in Table 2-4.

Rainfall locations (Figure 2-5) and climate and evaporation zones (Figure 2-6) used in the future climate predictive scenarios corresponded to the nine locations used for the current climate scenarios for the Murray regional model. This spatial and temporal resolution of the future climate scenario data allowed for direct and unbiased comparison between future and current climate scenarios.

The climate data was also used for the Streamflow Quality Affecting Rivers and Estuaries (SQUARE) model to develop surface-water-inflow boundary conditions for the channel flow model (Mike 11). The SILO rainfall data was implemented at the centroid of each of the surface water catchments, and the surface water models run for the equivalent 30-year period to the regional model climate scenarios. Average annual inflow quantities for each of the Mike 11 inflow boundaries and each of the climate scenarios are shown in Table 2-5.

Table 2-5: *Average annual surface-water-inflow quantities for each of the climate scenarios*

Inflow from waterway (GL/yr)	Current	Future wet	Future medium	Future dry	Historical wet
Serpentine River	88.9	88.3	60.5	38.3	204.7
Coolup Drain	7.3	7.1	5.4	4.1	13.7
North Dandalup Tributary	1.0	1.0	0.9	0.7	1.7
Conjuranup Creek	10.7	10.5	8.7	7.2	17.2
Oakley Brok	2.7	2.7	2.2	1.8	4.4
Murray River	267.5	261.5	216.8	176.3	780.4

Sea-level rise

Current sea-level rise has occurred at a mean rate of 1.8 mm/year for the past century. More recently, rates have been estimated near 2.8 to 3.1 mm/year (1993 – 2003) (IPCC 2007). The IPCC predicts maximum sea-level rise of 0.59 m for the year 2100; however, additional contribution from a dynamic response of the Greenland and Antarctic ice sheets to global warming is not included in this prediction. To account for both contributions, the technical advisory group requested that the Water Science Branch implement a worst-case scenario of 0.9 m sea-level rise by the year 2100 for the Murray DWMP project.

3 Murray regional model scenarios: results and analysis

A list of possible future scenarios were constructed using a combination of potential climate, subsurface drainage and development options. The resulting matrix had a total of 36 potential scenarios that could be compared with the current condition (base-case) scenario. Of the 36 scenarios, it was agreed that Water Science Branch would run a maximum of 15, which would be distributed over three scenario phases. The technical advisory group identified the scenarios for Water Science Branch to simulate. The results of the first phase of scenarios were used to inform the selection of scenarios for subsequent phases.

In addition to the matrix of 36 potential scenarios, the technical advisory group requested that the historical wet scenario (using rainfall from 1945 – 1975) and a scenario simulating the effect of worst-case sea-level rise be included – creating a total of 38 possible scenarios. The matrix of potential scenarios and the selection of scenarios for each of the three phases are shown in Table 3-1.

Each of the scenarios reported water balance and spatial results. Spatial results were delivered to the Drainage and Waterways Branch as electronic contours (polyline shape files), rasters (suitable for GIS software) and ASCII grids. Spatial results for each scenario included AAMaxGL, AAMinGL, AveGL, MaxGL and MinGL.

The following section outlines the implementation of each of the 15 scenarios and discusses their results. All simulations were generated using 30 years of data. Water balances were calculated using the post-processing water-balance module included in the suite of tools associated with the Mike SHE software. The water balance tool was used to calculate the average annual water balance for the Murray regional model as well as the model subareas for the entire 30-year period of the simulation (excluding the model spin-up period). The flow-rate and source-of-flow components were integrated over the period to obtain cumulative volumes. Water balances for all fluxes for each of the scenarios at each of the development areas are shown in Appendix A.

Table 3-1: *Table for the selection of regional model scenarios*

Scenario number	Climate scenario	Subsurface drainage scenario	Development scenario	Done
S0	Current climate	No drains	current	✓
S1	Current climate	Ground level with 1m fill	current + immediate	
S2	Current climate	Ground level with 1m fill	current + immediate + further	
S3	Current climate	0.5 mBGL with 0.5m fill	current + immediate	
S4	Current climate	0.5 mBGL with 0.5m fill	current + immediate + further	
S5	Current climate	1 mBGL with 0m fill	current + immediate	
S6	Current climate	1 mBGL with 0m fill	current + immediate + further	
S7	Current climate	Drains at AAMaxGL	current + immediate	
S8	Current climate	Drains at AAMaxGL	current + immediate + further	
S9	Future wet climate	No drains	current	✓
S10	Future wet climate	Ground level with 1m fill	current + immediate	
S11	Future wet climate	Ground level with 1m fill	current + immediate + further	✓
S12	Future wet climate	0.5 mBGL with 0.5m fill	current + immediate	
S13	Future wet climate	0.5 mBGL with 0.5m fill	current + immediate + further	
S14	Future wet climate	1 mBGL with 0m fill	current + immediate	
S15	Future wet climate	1 mBGL with 0m fill	current + immediate + further	✓
S16	Future wet climate	Drains at AAMaxGL	current + immediate	
S17	Future wet climate	Drains at AAMaxGL	current + immediate + further	
S18	Future medium climate	No drains	current	✓
S19	Future medium climate	Ground level with 1m fill	current + immediate	
S20	Future medium climate	Ground level with 1m fill	current + immediate + further	✓
S21	Future medium climate	0.5 mBGL with 0.5m fill	current + immediate	
S22	Future medium climate	0.5 mBGL with 0.5m fill	current + immediate + further	
S23	Future medium climate	1 mBGL with 0m fill	current + immediate	
S24	Future medium climate	1 mBGL with 0m fill	current + immediate + further	
S25	Future medium climate	Drains at AAMaxGL	current + immediate	
S26	Future medium climate	Drains at AAMaxGL	current + immediate + further	✓
S27	Future dry climate	No drains	current	✓
S28	Future dry climate	Ground level with 1m fill	current + immediate	
S29	Future dry climate	Ground level with 1m fill	current + immediate + further	✓
S30	Future dry climate	0.5 mBGL with 0.5m fill	current + immediate	
S31	Future dry climate	0.5 mBGL with 0.5m fill	current + immediate + further	
S32	Future dry climate	1 mBGL with 0m fill	current + immediate	
S33	Future dry climate	1 mBGL with 0m fill	current + immediate + further	✓
S34	Future dry climate	Drains at AAMaxGL	current + immediate	
S35	Future dry climate	Drains at AAMaxGL	current + immediate + further	
S36	Historical wet climate	No drains	current	✓
S37	Maximum sea level rise	No drains	current	✓
S38	Wet climate, 1955 rainfall	No drains	current	✓
S39	Future medium climate	Drains at MaxGL	current + immediate + further	✓
S40	Future medium climate	Ground level, 1m fill, domestic bores	current + immediate + further	✓

3.1 Base case scenario (S0)

The base-case scenario (S0) represents current conditions, and uses the parameters derived from the model calibration. The base-case scenario was simulated over the 30-year period between the years 1978 – 2007 (with an additional five years of model spin-up period from 1973 – 1978). A detailed description of the base-case model parameters and water balance is presented in the *construction and calibration report* (Hall et al 2010b). Model contours and raster outputs for AAMaxGL are shown in Figure 3-1. AAMaxGL, AAMinGL, AveGL, MaxGL and MinGL contours and rasters for each of the regional model scenarios were delivered to the Drainage and Waterways Branch, and are available on request.

3.2 Climate scenarios (S09, S18, S27 and S36)

Three future climate scenarios were simulated (dry, medium and wet) for the years 2010 – 2039, and one historical climate sequence was simulated using SILO data between the years 1945 – 1974. Changes to the base-case model (S0) to adjust for climate change included:

- evapotranspiration and rainfall for the nine climate zones were adjusted to the appropriate climate change scenario time-series
- Mike 11 inflow boundaries were adjusted to the inflows calculated by the SQUARE model, using the corresponding climate sequence as rainfall inputs
- for the future climate scenarios, the saturated-zone boundary condition on the western side increased by 0.2 m to account for IPCC sea-level rise predictions by 2031
- for the future climate scenarios, water-level boundary conditions for the downstream end of the Mike 11 rivers increased by 0.2 m to account for sea-level rise predictions.

These four scenarios (S09, S18, S27 and S36) did not involve development or drainage changes and were analysed and compared with the base-case scenario (S0). The average change in AAMaxGL, AAMinGL, AveGL, MaxGL and MinGL for the Murray DWMP area for each of the climate sequences was calculated and compared with the base-case scenario (Table 3-2).

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

Scenario number	Scenario name	Rainfall	AAMaxGL	AAMinGL	AverageGL	MaxGL	MinGL
		mm	mAHD	mAHD	mAHD	mAHD	mAHD
S0	Base case	841	14.57	13.23	13.78	15.00	12.96
S09	Future wet climate	829	14.53	13.22	13.75	14.99	12.94
S18	Future medium climate	768	14.30	13.14	13.62	14.80	12.84
S27	Future dry climate	705	14.01	13.03	13.44	14.56	12.70
S36	Historical wet climate	967	14.99	13.41	14.07	15.52	13.20
S37	Sea level rise	841	14.61	13.29	13.85	15.26	13.04
S38	Wet climate + 1955	-	-	-	-	15.28	-
Change from base case (S0)		**mm**	**m**	**m**	**m**	**m**	**m**
S09	Future wet climate	-12	-0.04	-0.01	-0.03	-0.01	-0.02
S18	Future medium climate	-73	-0.27	-0.09	-0.16	-0.20	-0.12
S27	Future dry climate	-136	-0.56	-0.20	-0.33	-0.45	-0.26
S36	Historical wet climate	126	0.42	0.18	0.29	0.52	0.23
S37	Sea level rise	0	0.04	0.06	0.07	0.26	0.08
S38	Wet climate + 1955		-	-	-	0.27	-

The future wet climate scenario (S09) corresponds to a 1.43% reduction in average annual rainfall and predicts similar groundwater heads and flows to the base-case scenario (S0). Average changes in AAMaxGL, AAMinGL, AveGL, MaxGL and MinGL range from 0.01 to 0.04 m. The spatial changes in AAMaxGL and AAMinGL for the difference between S0 and S09 are shown in Figure 3-2 and Figure 3-3 respectively. The change in AAMaxGL ranges from -0.2 to >0.1 m in the Murray DWMP area. Increases in groundwater level in the S09 scenario are restricted to regions bordering the estuary, coast and the Murray and Serpentine rivers where sea-level rise has affected maximum and minimum groundwater levels. The largest decreases in groundwater level within the DWMP area are in the eastern Nambeelup development and throughout the catchment's centre, mostly in the sand dune areas. AAMinGL is very similar for the S0 and S09 scenarios, and most development areas are within 0.05 m of the base-case scenario.

The future medium climate scenario (S18) corresponds to an average annual decrease in rainfall of 8.7%, and predicts decreases in AAMaxGL of between 0.1 and 0.5 m bgl for most of the Murray DWMP area (Figure 3-4). The scenario predicts decreases of between 0.2 and 0.4 m (most commonly) across the development areas. Larger decreases in AAMaxGL occur in the eastern Nambeelup development and along the Murray River, and in the South Murray and Pinjarra regions. Predictions in decreases in AAMinGL are smaller, and range between 0.0 and 0.4 m for most of the Murray DWMP area (Figure 3-5).

The future dry climate scenario (S27) corresponds to a 16.2% decrease in average annual rainfall, and predicted average declines in groundwater of between 0.2 and 0.56 m when compared with the base-case scenario. Figures 3-6 and 3-7 display the spatial changes in AAMaxGL and AAMinGL for the difference between S0 and S27. The most significant decrease in AAMaxGL is predicted to occur in the Nambeelup, Pinjarra, North Dandalup and

South Murray developments, where most have decreases in groundwater level in excess of 0.5 m. The decrease in AAMaxGL is usually between 0.1 and 1.0 m for the Murray DWMP area. The difference in AAMinGL is not predicted to be as large as the decrease in AAMaxGL. Changes in AAMinGL are predicted to be most severe in the Nambeelup, Pinjarra, North Dandalup and South Murray developments, where decreases are commonly in excess of 0.5 m. However, decreases in AAMinGL usually range between 0 and 0.4 m for the Murray DWMP area.

The historical wet climate scenario (S36) predicts a rise in AAMaxGL and AAMinGL over the entire Murray region (figures 3-8 and 3-9). The rise is generally between 0.05 and 1.0 m, with the most significant rises along the Murray River and in the eastern Nambeelup development. The most common groundwater level rises are 0.2 – 0.5 m for AAMaxGL and 0.0 – 0.2 m for AAMinGL in the development areas.

3.3 Sea-level rise scenario (S37)

The maximum sea-level change scenario was implemented by increasing the western boundary condition of the Murray regional model by 0.9 m, and by increasing the water-level boundary conditions in the Mike 11 model by 0.9 m. The model was simulated between the years 1978 – 2007.

The effect of the sea-level rise scenario is shown in figures 3-10 and 3-11, which display the change in AAMaxGL and AAMinGL compared with the base-case scenario. The effects of sea-level rise are confined to the western coastal corridor and the region surrounding the Murray River to Pinjarra. Most of the development areas are largely unaffected. Those that are affected include Barragup; South Murray; Pinjarra; Yunderup; Carcoola; the eastern side of Austin, Nambeelup and Nerrima; the northern border of Buchanans; and the southern border of Ravenswood. The developments close to the Murray River (apart from Buchanans and Yunderup) are unlikely to be affected by increased groundwater due to sea-level rise, because the minimum depth to groundwater is large (above 2 m) in these locations. The eastern border of Nerrima, Austin and Nambeelup, as well as the Yunderup and Buchanans development, are more likely to have drainage affected by sea-level rise.

The effect of saltwater intrusion as a consequence of sea-level rise was not modelled as part of the DWMP project. It is a limitation of the model (Mike SHE assumes constant density of fluids). A variable density model would be required to determine the effect of the seawater intrusion due to sea-level rise on the hydrology and water quality.

3.4 Land development and drainage scenarios (S11, S15, S20, S26, S29, S33 and S39)

Drainage scenarios were undertaken for the future wet climate with drains at ground level and 1.0 m bgl (S11 and S15); for the future medium climate with drains at ground level, at AAMaxGL and at MaxGL (S20, S26 and S39); and for the future dry climate with drains at ground level and at 1.0 m bgl (S29 and S33). The total drainage volume (surface water and groundwater drainage) from each of the development areas (Figure 2-2) was recorded for each of the drainage scenarios (see Table 3-3).

Table 3-3: *Predicted drainage quantities for the future wet, dry and medium climate scenarios for each of the development areas under various subsurface drainage scenarios*

Total drainage volume from development area	Future wet climate		Future medium climate			Future dry climate	
	Drains at ground level S11 (ML)	Drains at 1 m bgl S15 (ML)	Drains at ground level S20 (ML)	Drains at AAMaxGL S26 (ML)	Drains at MaxGL S39 (ML)	Drains at ground level S29 (ML)	Drains at 1 m bgl S33 (ML)
South Yunderup	45	367	19	75	5	6	168
Austin Cove	1084	1599	834	919	765	690	1004
Nerimma	2223	2785	1817	1994	1799	1841	1833
Buchanans	4471	5715	3615	4014	3528	3509	3626
Pinjarra	441	418	401	436	395	349	333
South Murray	94	174	43	189	69	28	48
Barragup	82	493	40	297	56	15	145
Ravenswood	3394	4587	2597	3122	2609	2727	2742
Nambeelup	3954	5554	2945	3460	2871	2572	3137
Carcoola	474	672	371	460	353	278	376
North Dandalup	720	1024	567	581	560	426	674
TOTAL	**16 982**	**23 387**	**13 249**	**15 546**	**13 008**	**12 441**	**14 087**

For all climate scenarios, a significant increase in drainage volume from developments occurred when the subsurface drainage was implemented. Without subsurface drainage, a significant quantity of groundwater is lost to evapotranspiration when the watertable is close to the ground surface. When subsurface drainage is implemented, a significant amount of the water that would otherwise have risen close to the ground surface and subsequently been lost to evapotranspiration, is routed through the subsurface drains instead. This is compounded by increasing recharge rates when urban developments are implemented. In catchments where the pre-development land use is primarily grazing pasture, the recharge increase due to development is small (e.g. Pinjarra or Austin). However, regions with significant deep-rooted vegetation have large increases in recharge. The increase in recharge and the decrease in evapotranspiration from the groundwater surface are the primary drivers for significant increases in drainage when subsurface drains and development is implemented.

When subsurface drainage is implemented at 1.0 m bgl, the phreatic surface is more likely to encounter drains, resulting in larger drainage volume. Figure 3-12 shows the total drainage quantities from all the developments for the future wet and dry climate scenarios with no drains, drains at ground level with 1.0 m fill, and drains at 1.0 m bgl.

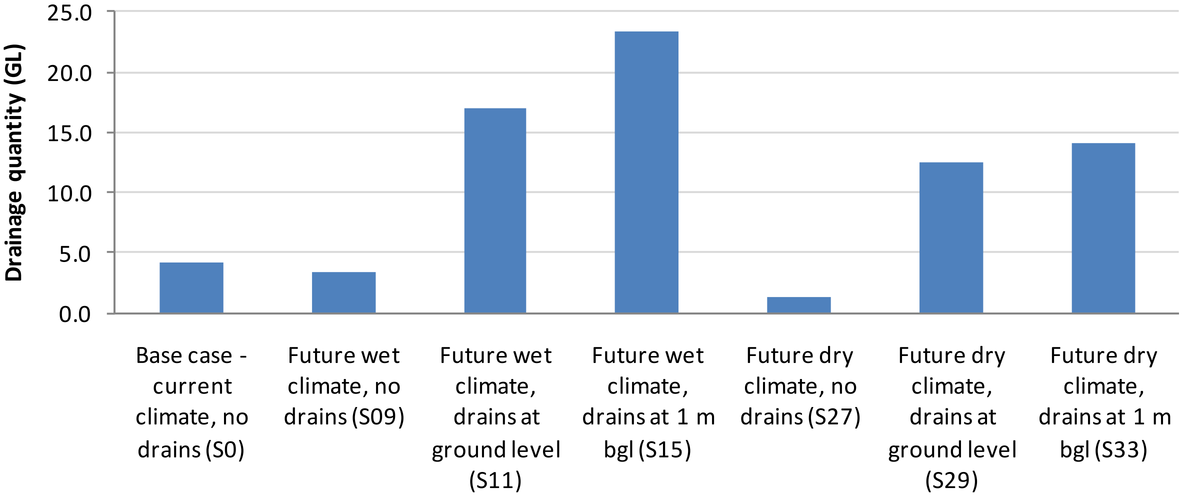


Figure 3-12: *Total drainage quantity from developments for the various drainage scenarios for the future wet and dry climate scenarios*

For the future wet climate scenario, drainage quantities are predicted to increase from 3.5 to 17.0 GL when drains are at ground level, and to 23.4 GL when drains are at 1.0 m bgl. Drainage quantities for individual developments are shown in Figure 3-12. Relative drainage quantities (Figure 3-13a) average approximately 270 mm for drains at 1.0 m bgl and 180 mm for drains at ground level, compared with an average of 60 mm for no drains. Absolute drainage quantities (Figure 3-13b) are largest for developments with the largest areas (Buchanans, Ravenswood, Nambeelup, Nerrima and Austin).

Figures 3-14 and 3-15 show the change in AAMaxGL and AAMinGL for the future wet climate scenario with drains at ground level with 1.0 m fill (S11). AAMinGL increases in all development areas due to an increase in recharge and a decrease in evapotranspiration. AAMaxGL also increases in most development areas due to increases in fill and recharge.

Figures 3-16 and 3-17 show the change in AAMaxGL and AAMinGL for the future wet climate scenario with drains at 1.0 m bgl (S15). All development areas have a predicted increase in AAMinGL. The AAMinGL for the wet scenario with no drains (S09) is always deeper than 1.0 m bgl, and since the drain level is not below the AAMinGL, the AAMinGL is not reduced. However, there are large decreases in AAMaxGL, because the level of the drains is below the level of the AAMaxGL in many regions of the model. This is particularly relevant in the more waterlogged regions, where the AAMaxGL is close to the ground surface near Austin, Nerrima, Buchanans, Ravenswood, North Dandalup and west Nambeelup.

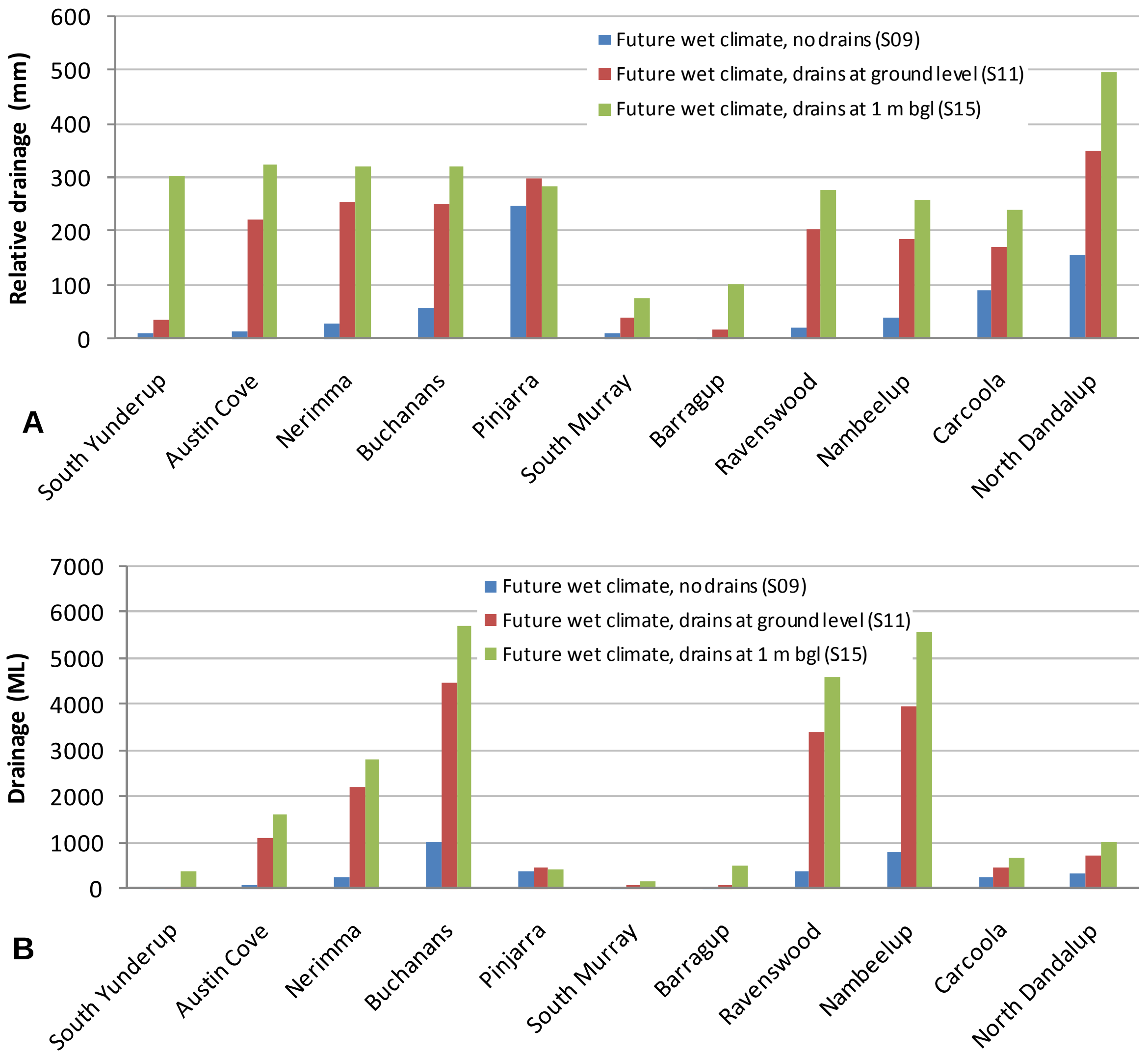
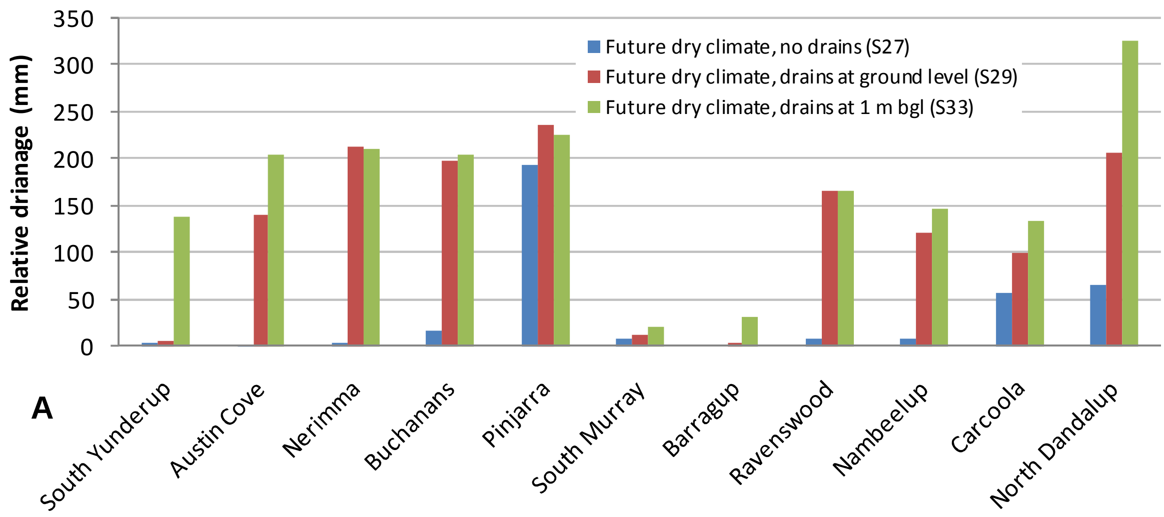


Figure 3-13*: Drainage flux quantities for future wet climate scenarios under various subsurface drainage levels: A) relative drainage quantities (mm), B) absolute drainage quantities (ML)*

Figure 3-18 shows simulated drainage quantities for individual developments for the future dry climate scenario (S27, S29 and S33). Drainage quantities are predicted to increase from 1.2 to 12.4 GL when subsurface drains are implemented at ground level, and to 14.1 GL when drains are at 1.0 m bgl. As discussed in Section 2.2, the reported drainage volume is indicative of the quantity of water requiring management for each of the development areas. It includes the sum of the surface water drainage (channel flow), overland flow, and subsurface drainage produced within the development areas, and does not include inflows from upstream. Relative drainage quantities average approximately 180 mm for drains at 1.0 m bgl and 164 mm for drains at ground level, compared with an average of 60 mm for no drains. The reduction in drainage quantities for the future dry climate scenario is due to reduced recharge and reduced groundwater levels.

Figures 3-19 and 3-20 compare the AAMaxGL and AAMinGL for the future dry climate scenario with drains at 1.0 m bgl (S33). AAMinGL increases in all development areas by between 0.1 and 1.0 m. For the future dry scenario the decreases in AAMaxGL are not as prominent as for the future wet scenario. This is due to a general decrease in groundwater levels, so the AAMaxGL for the dry scenario is more commonly below the 1.0 m bgl drain level.



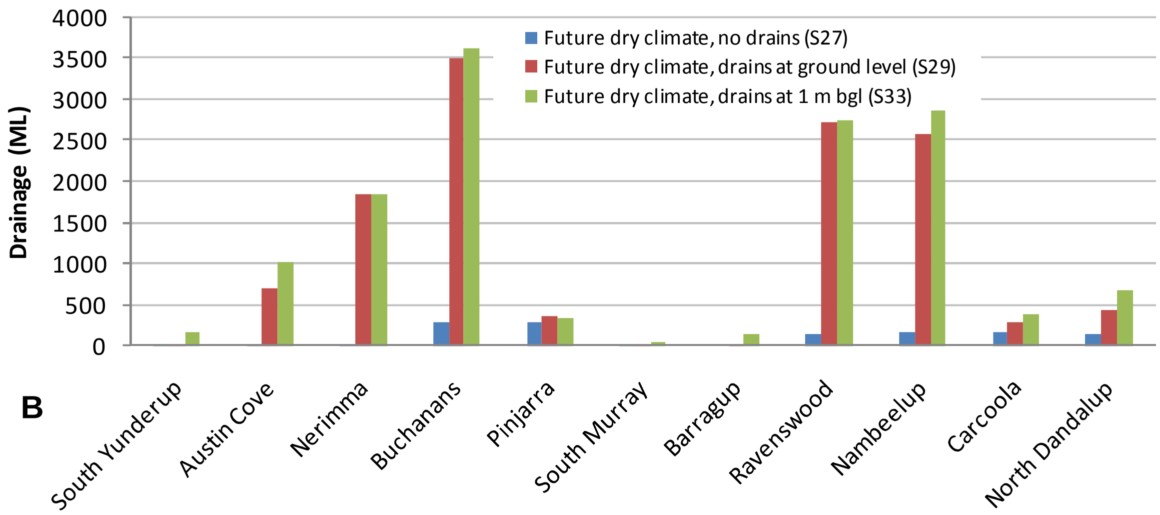


Figure 3-18: *Drainage flux quantities for future dry climate scenarios under various subsurface drainage levels: A) relative drainage quantities (mm), B) absolute drainage quantities (ML)*

The future medium climate scenario was simulated with drains at ground level, drains at AAMaxGL, drains at MaxGL (where AAMaxGL and MaxGL were calculated using the base-case groundwater levels) and drains at ground level with garden bore abstraction.

Figure 3-21 shows the simulated drainage quantities for all developments with the future medium climate for the various drainage scenarios. Predicted drainage quantities are similar for drainage at ground level, at AAMaxGL and at MaxGL (13.2, 15.5 and 13.0 GL/year respectively).

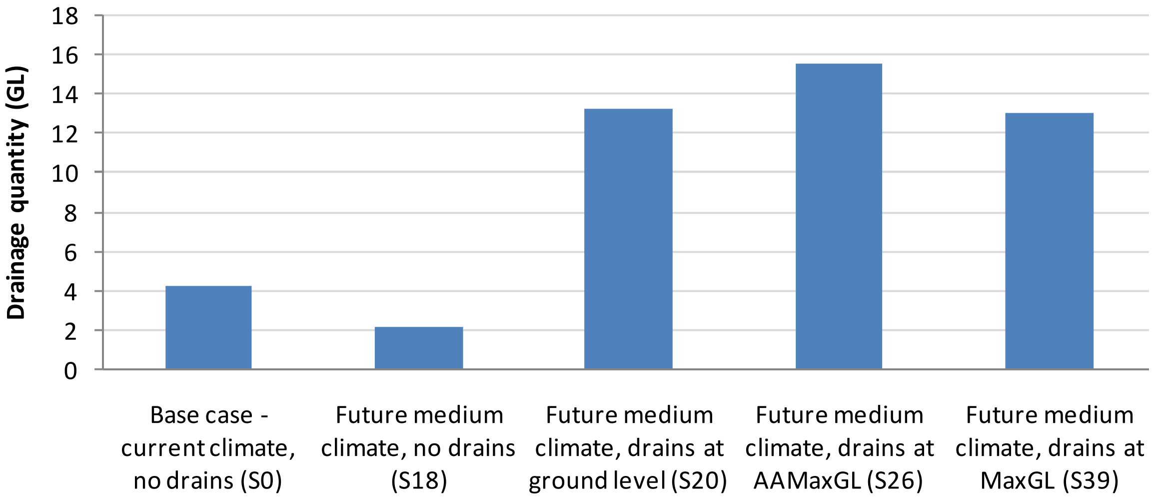


Figure 3-21: *Total drainage quantity from developments for the various drainage scenarios for the future medium climate scenario*

Figure 3-22 shows simulated drainage quantities for individual developments for the medium climate scenario. Relative and absolute drainage quantities average approximately 145 mm for drains at ground level compared with an average of 46 mm for no drains. The relative and absolute drainage quantities for the medium climate scenario are approximately mid-way between the dry and wet climate scenarios.

In all developments, the drainage quantities are similar for drains at ground level with 1.0 m fill and for drainage at MaxGL. Overall, approximately 12% more drainage is predicted for drainage at AAMaxGL compared with drainage at MaxGL; however, this value varies depending on the development area.

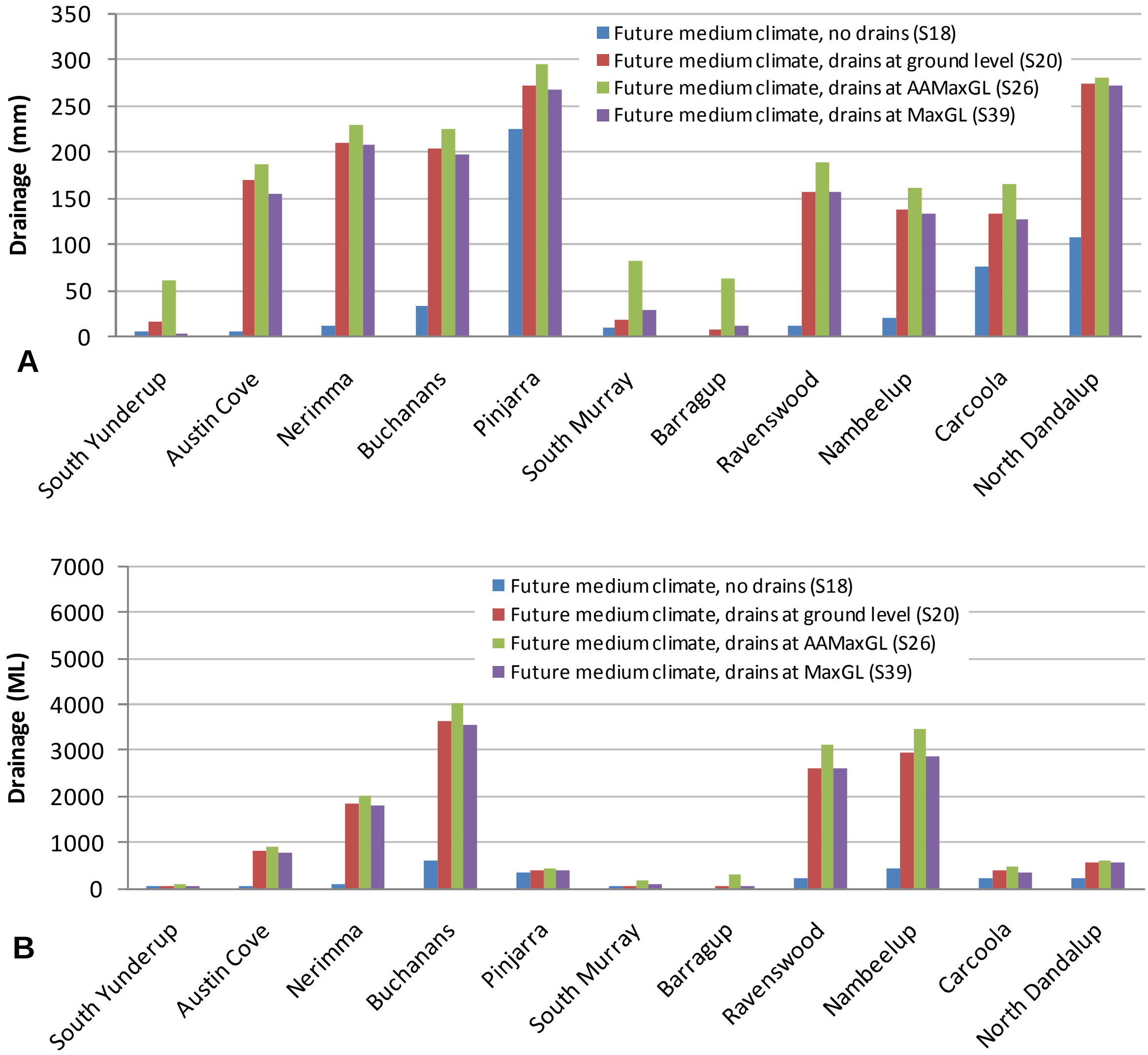


Figure 3-22: *Drainage flux quantities for future dry climate scenarios under various subsurface drainage levels: A) relative drainage quantities (mm), B) absolute drainage quantities (ML)*

3.5 Domestic bore abstraction scenario (S40)

The domestic bore scenario (S40) was applied to the future medium climate scenario with drainage at ground level and 1.0 m fill (S20). Figure 3-23 shows the simulated drainage quantities for all developments with the future medium climate for the various drainage scenarios and includes the domestic bore abstraction scenario. The application of garden bores is predicted to reduce drainage quantities by more than 50% when compared with drainage at ground level, at AAMaxGL and at MaxGL.

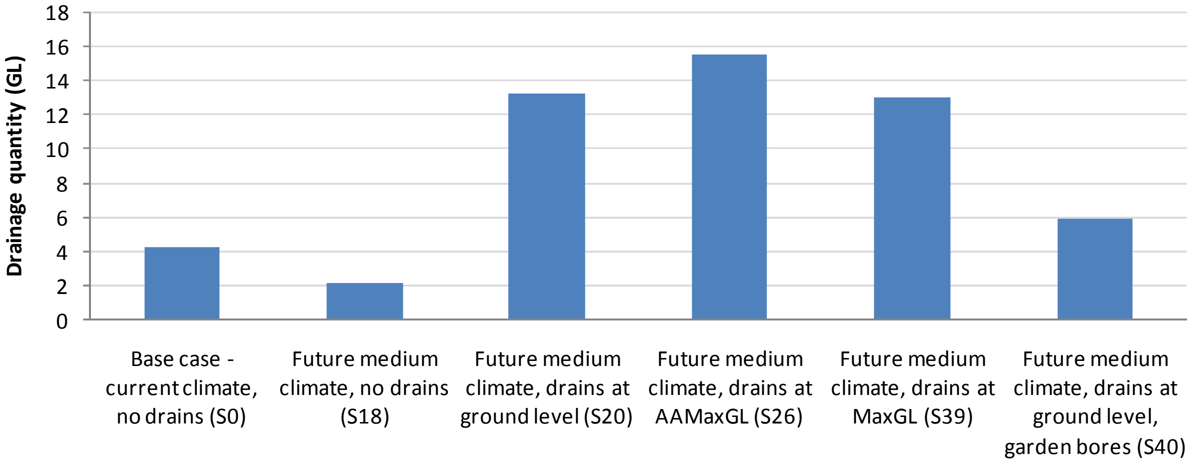


Figure 3-23: *Total drainage quantity from developments for the various drainage scenarios for the future medium climate, including application of garden bores*

Table 3-4 shows the simulated average annual water balance fluxes for the three future medium climate scenarios, and Figure 3-24 shows the evapotranspiration, drainage, horizontal flow and abstraction components of the water balance for each of the scenarios.

Table 3-4: *Water balance fluxes for scenarios with and without garden bore abstraction*

Flux	No development S18 (mm)	Drainage, no garden bores S20* (mm)	Drainage with garden bores S40* (mm)	No development S18 (GL)	Drainage, no garden bores S20* (GL)	Drainage with garden bores S40* (GL)
Rainfall	759	759	759	63.9	63.9	63.9
Recharge	181	303	303	15.2	25.5	25.5
Drainage	25	158	80	2.1	13.3	6.7
Abstraction	9	9	139	0.8	0.8	11.7
Horizontal flow	61	137	86	5.2	11.5	7.2
Evapotranspiration	663	454	454	55.8	38.2	38.2

* drainage scenario is for subsurface drains at ground level with 1 m fill

The use of domestic bores was predicted to have significant effects on subsurface drainage quantities and on minimum groundwater levels. The change in AAMinGL due to garden bore abstraction (S20 compared with S40) is shown in Figure 3-25. AAMinGL is predicted to decrease by approximately 1.0 m. However, when the domestic bore scenario (with drainage at ground level and 1.0 m fill) is compared with the 'no development' scenario of the equivalent climate sequence (S18), only a few regions within the model show a reduction in AAMinGL; in these cases, the reduction is a maximum of approximately 0.4 m (see Figure 3-

26). In most development regions, the reduction in AAMinGL due to the presence of garden bores is offset by the increase in AAMinGL due to increased fill and higher recharge rates. The change in AAMinGL due to the application of garden bores depends on the drainage design (level of drains and quantity of fill).

Subsurface drainage quantities are predicted to decrease with the inclusion of domestic bores. The drawdown of the groundwater in summer provides extra storage for winter recharge, therefore less water is available for drainage. The model predicted that subsurface drainage quantity is likely to decrease by a factor of two for the domestic bore abstraction scenario modelled. The domestic bore abstraction quantities and installation rates are associated with high degrees of uncertainty. Results of the drainage and abstraction values for the domestic bore scenario should be viewed as indicative, because there is too much uncertainty in the model inputs to have confidence in absolute values.

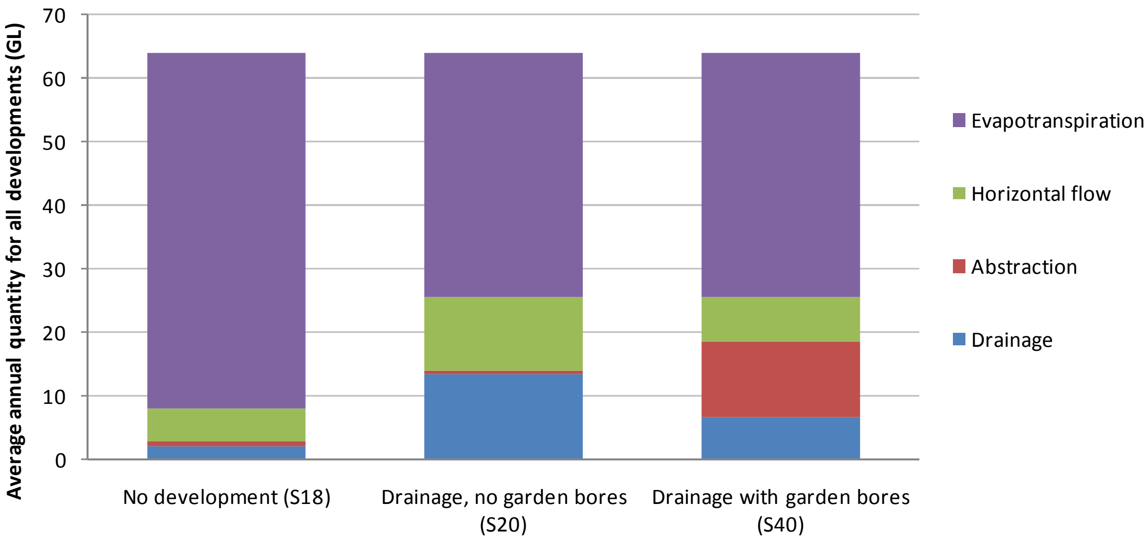


Figure 3-24: *Water balance for the future medium climate scenario with no development, with drainage at ground level with no garden bores, and with drainage at ground level and extensive garden bore use*

When considering the use of domestic bores, the presence of potential acid sulfate soils in the subsoil must be considered – given that drawdown of the watertable and subsequent oxidation of these sediments has the potential to cause acidification of the bore water, and the release of heavy metals. This is particularly relevant to community bores, where localised drawdown of the watertable is likely to exceed the rates for individual properties, and to dewatering works for development infrastructure requirements (e.g. sewerage installation). Further details on acid sulfate soil risks in the Murray region are available in Kretschmer et al. (2010).

3.6 Analysis of high annual rainfall year (S38)

S38 was undertaken to determine the effect of a large historic rainfall event in line with the future rainfall scenario predictions. The scenario was run for 31 years, using the 30 years of the wet climate scenario rainfall and evaporation, with the 1955 rainfall and evaporation at the end of the sequence. 1955 was the region's wettest year in the 20th century (according to the Pinjarra rainfall gauge's SILO data) with 1493 mm of annual rainfall. Results for MaxGL were compared with the flood study data to determine regions within the DWMP domain where inundation water levels were likely to be higher than event-based flood water levels. The analysis of the event-based flood levels versus annual MaxGL is outside the scope of the groundwater studies, and is not presented in this report. The MaxGL (for the final year of analysis) was the only dataset extracted from S38. Analysis of waterlogging from this scenario is discussed in Section 3.7.

3.7 Waterlogging analysis

Waterlogging occurs when the phreatic surface is above the ground surface. Waterlogging was analysed by extracting the maximum phreatic surface for each of the 200 m grid cells over the modelling time-period, smoothing the topographic grid to a 10 m grid size, and subtracting from the 10 m DEM. Waterlogging for the base case (S0), future dry climate scenario (S27), future medium climate scenario (S18), future wet climate scenario (S09), and future wet climate scenario with 1955 rainfall at the end of the sequence (S38) are shown in figures 3-27 to 3-31.

For the base case (S0) (Figure 3-27), waterlogging is less prominent in the South Murray and Pinjarra developments, as depths to the groundwater are much larger in the immediate vicinity of the Murray River. Also the Barragup development shows a low risk of waterlogging. Austin Cove, Nerrima, Buchanans and Ravenswood have extensive regions where the phreatic line is above the ground surface. Regions of the Nambeelup and North Dandalup developments are also prone to waterlogging.

The future dry climate scenario (Figure 3-28) predicts a much lower prominence of waterlogging, with Austin, Nerrima and Buchanans the only developments with extensive areas of inundation. The future medium and future wet climate scenarios (figures 3-29 and 3-30) show increasing levels of inundation, and the wet scenario is very similar to the base-case scenario. The future wet climate scenario with 1955 rainfall and evapotranspiration at the end of the climate sequence (S38) displays extensive waterlogging in all developments apart from Pinjarra, South Murray and Barragup (Figure 3-31).

Because most of the Murray DWMP area is seasonally waterlogged, a large proportion of its surface water runoff is generated from recharge-rejection (when rain falls onto a full superficial aquifer, causing water to move laterally over the topography rather than soak into the soil). Surface water runoff is much more sensitive to changes in annual rainfall than AAMaxGL. Surface water expression primarily occurs when the aquifer has reached or is close to MaxGL. Table 3-5 shows the changes in rainfall, predicted AAMaxGL and predicted surface water runoff for the Murray DWMP area for all climate scenarios that were modelled.

Table 3-5: *Changes in rainfall, AAMaxGL and surface water runoff*

Scenario number	Scenario name	Rainfall		AAMaxGL		Surface water	
		mm	Δ (mm)	mAHD	Δ (mAHD)	mm	Δ (%)
S0	Base case	841	-	14.57	-	37	-
S09	Future wet climate	829	-1%	14.53	-0.04	33	-11%
S18	Future medium climate	768	-9%	14.30	-0.27	27	-28%
S27	Future dry climate	705	-16%	14.01	-0.56	21	-43%
S36	Historical wet climate	967	15%	14.99	0.42	68	87%

For the historical wet climate scenario, a 15% increase in rainfall resulted in a large predicted increase in surface water flow (87%), but a relatively small change in AAMaxGL (0.42 m). Conversely, the future dry climate predicts a large decrease in surface water flow (-43%), but also predicts a relatively small change in AAMaxGL (-0.56 m). To put this into context, regions of the south-west with minimal seasonal waterlogging (e.g. the Gnangara Mound and the Blackwood Plateau) had predicted reductions in groundwater levels in excess of 10 m for the future dry scenario in the CSIRO's SWSY project (CSIRO 2009). In the Murray DWMP region, surface flow acts as a buffer for the change in maximum groundwater level. If rainfall should continue to decrease, the waterlogged areas in the Murray region would also decrease and could effectively exhaust the buffer capacity. Should this occur, groundwater levels could decline more drastically with further changes in annual rainfall.

4 Wetland scenarios

Wetland scenarios formed part of the EWR component of the Murray DWMP project. The scenarios were developed by the EWR technical advisory group, which comprised members from the Department of Water (Drainage and Waterways and Allocation Planning branches), DEC (wetlands section) and GHD (wetlands team). The list of wetland scenarios is shown in Table 4-1.

Table 4-1: *List of wetland scenarios for the EWR component of the DWMP project*

Scenario ID	Scenario name	Climate	Subsurface drainage	Other changes
EWR_S0	Base case	Current	No drains	No change
EWR_S1	Sand dune analysis	Current	No drains	Without sand dune
EWR_S2	Hydrological zone analysis (AAMaxGL)	Current	Drainage at AAMaxGL	Hydrological zone analysis
EWR_S3	Hydrological zone analysis (0.5m)	Current	Shallow = 0.5m BGL	Hydrological zone analysis
EWR_S4	Hydrological zone analysis (1m)	Current	Medium = 1m BGL	Hydrological zone analysis
EWR_S5	Wet climate	Wet	No drains	No change
EWR_S7	Dry climate	Dry	No drains	No change
EWR_S8	Historical wet climate	Historical wet	No drains	No change
EWR_S9	Sea level rise	Current	No drains	0.9m sea level rise

Eight wetlands were selected by the EWR technical advisory group for modelling using five separate wetland models. Each of the wetland models is discussed in detail in the *construction and calibration report* (Hall et al. 2010b). Saturated-zone boundary conditions for the wetland models were extracted from the regional model (for the corresponding climate scenarios). The eight key wetlands and model domains are shown in Figure 4-1.

The vegetation EWR consultant (GHD Pty Ltd) provided the Water Science Branch with vegetation transects for each of the key wetlands. Groundwater-level data for each scenario was calculated and supplied to GHD for each transect, for inclusion in the EWR analysis. GHD surveyed and mapped the locations of a series of vegetation communities along each transect. The lowest point along each transect was also surveyed. GHD used the daily groundwater-level results to help develop the wetland EWRs. The transect points, vegetation communities, and lowest points on the transects for the eight key wetlands are shown in figures 4-2 to 4-7. The following section outlines how the scenarios were applied to the model, and discusses the modelling results.

4.1 Sand dune analysis (EWR_S1)

Fringing sand dunes are believed to be drivers of wetland water levels. Localised groundwater mounds that form beneath sand dunes bordering wetlands are understood to increase both wetland water levels and the duration of wetland inundation. Sand dunes are useful for urban development, because they provide cost-effective and locally available fill for development foundations. The sand dune analysis scenario (EWR_S1) aims to identify the wetlands with significant sand dunes, and then to use the model to compare the changes in wetland water levels and duration of inundation with and without the dunes. This provides a quantitative approach to determining the significance of the fringing sand dunes on wetland hydrology, and allows the potential impact on the ecology to be assessed.

Two wetland models had wetlands with significant fringing sand dunes: the Lakes Road model and the Scott Road model. The sand dune analysis scenario was run for the same climate sequence and boundary conditions as the base-case model. The only changes to the base-case scenario (EWR_S0) were the changes in model topography. The land use was assumed to be constant for both scenarios, and root-depth and LAI parameters were identical for both scenarios. Therefore any change in wetland hydrology can be attributed to a change in the topography associated with the sand dunes, rather than a change in recharge and infiltration rates resulting from a land-use change.

Scott Road model

The Scott Road model has significant sand dunes located around the northern half of the Benden Road wetland, and east and north-east of the Scott Road wetland. The dunes north of Benden Road are up to 4 m high. The significant dune east of the Scott Road wetland is approximately 5.5 m high.

Figure 4-8 identifies the sand dunes that were removed for the Scott Road model, and shows the model topography before and after sand dune removal. The change in topography between the EWR_S0 and EWR_S1 scenarios is also shown, indicating the height of the dunes that were removed.

The annual maximum wetland water level modelled from the lowest point in each of the wetland transects was calculated for the base-case and the sand dune analysis (Table 4-2). The change in average annual maximum wetland water level was 0.01 m for Scott Road wetland and 0.04 m for Benden Road wetland, which corresponded to a 2.3% and 3.1% reduction in water level. Changes in wetland water level due to the presence of the surrounding sand dunes do not appear to be significant in the case of Benden and Scott Road wetlands.

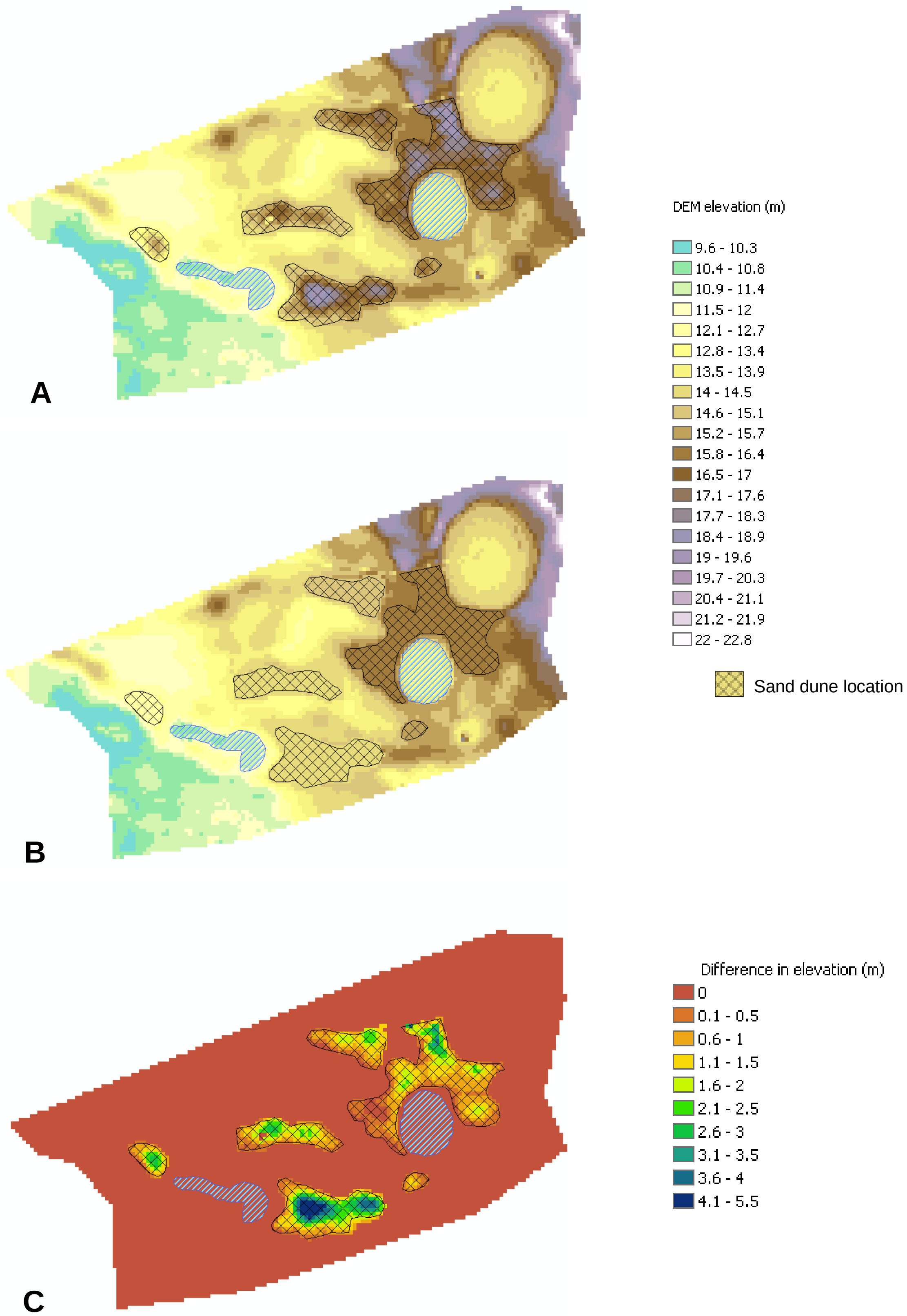


***Figure 4-8**: A) sand dunes identified for the Scott Road model with the original model topography; B) model topography after sand dunes have been removed from the model; and C) the difference in elevation between A and B (the level of the sand dunes removed)*

Table 4-2*: Maximum wetland water levels for Scott Road and Benden Road wetlands in the Scott Road model for base-case and sand dune analysis scenarios*

Year	Scott Road wetland		Benden Road wetland	
	Base case EWR_S0 max depth (m)	Sand dune analysis EWR_S1 max depth (m)	Base case EWR_S0 max depth (m)	Sand dune analysis EWR_S1 max depth (m)
1978	0.63	0.61	1.11	1.09
1979	0.44	0.43	0.75	0.72
1980	0.70	0.69	1.19	1.16
1981	0.80	0.78	1.36	1.32
1982	0.60	0.59	1.26	1.21
1983	0.81	0.79	1.32	1.27
1984	0.85	0.82	1.50	1.44
1985	0.74	0.72	1.33	1.27
1986	0.71	0.68	1.25	1.19
1987	0.58	0.57	0.94	0.92
1988	0.73	0.71	1.30	1.27
1989	0.72	0.69	1.36	1.32
1990	0.55	0.54	1.08	1.04
1991	0.92	0.91	1.58	1.56
1992	0.92	0.91	1.63	1.59
1993	0.54	0.53	1.09	1.03
1994	0.79	0.77	1.26	1.23
1995	0.77	0.75	1.29	1.24
1996	0.78	0.76	1.34	1.30
1997	0.71	0.69	1.25	1.21
1998	0.60	0.60	1.06	1.04
1999	0.82	0.79	1.45	1.40
2000	0.79	0.75	1.35	1.28
2001	0.40	0.38	0.75	0.69
2002	0.53	0.52	0.88	0.86
2003	0.60	0.59	1.04	1.03
2004	0.60	0.60	1.00	0.99
2005	0.76	0.75	1.40	1.38
2006	0.35	0.33	1.01	0.98
2007	0.47	0.45	0.85	0.82
Average 1979-2008	0.67	0.66	1.20	1.16
Change	-	-2.3%	-	-3.1%

Lakes Road model

The Lakes Road model has significant sand dunes located north and south-west of Greyhound Road wetland, and around the eastern half of Airfield wetland. The dunes north of Greyhound Road wetland are approximately 4 m high. The significant dunes surrounding Airfield wetland are approximately 6 m high. There are no significant dunes around Lakes Road wetland, and thus it was not included in the analysis.

Figure 4-9 shows the removal of sand dunes within the Lakes Road model, as well as the model topography before and after sand dune removal. The change in topography between the EWR_S0 and EWR_S1 scenarios is also shown, indicating the height of the dunes that were removed.

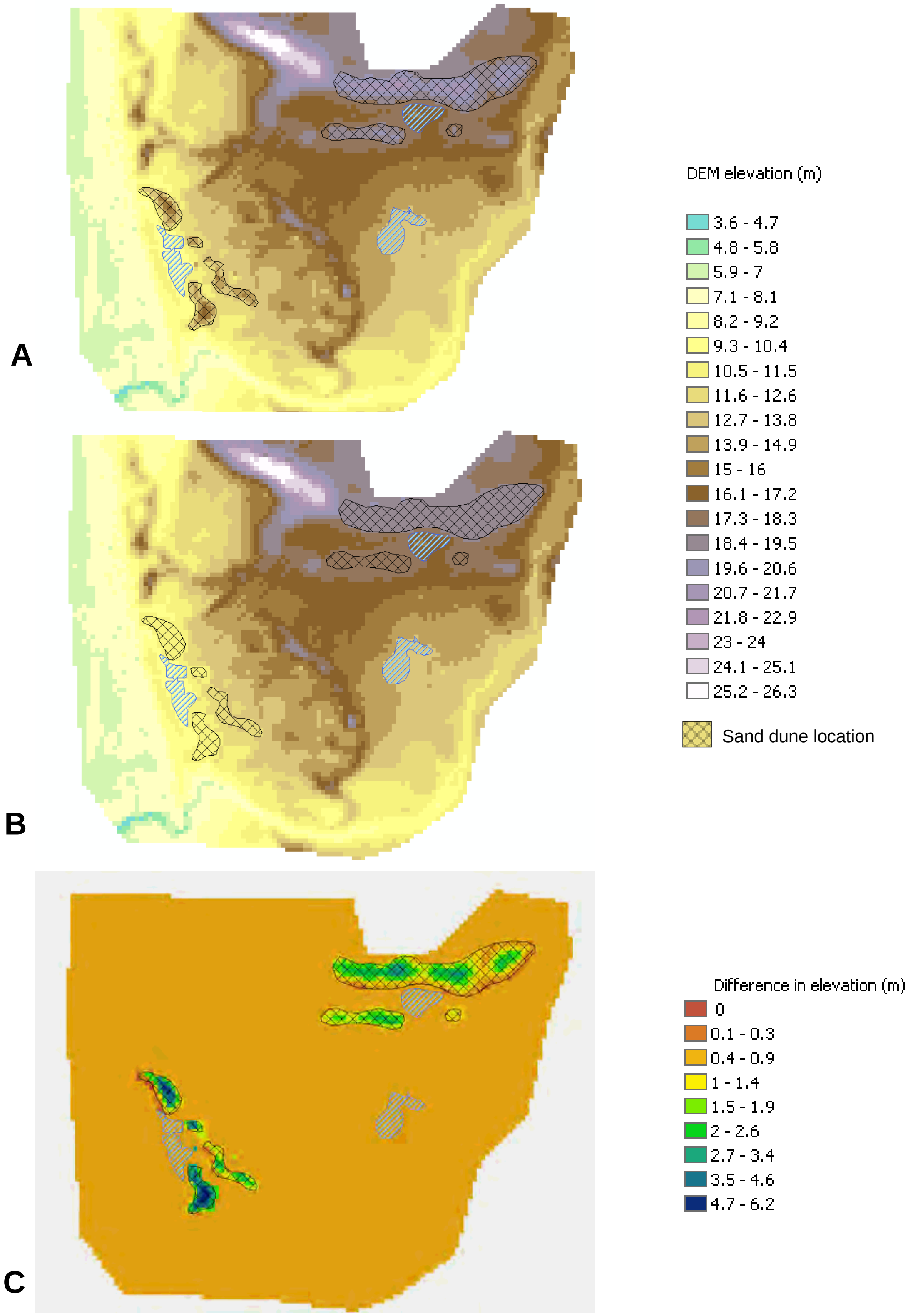


Figure 4-9: *A) sand dunes identified for the Lakes Road model with the original model topography; B) model topography after sand dunes have been removed from the model; and C) the difference in elevation between A and B (the level of the sand dunes removed)*

The modelled annual maximum wetland water levels were calculated for the base case and the sand dune analysis scenarios (Table 4-3). The change in average annual maximum wetland water level was approximately 0.01 m for each wetland, which corresponded to a 0.8%, 0.7% and 1.1% average reduction in water level for Greyhound Road, Airfield North and Airfield South wetlands respectively.

Table 4-3: *Maximum wetland water levels for Greyhound Road and Airfield wetlands in the Lakes Road model for base-case and sand dune analysis scenarios.*

	Greyhound wetland		Airfield North wetland		Airfield South wetland	
Year	Base case EWR_S0 max depth (m)	Sand dune analysis EWR_S1 max depth (m)	Base case EWR_S0 max depth (m)	Sand dune analysis EWR_S1 max depth (m)	Base case EWR_S0 max depth (m)	Sand dune analysis EWR_S1 max depth (m)
1978	0.52	0.51	1.01	0.99	0.66	0.64
1979	0.48	0.48	0.63	0.60	0.28	0.26
1980	0.52	0.52	1.10	1.08	0.75	0.73
1981	0.54	0.53	1.29	1.30	0.94	0.95
1982	0.51	0.50	1.10	1.08	0.75	0.73
1983	0.53	0.53	1.28	1.32	0.93	0.97
1984	0.53	0.53	1.45	1.47	1.10	1.12
1985	0.53	0.52	1.23	1.22	0.88	0.87
1986	0.52	0.52	1.14	1.12	0.79	0.77
1987	0.51	0.51	0.89	0.87	0.54	0.52
1988	0.53	0.53	1.23	1.21	0.88	0.86
1989	0.53	0.52	1.25	1.23	0.90	0.88
1990	0.49	0.49	0.91	0.88	0.56	0.53
1991	0.57	0.57	1.67	1.68	1.32	1.33
1992	0.55	0.54	1.63	1.66	1.28	1.30
1993	0.50	0.49	0.99	0.96	0.65	0.62
1994	0.56	0.56	1.26	1.28	0.91	0.93
1995	0.53	0.52	1.25	1.26	0.90	0.91
1996	0.52	0.52	1.27	1.27	0.92	0.92
1997	0.52	0.51	1.14	1.12	0.79	0.77
1998	0.51	0.50	0.96	0.94	0.61	0.58
1999	0.53	0.52	1.35	1.35	1.00	1.00
2000	0.53	0.52	1.30	1.32	0.95	0.97
2001	0.48	0.48	0.61	0.59	0.26	0.24
2002	0.49	0.49	0.82	0.80	0.46	0.45
2003	0.51	0.51	0.99	0.97	0.64	0.62
2004	0.51	0.50	0.95	0.92	0.60	0.57
2005	0.52	0.52	1.38	1.38	1.03	1.03
2006	0.31	0.30	0.92	0.90	0.57	0.55
2007	0.49	0.49	0.68	0.66	0.33	0.31
Average	0.51	0.51	1.12	1.11	0.77	0.76
Change	-	-0.8%	-	-0.7%	-	-1.1%

The absolute and relative change in water level is similar for the Greyhound Road and Airfield wetlands when compared with the Scott Road and Benden Road wetlands. For most years, it is likely the maximum water depth of the Greyhound Road wetland is limited by the drain to its south; thus it is possible that the effect of removing sand dunes on this wetland is less severe. Benden Road wetland has the largest surrounding dune system, and it is likely that this contributes to the larger influence of these dunes on wetland water level.

4.2 Hydrological zone analysis (EWR_S2, EWR_S3 and EWR_S4)

Buffers are designed to protect wetlands from potential impacts while helping safeguard and maintain ecological processes and functions within the wetland. Buffer distances are measured from the outside extent of wetland-dependent vegetation (the wetland function area) to the outside edge of any proposed development or activity. Wetland buffers can generally be divided into two categories: hydrological and ecological. A hydrological buffer means that hydrological alterations are not permitted within the buffer zone (e.g. drainage below the groundwater level, abstraction) although development can occur within the buffer. An ecological buffer generally means that no disturbance or development is allowed within the buffer zone. The following section refers to hydrological buffers as ‘wetland hydrological zones’ to avoid confusion with wetland ecological buffers.

Subsurface drainage can lower the watertable and adversely affect the hydrology of wetlands (lower water levels and decreased periods of inundation). However, the magnitude of the subsurface drainage system’s effect is likely to depend on the extent of the wetland’s hydrological zone radius, the level of its subsurface drains, and its natural hydrological regime.

The wetland hydrological zone analysis scenarios explore the effects of various drainage levels and zone radii on the wetland water regimes (EWR_S2 for drainage at 1.0 m bgl, EWR_S3 for drainage at 0.5 m bgl and EWR_S4 for drainage at AAMaxGL).

Wetland-function-area boundaries were provided by the Drainage and Waterways Branch and are shown in Figure 4-1. Drainage was modelled using the subsurface drainage function in Mike SHE. Subsurface drainage can be set at any depth for each grid cell within the model domain. When groundwater reaches the level of the drains, Mike SHE provides the following options:

1. drainage can be routed downhill based on adjacent drain levels

drainage can be forced to a certain region of the model (using grid codes)

drainage not routed, but removed from the model

For the purpose of the wetland hydrological zone analysis, option 3 was selected. The assumption is that subsurface drainage does not discharge to the wetlands (or to anywhere else on the model domain – the water is effectively removed from the model).

Zone radii of 50 m – 600 m were developed around the wetland function areas. For the 0.5 m and 1.0 m drainage scenarios (EWR_S3 and EWR_S4), implementation of drainage to the model was as follows:

- for each cell in the model domain, a drainage layer was created, and drainage was set to 0.5 m bgl or 1.0 m bgl
- the drainage zones were intersected with the drainage grids, and any grids that were within the hydrological zones were set to a level of 0 m drainage
- the drainage time-constant was set to ensure any water reaching the level of the drains would be removed from the model within the modelling time-step.

An example of a completed drainage input file is shown in Figure 4-10. The example is for the Scott Road model, for EWR_S3 (0.5 m drainage) with a 200 m hydrological zone radius. The only change for the simulation in the EWR_S3 and EWR_S4 scenarios compared with the base-case scenario (EWR_S0) was the inclusion of the drainage file. All other inputs (rainfall, evapotranspiration, LAI, root-depth, topography, boundary conditions etc.) remained the same for the base-case and hydrological zone analysis scenarios.

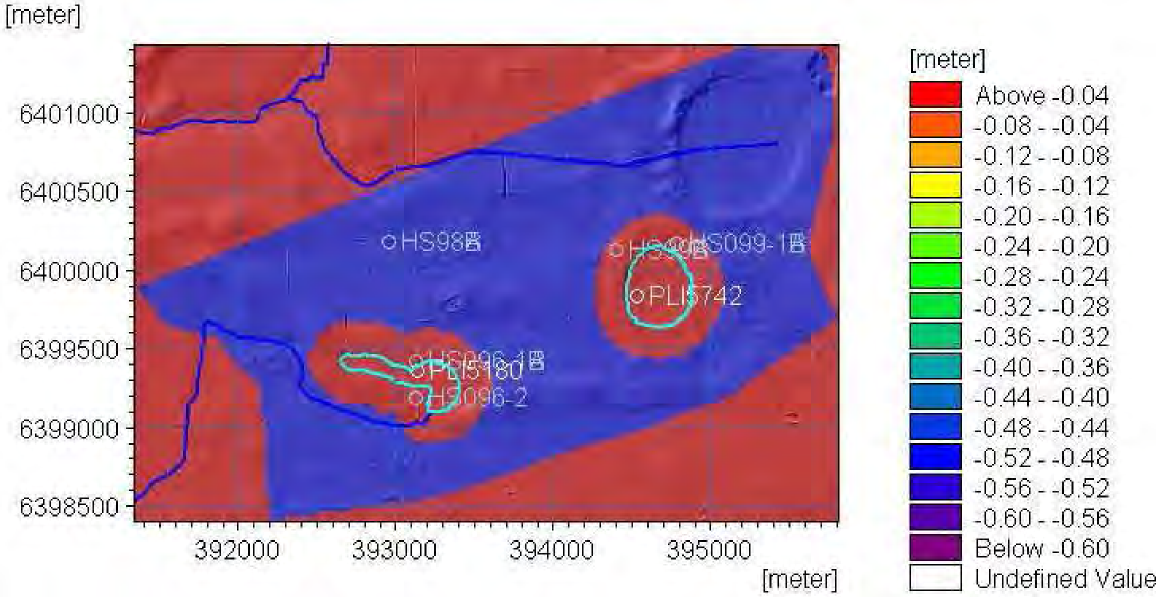


Figure 4-10: *Scott Road model with 0.5 m drainage and 200 m wetland hydrological zone radius*

Scenario EWR_S2 required subsurface drainage at AAMaxGL, rather than a constant level below the topography. For this scenario, the following process was used to construct the drainage file:

1. AAMaxGL was abstracted from the base-case scenario.

The DEM was subtracted from the AAMaxGL, to give the distance to AAMaxGL. This was used as the base drainage input file for the modelling domain. The depth of the drains was the distance to AAMaxGL.

If the distance to AAMaxGL was positive (i.e. the AAMaxGL was above ground level) the value was set to zero (drainage could not be above ground level).

The drainage hydrological zones were intersected with the drainage grids, and any grids that were within the hydrological zones were set to a level of 0 m drainage.

An example of the drainage input file for the Scott model, with drainage at AAMaxGL and a 300 m hydrological zone radius (EWR_S2), is shown in Figure 4-11.

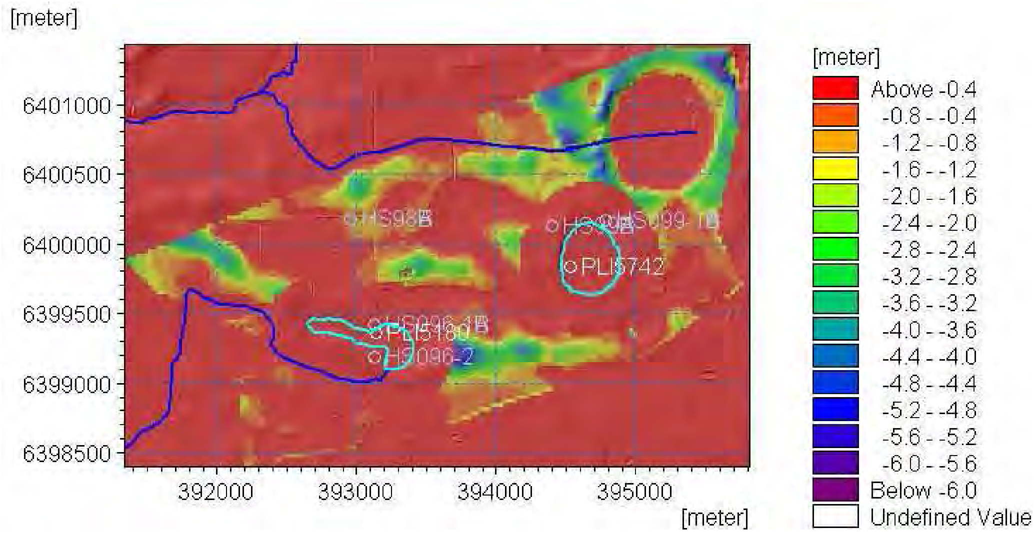


Figure 4-11: *Scott Road model with drainage at AAMaxGL and 300 m wetland hydrological zone radius (EWR_S2)*

Barragup Swamp model

For the Barragup Swamp model, hydrological zone radii were set at 50, 100, 200, 400, 600 and 800 m for all drainage depth scenarios. The change in average annual maximum wetland water depth (taken from the lowest point along the vegetation transect) was calculated for all model runs. The results of the change in maximum wetland water depth versus hydrological zone radius for the Barragup model are shown in Figure 4-12.

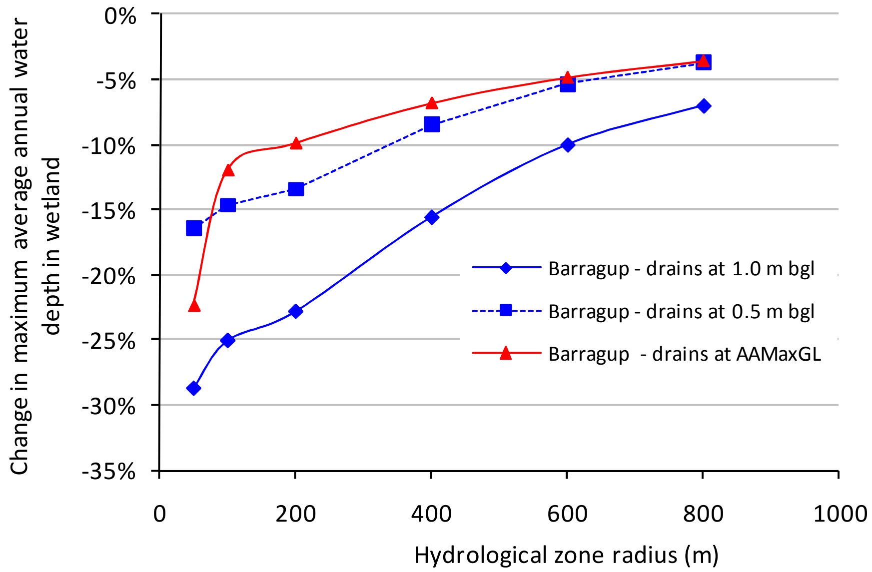


Figure 4-12: *Hydrological zone analysis for Barragup Swamp; change in average maximum wetland water level versus hydrological zone radius for drainage at 0.5 m bgl, 1.0 m bgl and drainage at AAMaxGL*

For drainage at 1.0 m bgl, the model predicts a minimum hydrological zone radius of at least 600 m is required for a change in average wetland water depth of less than 10%. For drainage of 0.5 m bgl, a radius of approximately 350 m is required. For drainage at AAMaxGL, a radius of 200 m is enough for a change in average annual maximum wetland water depth of less than 10%.

Greyhound Road wetland

The Greyhound Road wetland is within the Lakes Road model, where the 0.5 and 1.0 m bgl scenarios were simulated with hydrological zone radii of 100, 200, 300, 500, 700 and 900 m. The drainage at AAMaxGL was simulated with hydrological zone radii of 50, 100, 200, 300, 400, 500 and 600 m. The four wetlands responded differently to changes in drainage and hydrological zone radius.

The Greyhound Road wetland showed very small changes in maximum water levels for different drainage depths and hydrological zone radii. Modelling indicates that Greyhound Road wetland's maximum water level is constrained by the depth of the drain on the wetland's south side. This would be likely to influence the magnitude of the effect of drainage on the wetland, and would be responsible for the small changes in maximum wetland water depth compared with other wetlands (which are not constrained by drainage outflows). Figure 4-13 shows the hydrological zone analysis results for the Greyhound Road wetland.

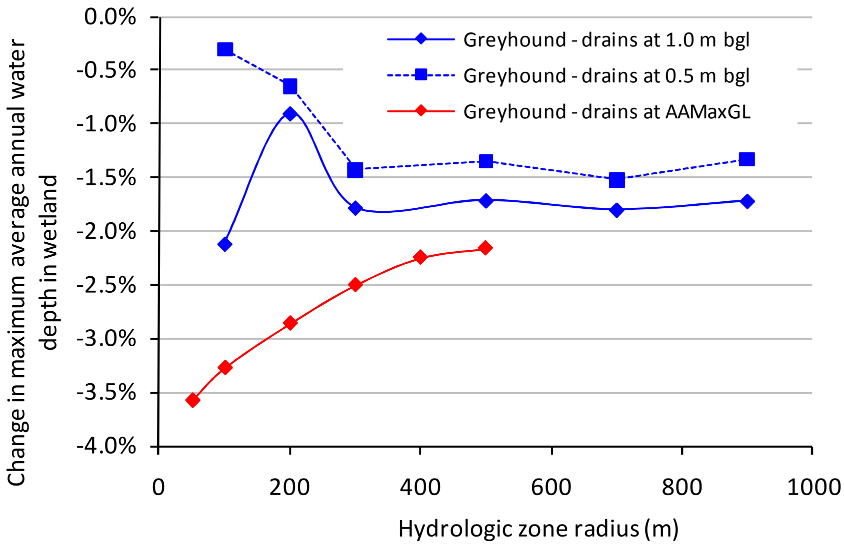


Figure 4-13: *Hydrological zone analysis for Greyhound Road wetland; change in average maximum wetland water level versus hydrological zone radius for drainage at 0.5 m bgl, 1.0 m bgl and drainage at AAMaxGL*

Lakes Road wetland

For the Lakes Road wetland, the drainage depth of 0.5 m and AAMaxGL responded in a similar curve. A hydrological zone radius of just over 300 m is required for a 10% change in average annual maximum wetland water depth. For the drainage scenario at 1.0 m bgl, a hydrological zone radius of approximately 450 m is required for a 10% change in average annual maximum wetland water level. The results of the Lakes Road hydrological zone analysis are shown in Figure 4-14.

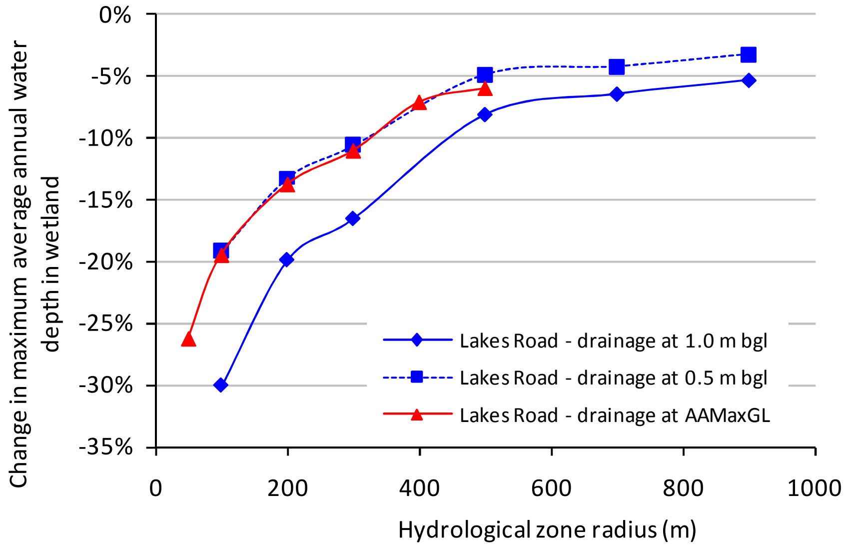


Figure 4-14: *Hydrological zone analysis for Lakes Road wetland; change in average maximum wetland water level versus hydrological zone radius for drainage at 0.5 m bgl, 1.0 m bgl and drainage at AAMaxGL*

Airfield wetland

The Airfield wetland is split into its waterbodies north and south of Lakes Road for analysis. The wetlands are connected hydrologically through a culvert in the road, and maximum elevation (AHD) of the wetland water is identical for most years. The absolute change in wetland water level as a result of the different drainage scenarios was identical for both wetlands. However, the northern wetland is deeper than the southern wetland, so the relative changes in maximum water level are greater for the southern wetland compared with the northern wetland (e.g. if the northern wetland has an average maximum depth of 1.0 m and the southern 0.5 m, a 0.1 m change will result in a 10% change for the northern wetland and a 20% change for the southern wetland).

The results of the hydrological zone analysis for the Airfield wetland's northern waterbody are shown in Figure 4-15, while results for the southern waterbody are shown in Figure 4-16.

The Airfield North wetland requires a hydrological zone radius of at least 100 m for a 10% change in average maximum wetland water depth for the 0.5 m bgl and AAMaxGL drainage scenarios. For the 1.0 m bgl drainage scenario, a hydrological zone radius of approximately 500 m is required for a minimum change in wetland depth of 10%. For the Airfield South wetland, when drainage is at AAMaxGL, a 300 m minimum radius is required for a 10% change in average annual maximum wetland water depth, a 400 m minimum for drainage at 0.5 m bgl, and a 700 m minimum for drainage at 1.0 m bgl.

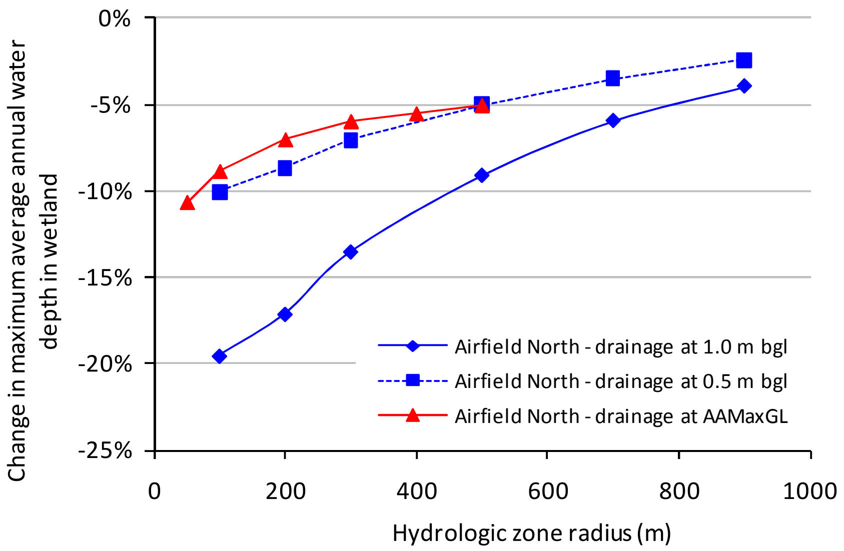


***Figure 4-15**: Hydrological zone analysis for Airfield North wetland; change in average maximum wetland water level versus hydrological zone radius for drainage at 0.5 m bgl, 1.0 m bgl and drainage at AAMaxGL*

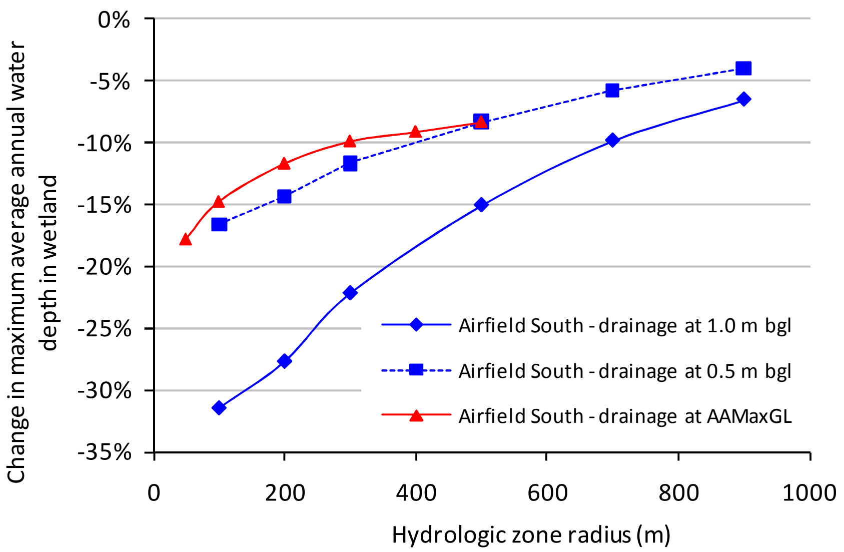


***Figure 4-16**: Hydrological zone analysis for Airfield South wetland; change in average maximum wetland water level versus hydrological zone radius for drainage at 0.5 m bgl, 1.0 m bgl and drainage at AAMaxGL*

Phillips Road wetland

The Phillips Road wetland was modelled with hydrological zone radii of 100, 200, 300, 400, 500 and 600 m for the 0.5 m bgl and 1.0 m bgl drainage scenarios, and at 50, 100, 200, 300, 400 and 500 m for the AAMaxGL drainage scenario. For the AAMaxGL and the 0.5 m scenarios, a hydrological zone radius of 200 m was enough for a change in average annual maximum wetland water level of below 10%, whereas the 1.0 m bgl scenario required a hydrological zone radius of 500 m. The results of the Phillips Road wetland hydrological zone analysis are shown in Figure 4-17.

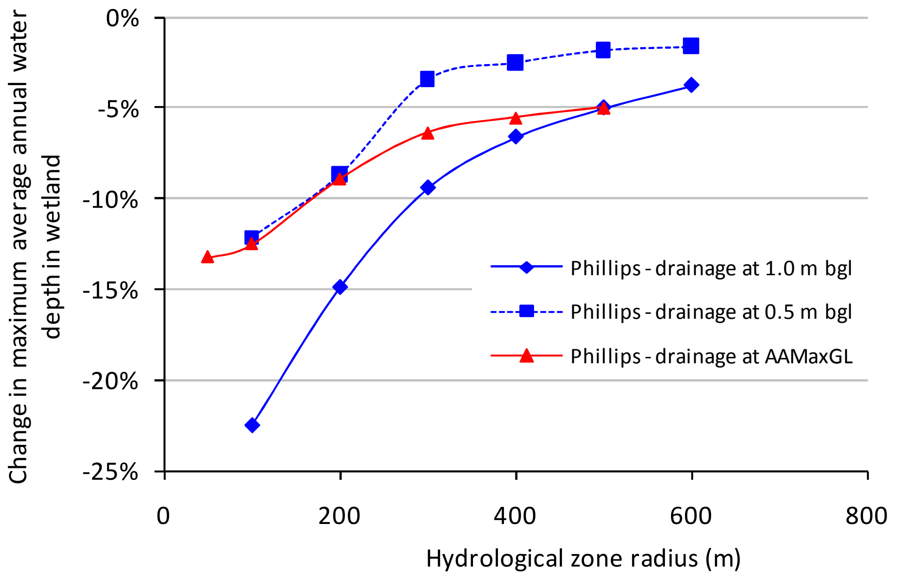


***Figure 4-17:** Hydrological zone analysis for Phillips Road wetland; change in average maximum wetland water level versus hydrological zone radius for drainage at 0.5 m bgl, 1.0 m bgl and drainage at AAMaxGL*

Elliot Road wetland

Elliot Road wetland was modelled with hydrological zone radii from 100 – 600 m. For the AAMaxGL and the 0.5 m bgl scenarios, a hydrological zone radius of 250 m was enough for a change in average annual maximum wetland water level of below 10%, whereas the 1.0 m bgl scenario required a radius of between 300 and 400 m.

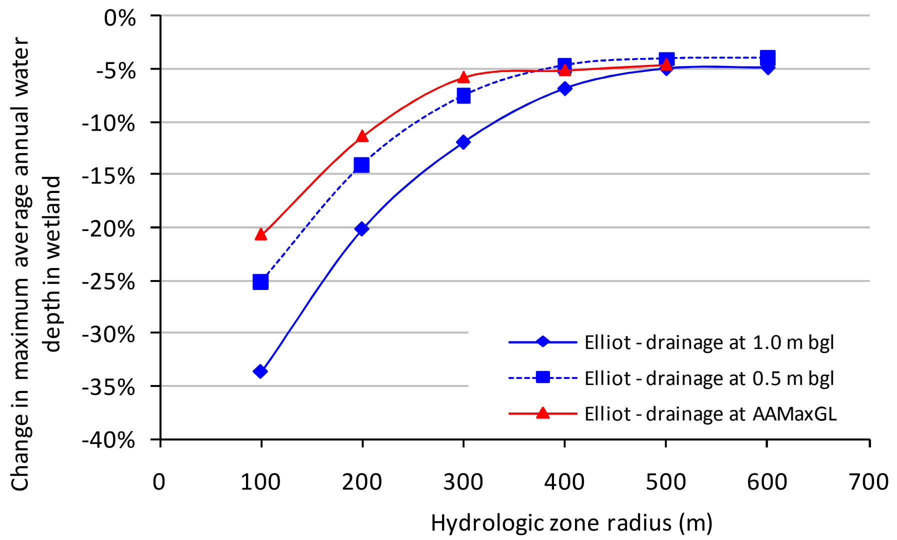


***Figure 4-18:** Hydrological zone analysis for Elliot Road wetland; change in average maximum wetland water level versus hydrological zone radius for drainage at 0.5 m bgl, 1.0 m bgl and drainage at AAMaxGL*

For the 0.5 m drainage scenario, a hydrological zone radius of approximately 250 m was required for a change in average annual maximum wetland water depth of 10%. Results for the Elliot Road wetland hydrological zone analysis are shown in Figure 4-18.

Scott and Benden Road wetlands

The Scott Road model was simulated for wetland hydrological zone radii of 100, 200, 300, 400, 500 and 600 m, for the 0.5 m bgl and 1.0 m bgl scenarios. For the scenario with drainage at 1.0 m bgl, the hydrological zone radius of 600 m was not suitable for a change in wetland depth of below 10% for the Benden Road wetland, but was appropriate for the Scott Road wetland. For the 0.5 m bgl scenario, a hydrological zone radius of 500 m was appropriate for the Benden Road wetland, while 400 m was appropriate for the Scott Road wetland. For the scenario with drains at AAMaxGL, all distances (including a 50 m radius) resulted in a change in average wetland water depth of less than 10%. The results of the hydrological zone analysis for the Benden Road and Scott Road wetlands are shown in figures 4-19 and 4-20.

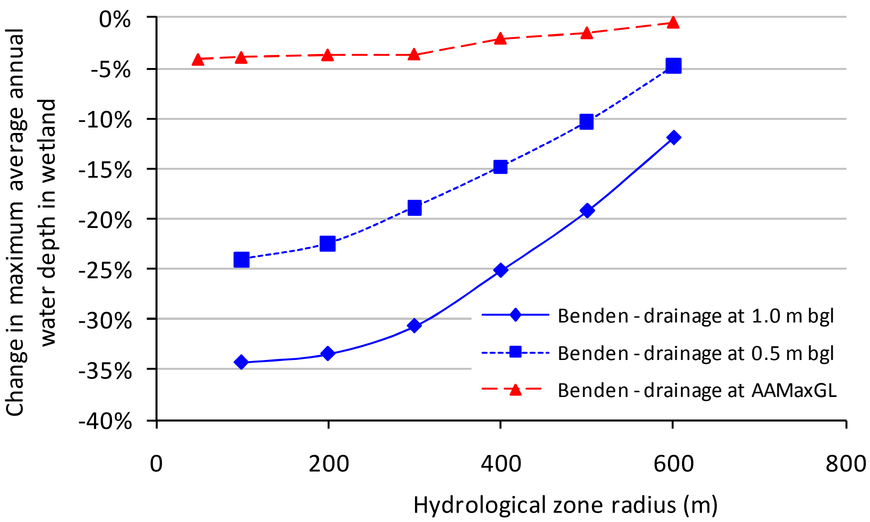


Figure 4-19: *Hydrological zone analysis for Benden Road wetland; change in average maximum wetland water level versus hydrological zone radius for drainage at 0.5 m bgl, 1.0 m bgl and drainage at AAMaxGL*

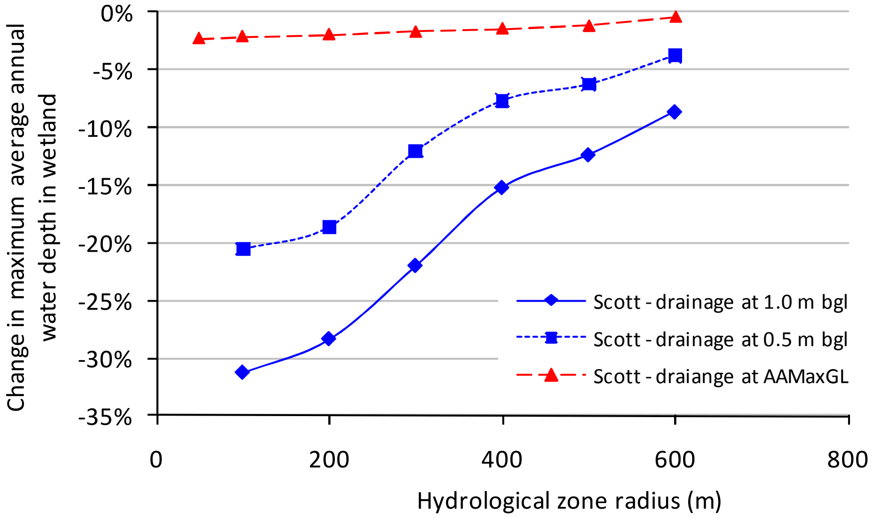


Figure 4-20: *Hydrological zone analysis for Scott Road wetland; change in average maximum wetland water level versus hydrological zone radius for drainage at 0.5 m bgl, 1.0 m bgl and drainage at AAMaxGL*

The results of the hydrological zone analysis vary from wetland to wetland but some general trends can be deduced for the wetlands of the Murray DWMP area. For drains at 1.0 m bgl, hydrological zone radii are generally required to be larger than 400 m for a minimum change in maximum wetland water level of 10%. If distances smaller than 400 m are desirable for drainage at 1.0 m bgl, wetlands would require supplementation by pumping or drainage, and appropriate approvals from DEC.

For drainage at 0.5 m bgl, the hydrological zone requirements are much smaller than for drainage at 1.0 m bgl, although the results vary from wetland to wetland. For three of the eight wetlands analysed, a radius of 200 m was required for a decline in average annual wetland water level of less than 10%. Drainage at AAMaxGL appeared to be the most appropriate CGL for hydrological zone radii of 200 m, and six out of eight wetlands required a 200 m radius for a change in average annual wetland water level of less than 10%.

4.3 Climate scenarios (EWR_S5, EWR_S7 and EWR_S8)

For each of the wetland models, the base-case scenario (EWR_S0) was simulated using SILO rainfall and evapotranspiration data for the years 1978 – 2007. This time period corresponded to the years 2010 – 2039 for the future climate scenarios.

The future wet and future dry climates used the same methodology for selection of climate data as the climate sequences used in the regional model, which corresponded to the 10th and 90th percentile for the change in annual rainfall for the 45 GCM models used in the SWSY project (CSIRO 2009). These were:

- future wet climate scenario: -1.4% change in mean annual rainfall from 1975 – 2007 (GCM NCAR-PCM, warming scenario 1℃)

- future dry climate scenario: -16.2% change in mean annual rainfall from 1975 – 2007 (GCM MRI, warming scenario 1.3℃).

All wetland scenarios were simulated over a 30-year time-period (in addition to a five-year model warm-up period) and did not include any of the drainage or development changes. The historical wet climate scenario (ERW_S8) used SILO data from 1945 – 1974, which corresponded to a 14.9% increase in mean annual rainfall compared with the period 1978 – 2007.

Saturated-zone boundary conditions were imported from the regional model for the corresponding climate sequence for all models – apart from the Barragup Swamp model, which used a fixed-head boundary condition. A 0.2 mAHD fixed-head was used for the future climate scenarios for the Barragup Swamp model to account for predicted sea-level rise. The Lakes Road model also required a channel flow (Mike 11) inflow as a boundary condition, which was extracted from the regional model.

The resulting changes in AAMaxGL and AAMinGL at each of the wetlands are shown in Table 4-4. The future wet climate scenario (EWR_S5) resulted in an average decrease in minimum and maximum groundwater levels of 0.05 m, but ranged from a 0.02 m increase in Barragup Swamp, to a 0.16 m decrease in Elliot Road wetland. The increase in head in Barragup Swamp was likely to be due to the 0.2 m sea-level rise modelled with each of the future climate scenarios.

Table 4-4: *Change in wetland groundwater levels for future wet, future dry and historical wet climate scenarios*

Wetland	Groundwater level	Change in groundwater compared to base case (S0) (m)		
		Future wet climate (EWR_S5)	Future dry climate (EWR_S7)	Historical wet climate (EWR_S8)
Barragup Swamp	AAMaxGL	0.01	-0.36	0.45
	AAMinGL	0.02	-0.24	0.36
Greyhound Road	AAMaxGL	-0.01	-0.11	0.06
	AAMinGL	-0.03	-0.13	0.06
Airfield North	AAMaxGL	-0.07	-0.55	0.32
	AAMinGL	-0.06	-0.28	0.18
Airfield South	AAMaxGL	-0.07	-0.50	0.32
	AAMinGL	-0.03	-0.23	0.06
Lakes Road	AAMaxGL	-0.02	-0.32	0.10
	AAMinGL	-0.01	-0.10	0.02
Elliot Road	AAMaxGL	-0.02	-0.26	0.10
	AAMinGL	-0.04	-0.17	0.05
Scott Road	AAMaxGL	-0.03	-0.33	0.08
	AAMinGL	-0.10	-0.34	0.05
Benden Road	AAMaxGL	-0.07	-0.54	0.24
	AAMinGL	-0.12	-0.60	0.19
Phillips Road	AAMaxGL	-0.03	-0.35	0.11
	AAMinGL	-0.02	-0.15	0.05

The future dry climate scenario (EWR_S7) predicted average decreases in minimum and maximum groundwater levels of approximately 0.3 m. This ranged from a decrease of 0.1 m in Lakes Road wetland to a decrease in AAMaxGL of 0.6 m in Benden Road wetland.

The historical wet climate sequence (EWR_S8) predicted average increases in maximum and minimum groundwater levels of approximately 0.15 m. This ranged from 0.45 m in Barragup Swamp to 0.06 m in Greyhound Road wetland.

The effect of climate scenarios on the average annual maximum wetland water depth is shown in Table 4-5. The future wet climate scenario (EWR_S5) predicts decreases in maximum wetland water levels of between 5% and 10%. Airfield South wetland predicts a 9% decrease, and Barragup Swamp a 1% increase, although this is likely to be due to the increase in sea level implemented for this scenario. The future dry climate scenario predicts decreases in average annual maximum wetland water depth of between 21% (Greyhound Road wetland) and 71% (Phillips Road wetland).

The historical wet climate scenario (EWR_S8) predicts increases of between 11% (Greyhound Road and Scott Road wetlands) and 42% (Airfield South wetland) in average annual maximum wetland water depth. The smaller decreases in the Scott Road, Elliot Road and Greyhound Road wetlands are likely to be due to the wetlands being constrained by drain depth. The wetland depth was taken from the lowest point along the wetland vegetation transect.

Table 4-5: *Change in average annual wetland water depth for various climate scenarios*

Wetland	Base case (EWR_S0)	Future wet climate (EWR_S5)		Future dry climate (EWR_S7)		Historical wet climate (EWR_S8)	
	Average annual	Average annual	% change from base	Average annual	% change from base	Average annual	% change from base
Barragup Swamp	1.28	1.29	1%	0.92	-28%	1.73	35%
Greyhound Road	0.51	0.51	-1%	0.40	-21%	0.57	11%
Airfield North	1.12	1.05	-6%	0.57	-49%	1.44	29%
Airfield South	0.77	0.71	-9%	0.28	-64%	1.10	42%
Lakes Road	0.44	0.42	-5%	0.12	-72%	0.54	23%
Elliot Road	0.65	0.63	-3%	0.39	-40%	0.75	15%
Scott Road	0.67	0.64	-5%	0.36	-46%	0.74	11%
Benden Road	1.20	1.13	-6%	0.70	-42%	1.43	19%
Phillips Road	0.50	0.47	-5%	0.15	-71%	0.61	22%

4.4 Sea-level rise (EWR_S9)

The sea-level rise scenario was only undertaken for wetland models identified as being affected by sea-level rise in the regional model. Figures 3-10 and 3-11 show the change in AAMaxGL and AAMinGL for the regional model. The only wetland from the EWR study affected by sea-level rise is Barragup Swamp (Figure 3-10).

The maximum sea-level rise of 0.9 m was used for the EWR_S9 scenario, using the same methodology as S37 for the Murray regional model. The sea-level rise scenario was modelled for Barragup Swamp by increasing all model boundaries from 0 mAHD to 0.9 mAHD. All other model inputs and parameters were identical to EWR_S0. The model was run from 1978 – 2007. The sea-level rise scenario resulted in higher maximum and minimum groundwater heads. The AAMaxGL increased by 0.21 m from 1.16 m to 1.37 m, and the AAMinGL increased by 0.26 m. Duration of inundation for the lowest point in the wetland increased from 92.9% to 98.7%. The results are shown in Table 4-6 and the time-series for the base-case versus the sea-level rise scenario are shown in Figure 4-21.

The effect of saltwater intrusion as a consequence of sea-level rise was not modelled. It is a limitation of the model, as Mike SHE assumes constant density of fluids. A variable-density model would be required to determine the effect of the seawater intrusion due to sea-level rise on the wetland hydrology and water quality.

Table 4-6*: Difference in AAMaxGL, AAMinGL and duration of inundation for base-case and sea-level rise scenarios for Barragup Swamp, lowest point along the vegetation transect.*

Scenario	AAMaxGL (mAHD)	AAMinGL (mAHD)	Duration of inundation (%)
Base case (EWR_S0)	1.16	0.07	92.9
Sea-level rise (0.9 m) (EWR_S9)	1.37	0.33	98.7

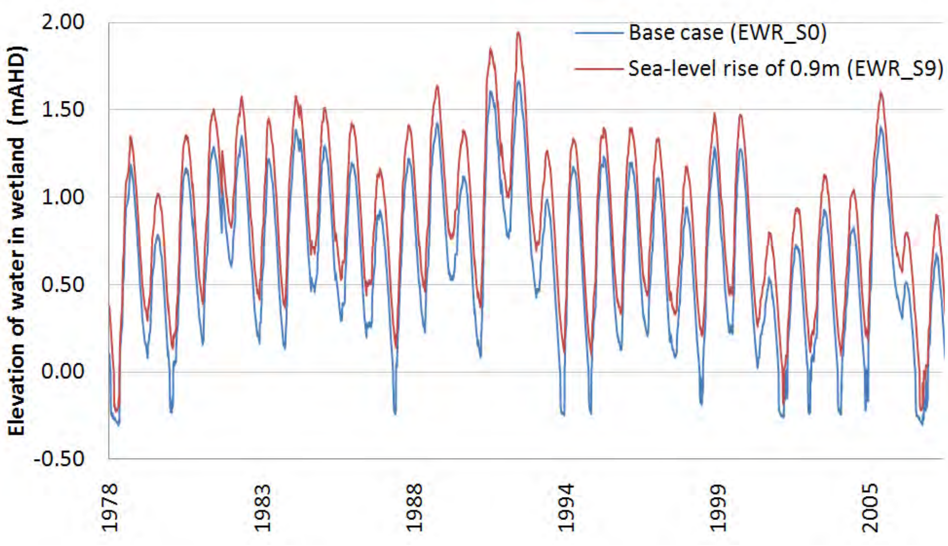


Figure 4-21*: Time-series for sea-level rise and base-case scenario for Barragup Swamp, lowest point on the vegetation transect.*

5 Conclusions and recommendations

This scenario report comprises the third and final phase of the Murray groundwater studies, and includes the analysis and results of scenarios that were undertaken to determine the change to water budgets and groundwater levels under various land development, drainage and climate scenarios. The phase included both modelled regional scenarios and finer-scaled wetland scenarios. The wetland scenarios supported development of the wetland EWRs.

Scenarios for the Murray regional model were decided by the Murray DWMP technical advisory group. The scenarios included:

- **Climate change scenarios** based IPCC predictions, including predictive changes in rainfall, evapotranspiration and sea-level rise. For the Murray DWMP project, the following climate change scenarios were chosen:
    - future wet: -1.4% change in mean annual rainfall from 1975 – 2007 (GCM NCAR PCM, warming scenario 1℃)
    - future medium: -8.7% change in mean annual rainfall from 1975 – 2007 (GCM MRI, warming scenario 0.7℃)
    - Future dry: -16.2% change in mean annual rainfall from 1975 – 2007 (GCM MRI, warming scenario 1.3℃)
    - historical wet: 14.3% increase in mean annual rainfall from 1975 – 2007 (uses actual rainfall from period 1945 – 1974).
- **Development scenarios** based on mapping from the *Draft south metropolitan and Peel structure plan – urban growth management strategy* (WAPC 2009). Development scenarios included ‘current development’, areas identified for ‘immediate detailed investigation’, and areas identified for ‘further investigation’.
- **Subsurface drainage scenarios** including depths of subsurface drains at ground level with 1.0 m clean-fill, drainage at 1.0 m bgl with no extra clean-fill and drainage at AAMaxGL.

Fifteen regional model scenarios were selected, which were a combination of the climate, drainage and development options above. The scenarios are listed in Table 5-1. The results of the scenarios were presented both spatially and quantitatively (changes in water balance). An analysis of catchment waterlogging was undertaken for each climate scenario, and water balances were undertaken to determine drainage quantities for various subsurface drainage depths and development scenarios.

Table 5-1: *Scenarios for the Murray regional model*

Scenario number	Climate scenario	Subsurface drainage scenario	Development scenario
S0	Current climate	No drains	current
S9	Future wet climate	No drains	current
S11	Future wet climate	Ground level with 1m fill	current + immediate + further
S15	Future wet climate	1 mBGL with 0m fill	current + immediate + further
S18	Future medium climate	No drains	current
S20	Future medium climate	Ground level with 1m fill	current + immediate + further
S26	Future medium climate	Drains at AAMaxGL	current + immediate + further
S27	Future dry climate	No drains	current
S29	Future dry climate	Ground level with 1m fill	current + immediate + further
S33	Future dry climate	1 mBGL with 0m fill	current + immediate + further
S36	Historical wet climate	No drains	current
S37	Maximum sea-level rise	No drains	current
S38	Wet climate, 1955 rainfall	No drains	current
S39	Future medium climate	Drains at MaxGL	current + immediate + further
S40	Future medium climate	Ground level, 1m fill, domestic bores	current + immediate + further

For the climate change scenarios (S09, S18, S27 and S36) the changes in average annual maximum and minimum groundwater levels for the Murray DWMP area, compared with the current climate scenario (S0), included:

- future wet climate (S09): -0.04 m for AAMaxGL, -0.01 m for AAMinGL
- future medium climate (S18): -0.27 m for AAMaxGL, -0.09 m for AAMinGL
- future dry climate (S27): -0.56 m for AAMaxGL, -0.20 m for AAMinGL
- historical wet climate (S36): +0.42 m for AAMaxGL, +0.18 m for AAMinGL

Subsurface drainage was modelled in 11 development areas of the Murray DWMP region at various depths and fill quantities. The quantity of drainage for each of the developments for each of the drainage scenarios is shown in Table 5-2.

The quantity shown in Table 5-2 is indicative of the quantity of water requiring management for each of the development areas. It does not necessarily represent the quantity of water draining away from the development areas, rather it represents the water that needs to be managed at the development scale and drained internally (e.g. to raingardens, biofilter systems or constructed lakes).

The drainage presented in the Murray DWMP Mike SHE model is conceptual: the regional model is not designed to be used as a detailed drainage tool. However, the regional model does provide first-pass estimates of drainage quantities that are likely to arise in the various development areas for a range of subsurface drainage levels and climate scenarios. If detailed drainage design is desired, a model of finer-grid resolution is recommended.

Development-scale models could use boundary conditions and inputs from the Murray regional model. Re-calibration is likely to be required; even so, the modelling parameters from the Murray regional model would provide good initial values for parameter estimation.

Table 5-2: *Drainage quantities for development subareas for various climate and drainage scenarios*

Total drainage volume from development area	Future wet climate		Future medium climate			Future dry climate	
	Drains at ground level S11 (ML)	Drains at 1 m bgl S15 (ML)	Drains at ground level S20 (ML)	Drains at AAMaxGL S26 (ML)	Drains at MaxGL S39 (ML)	Drains at ground level S29 (ML)	Drains at 1 m bgl S33 (ML)
South Yunderup	45	367	19	75	5	6	168
Austin Cove	1084	1599	834	919	765	690	1004
Nerimma	2223	2785	1817	1994	1799	1841	1833
Buchanans	4471	5715	3615	4014	3528	3509	3626
Pinjarra	441	418	401	436	395	349	333
South Murray	94	174	43	189	69	28	48
Barragup	82	493	40	297	56	15	145
Ravenswood	3394	4587	2597	3122	2609	2727	2742
Nambeelup	3954	5554	2945	3460	2871	2572	3137
Carcoola	474	672	371	460	353	278	376
North Dandalup	720	1024	567	581	560	426	674
TOTAL	**16 982**	**23 387**	**13 249**	**15 546**	**13 008**	**12 441**	**14 087**

The effects of a 0.9 m sea-level rise are confined to the western coastal corridor and the region surrounding the Murray River to Pinjarra. Most of the development areas are largely unaffected. The developments close to the Murray River (apart from Buchanans and Yunderup) are unlikely to be affected by sea-level rise because large depths to groundwater already exist in these areas.

The effect of saltwater intrusion as a consequence of sea-level rise has not been modelled as part of the DWMP project. It is a limitation of the model, as Mike SHE assumes constant density of fluids. If the effects of seawater intrusion due to sea-level rise are desired, a variable density model is recommended.

Waterlogging (groundwater inundation) is predicted to be extensive throughout the DWMP area, and is most severe in the modelling regions in the low-lying coastal plain, away from major rivers and sand dune systems. The presence of widespread and severe inundation highlights the requirement for adequately designed subsurface drainage systems, as well as detailed modelling and monitoring at an appropriate scale when undertaking more detailed design.

Domestic bore abstraction was modelled for the development areas. The abstraction was modelled at a rate of 800 kL/domestic bore/year, assuming 20% of residents use domestic bores (one in five houses) and housing block sizes average 600 m^2. Information on bore installation rates and abstraction quantities was taken from Department of Water (2009). The use of domestic bores was predicted to have significant effects on subsurface drainage quantities and MinGL. AAMinGLs were predicted to decrease by approximately 0.6 – 0.9 m. The use of domestic bores was predicted to significantly decrease the subsurface drainage quantity – a decrease from 12.4 to 5.4 GL/year was predicted for the future medium climate scenario. The domestic bore abstraction quantities and installation rates are associated with high degrees of uncertainty. Results of the drainage and abstraction values for the domestic bore abstraction scenario are indicative at best, because uncertainty in the model inputs is too large to have a high level of confidence in the absolute values.

A suite of wetland scenarios was developed for the wetland EWR component of the Murray DWMP project (Table 5-3). The wetland scenarios included climate change, subsurface drainage, hydrological zone analysis and an analysis of fringing sand dunes with respect to wetland hydrology. Wet and dry climate inputs were identical to the Murray regional model.

Table 5-3: *List of wetland scenarios*

Scenario ID	Scenario name	Climate	Subsurface drainage	Other changes
EWR_S0	Base case	Current	No drains	No change
EWR_S1	Sand dune analysis	Current	No drains	Without sand dune
EWR_S2	Hydrological zone analysis (AAMaxGL)	Current	Drainage at AAMaxGL	Hydrological zone analysis
EWR_S3	Hydrological zone analysis (0.5m)	Current	Shallow = 0.5m BGL	Hydrological zone analysis
EWR_S4	Hydrological zone analysis (1m)	Current	Medium = 1m BGL	Hydrological zone analysis
EWR_S5	Wet climate	Wet	No drains	No change
EWR_S7	Dry climate	Dry	No drains	No change
EWR_S8	Historical wet climate	Historical wet	No drains	No change
EWR_S9	Sea level rise	Current	No drains	0.9m sea-level rise

EWR_S1 involved analysing the effect of removing fringing sand dunes, and was undertaken for Scott Road, Benden Road, Greyhound and Airfield wetlands. All wetlands had predicted decreases in average maximum wetland water depth of less than 4% when the fringing sand dunes were removed. Greyhound Road wetland predicted the smallest change in average annual maximum wetland water depth (less than 0.01 m or 1%) when the fringing sand dunes were removed; however, in this wetland the maximum depth was likely to be limited by the outflow drain invert level. Benden Road wetland had the largest proportion of dunes removed from its fringes, resulting in the largest decrease in average wetland water depth (0.04 m or 3.1%).

The wetland hydrological zone analysis scenarios (EWR_S2, EWR_S3 and EWR_S4) explored the effects of various drainage levels and hydrological zone radii on the wetland water regimes. The objective was to quantify the effect of various hydrological zones on each wetland's hydrological regime, for a range of subsurface drainage levels. For drains at 1.0

m bgl, hydrological zone radii were generally required to be larger than 400 m for a minimum change in maximum wetland water level of 10%. If zone radii smaller than 400 m are desirable for drainage at 1.0 m bgl, wetlands would require supplementation by pumping or drainage, which would require approval by DEC.

For drainage at 0.5 m bgl, the hydrological zone requirements were much smaller than for drainage at 1.0 m bgl, however the results varied from wetland to wetland. For three of the eight wetlands analysed, a zone radius of 200 m was required for a decline in average annual water level of less than 10%. Drainage at AAMaxGL appeared to be the most appropriate CGL for a radius of 200 m, and six out of eight wetlands required a 200 m radius for a change in average annual wetland water level of less than 10%.

The future wet climate scenarios predicted changes in average annual wetland water depth ranging from a 1% increase (Barragup Swamp) to a 9% decrease (Airfield South). The 1% increase in Barragup Swamp was likely to be due to the 0.2 m sea-level rise implemented for the future climate scenarios. The future dry climate scenario predicted decreases in average annual wetland water depth ranging from 21% (Greyhound Road wetland) to 71% (Phillips Road wetland). The historical wet climate (1945 – 1974) predicted increases in maximum wetland water depth ranging from 11% (Scott Road wetland and Greyhound Road wetland) to 42% (Airfield South wetland). Sea-level rise is predicted to influence one of the eight wetlands (Barragup Swamp): a 0.9 m increase in sea level is predicted to result in an average annual wetland water level increase of approximately 0.21 m.

Figures

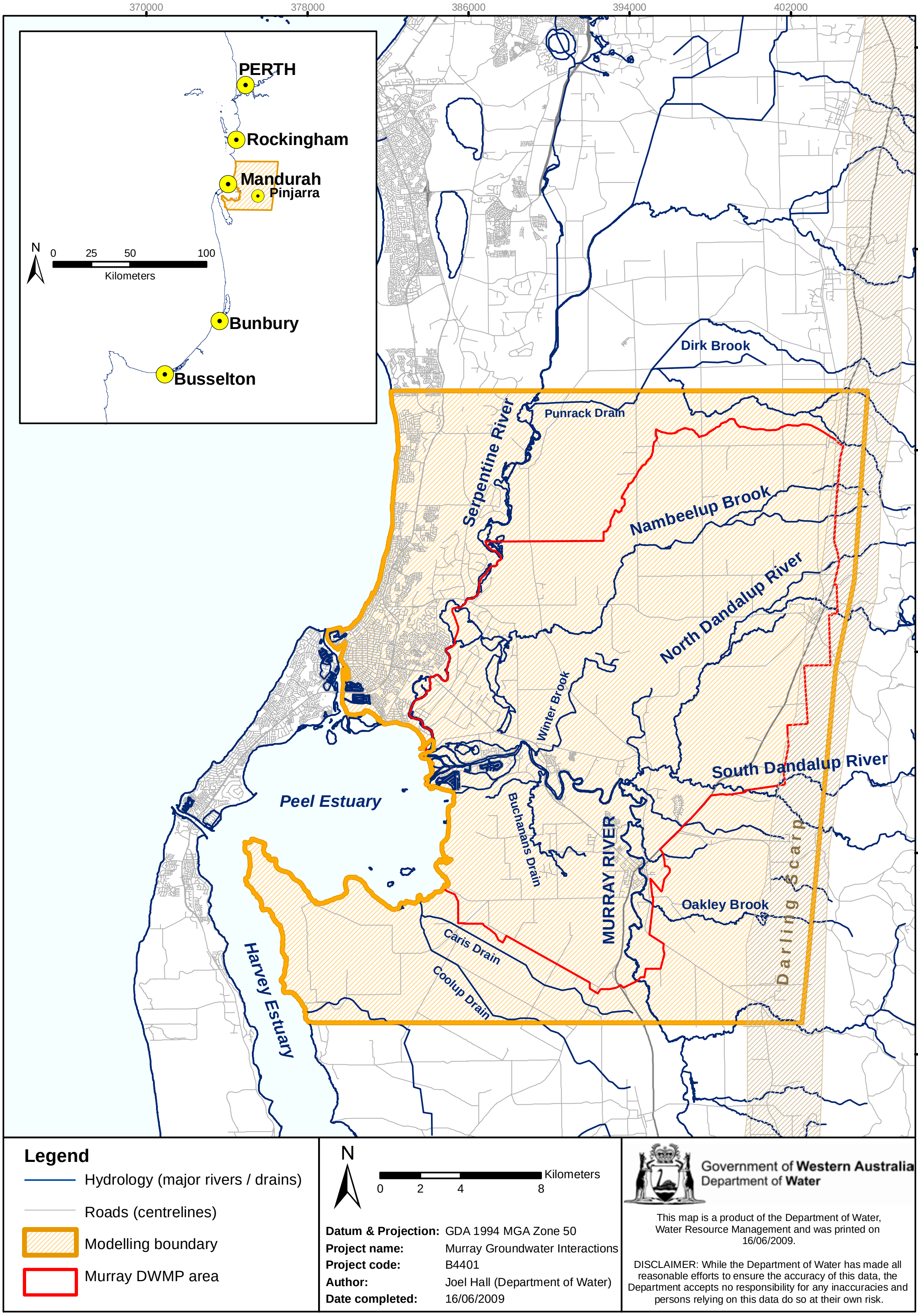


Figure 1-1: *Murray regional model boundary and Murray DWMP boundary*

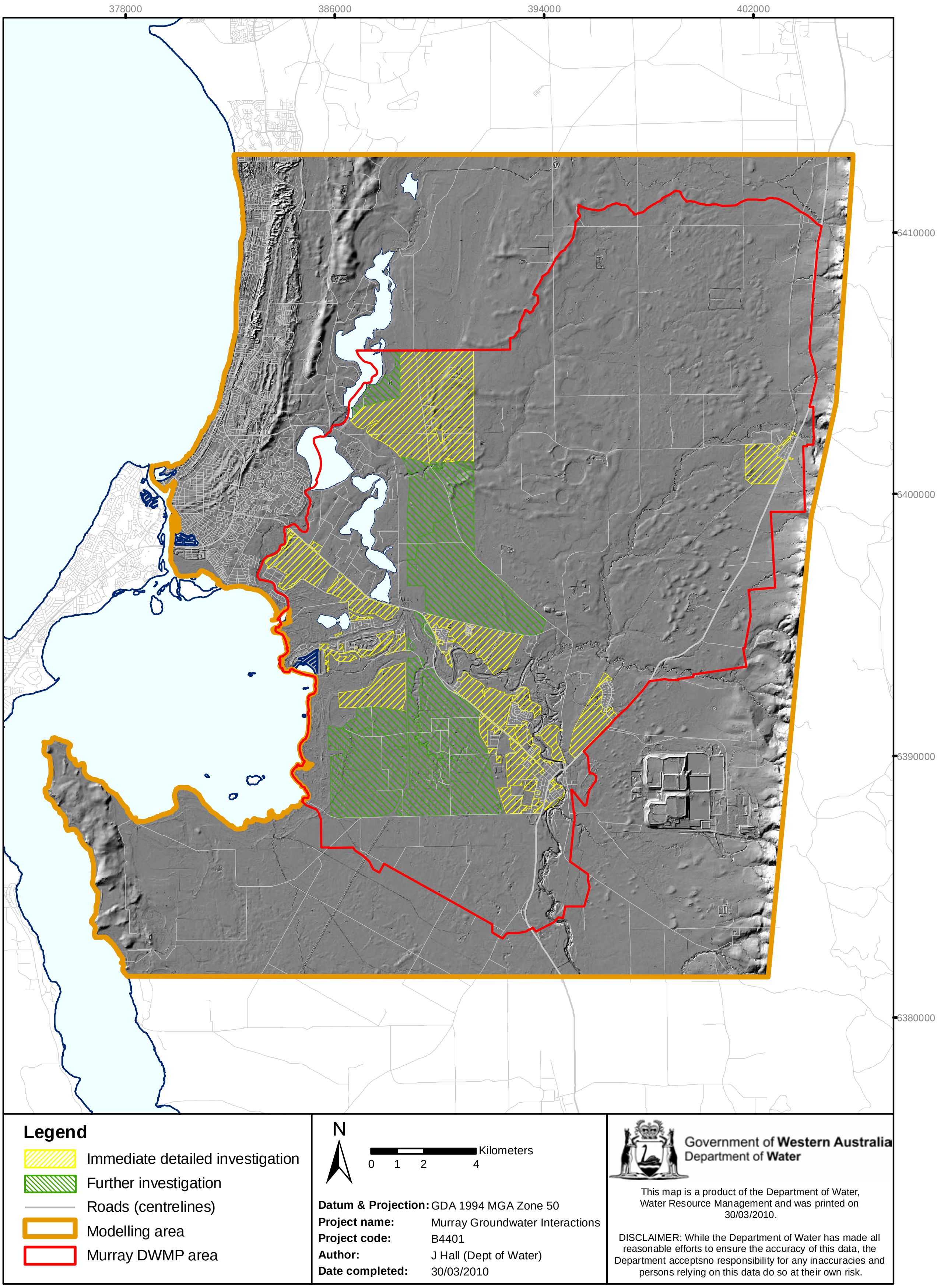


Figure 2-1: *Development regions for the Murray DWMP area*

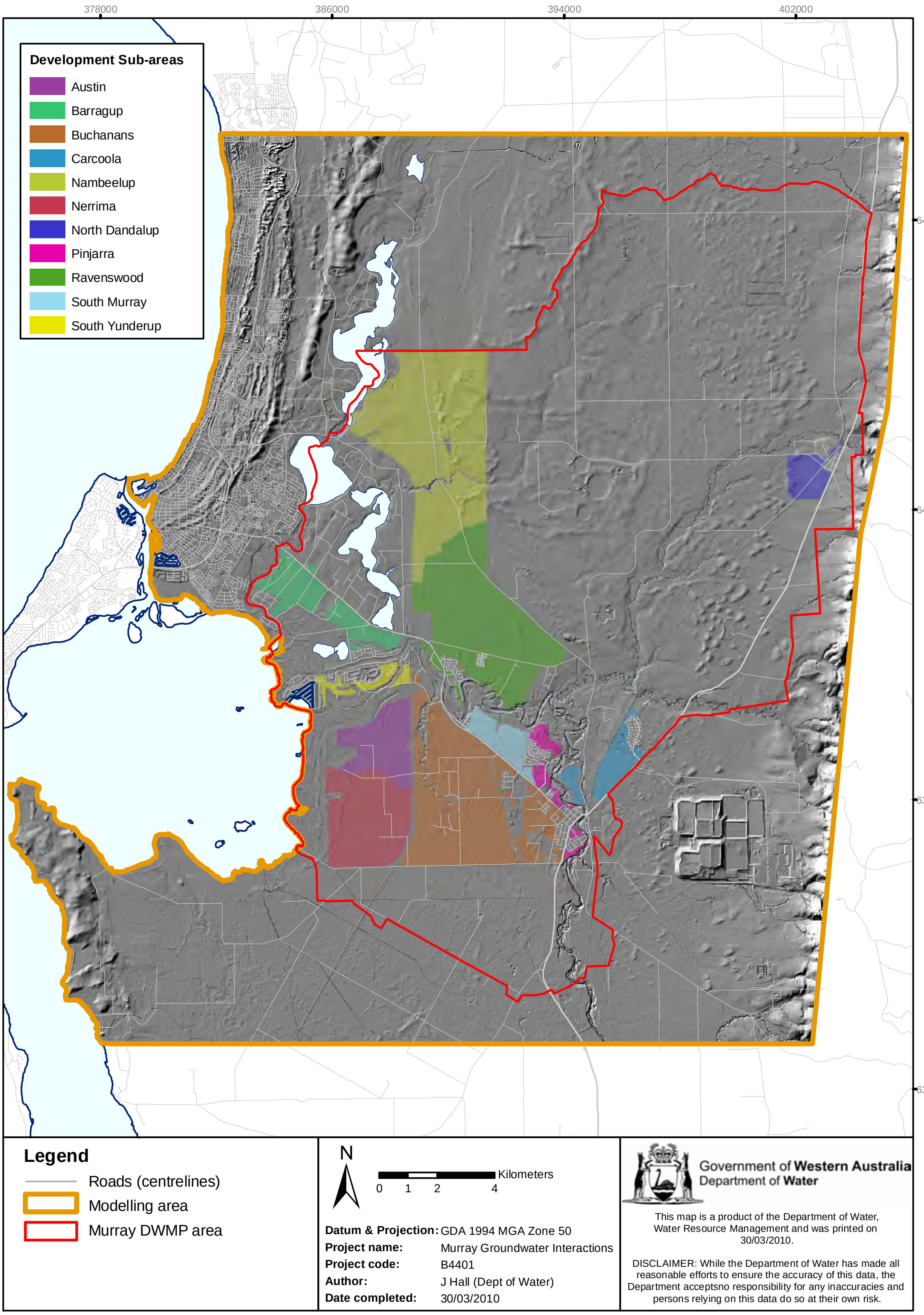


***Figure 2-2:** Development subareas for the Murray DWMP area*

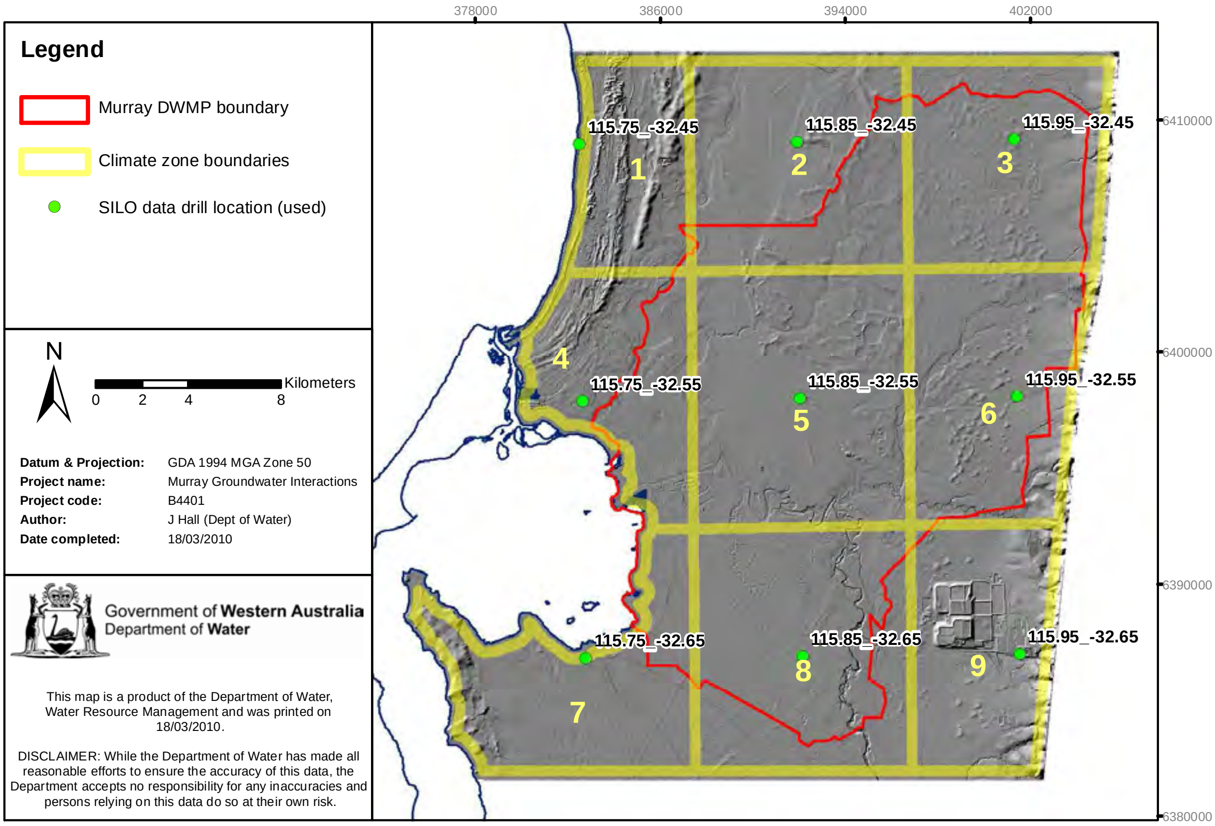


***Figure 2-5**: Rainfall locations for future rainfall and evaporation time-series*

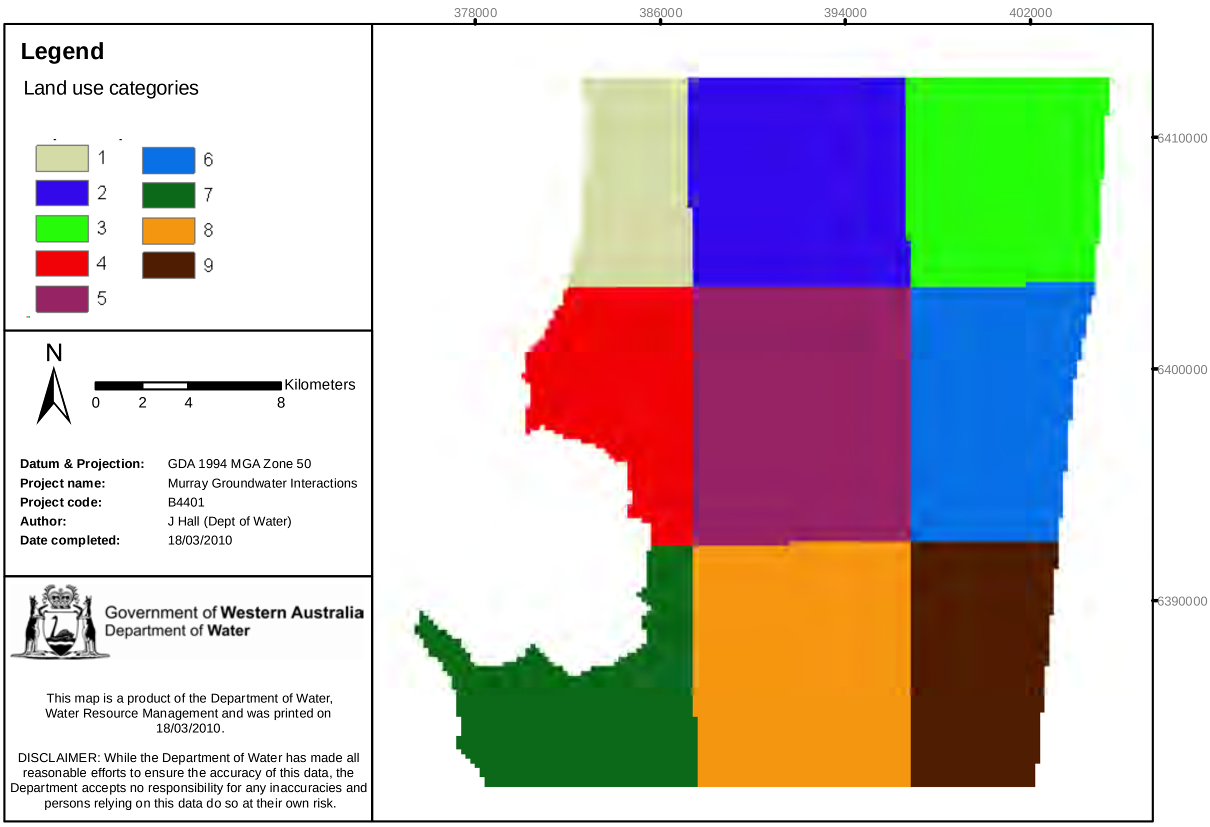


***Figure 2-6**: Climate change rainfall and evapotranspiration zones for regional model*

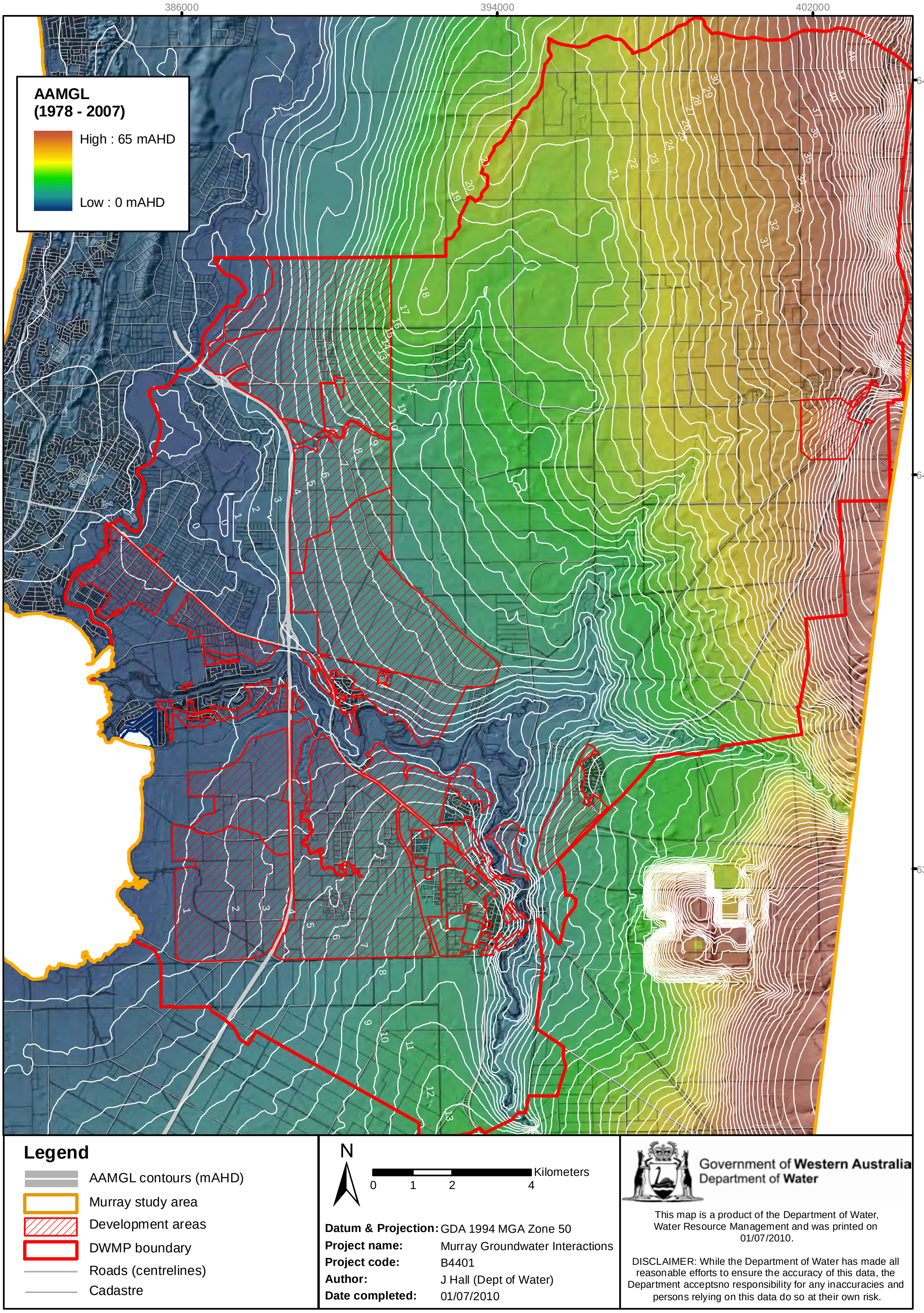


Figure 3-1: *Raster and contour outputs for AAMaxGL for the base-case scenario (S0)*

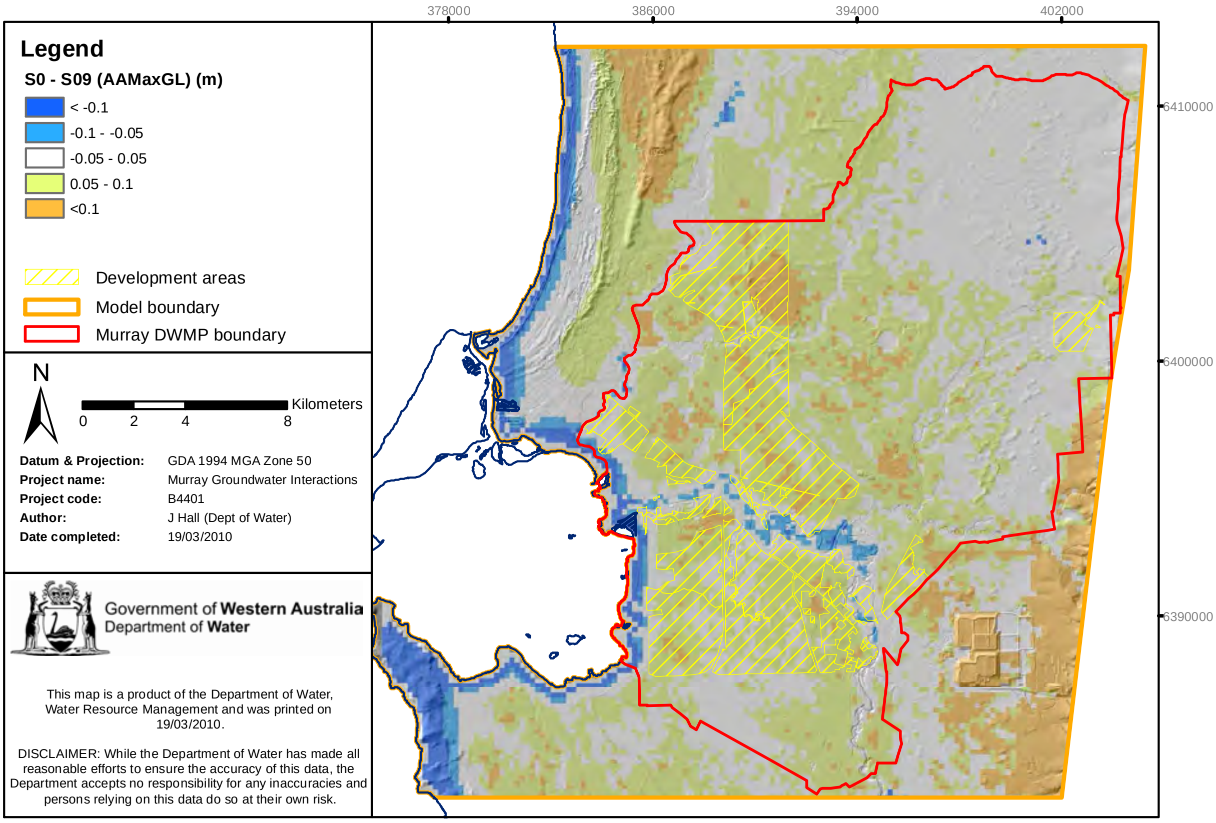


Figure 3-2: *Difference between current and future wet climate scenario (AAMaxGL)*

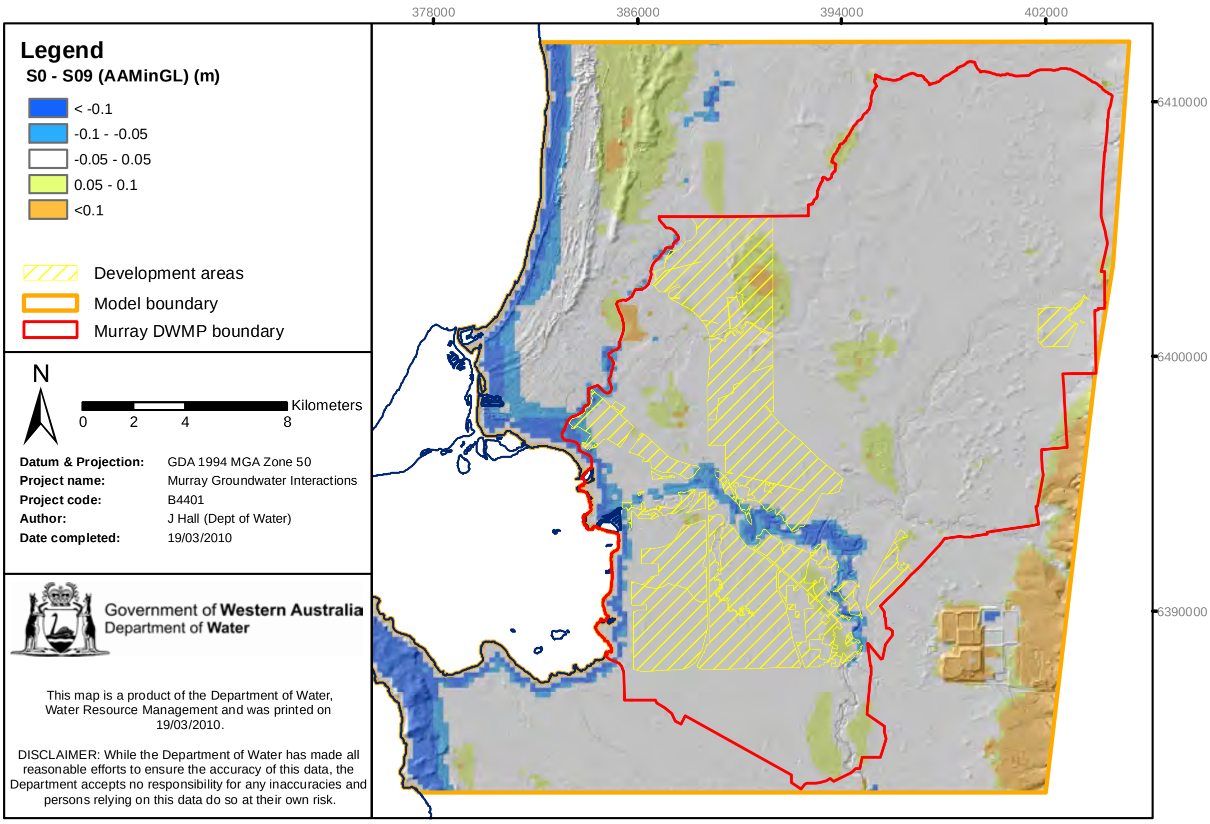


Figure 3-3: *Difference between current and future wet climate scenario (AAMinGL)*

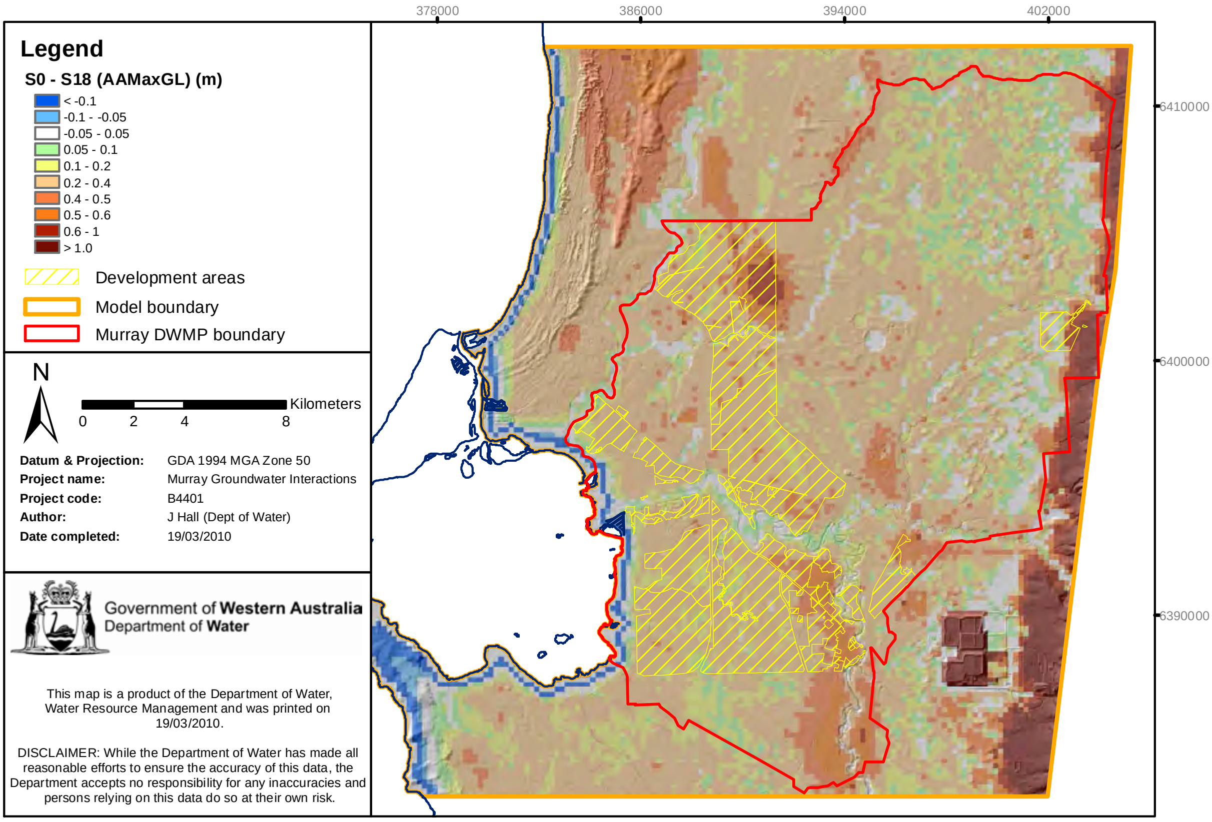


Figure 3-4: *Difference between current and future medium climate scenario (AAMaxGL)*

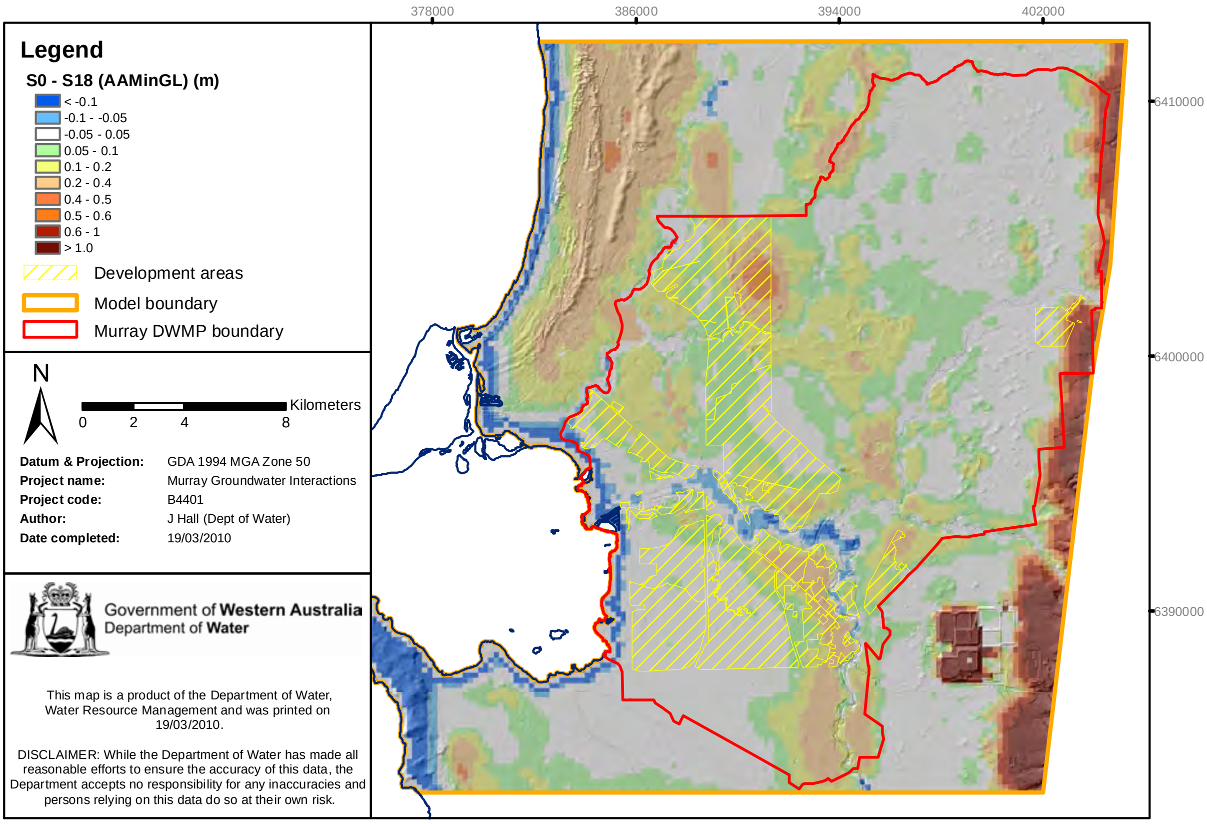


Figure 3-5: *Difference between current and future medium climate scenario (AAMinGL)*

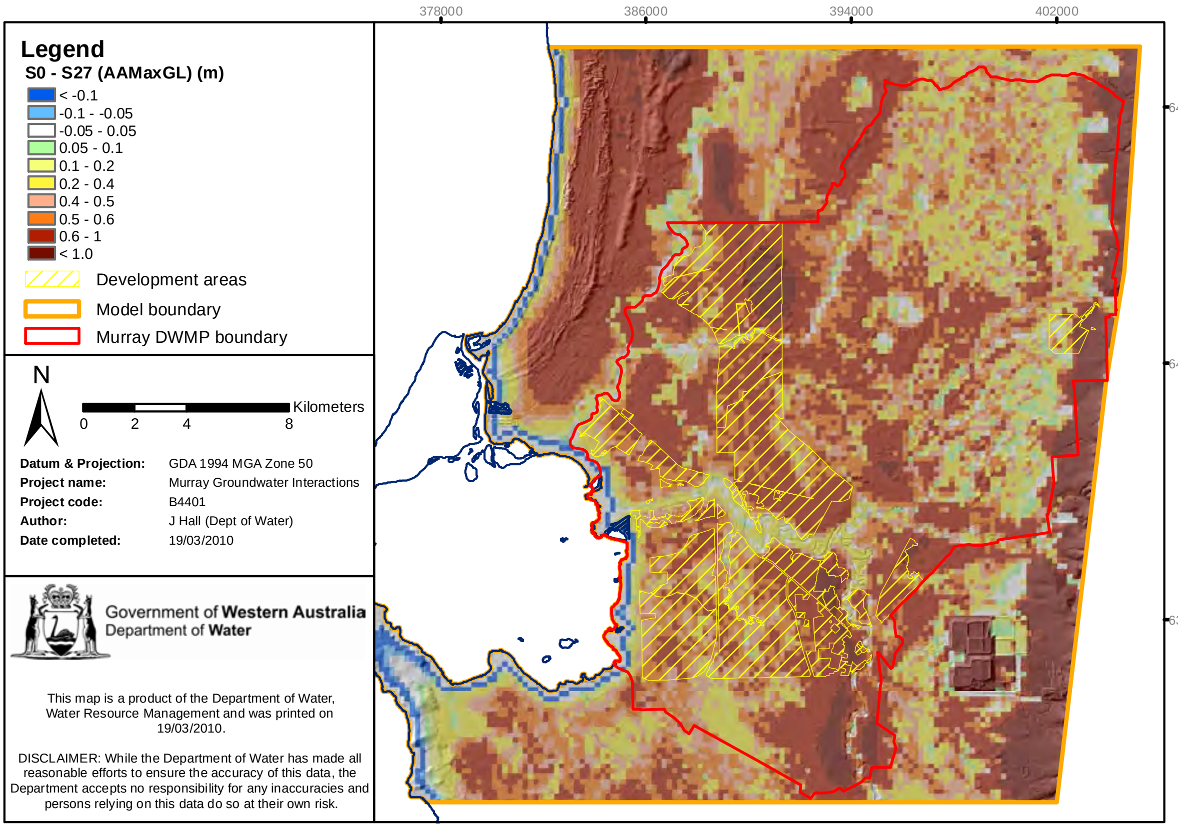


***Figure 3-6:** Difference between current and future dry climate scenario (AAMaxGL)*

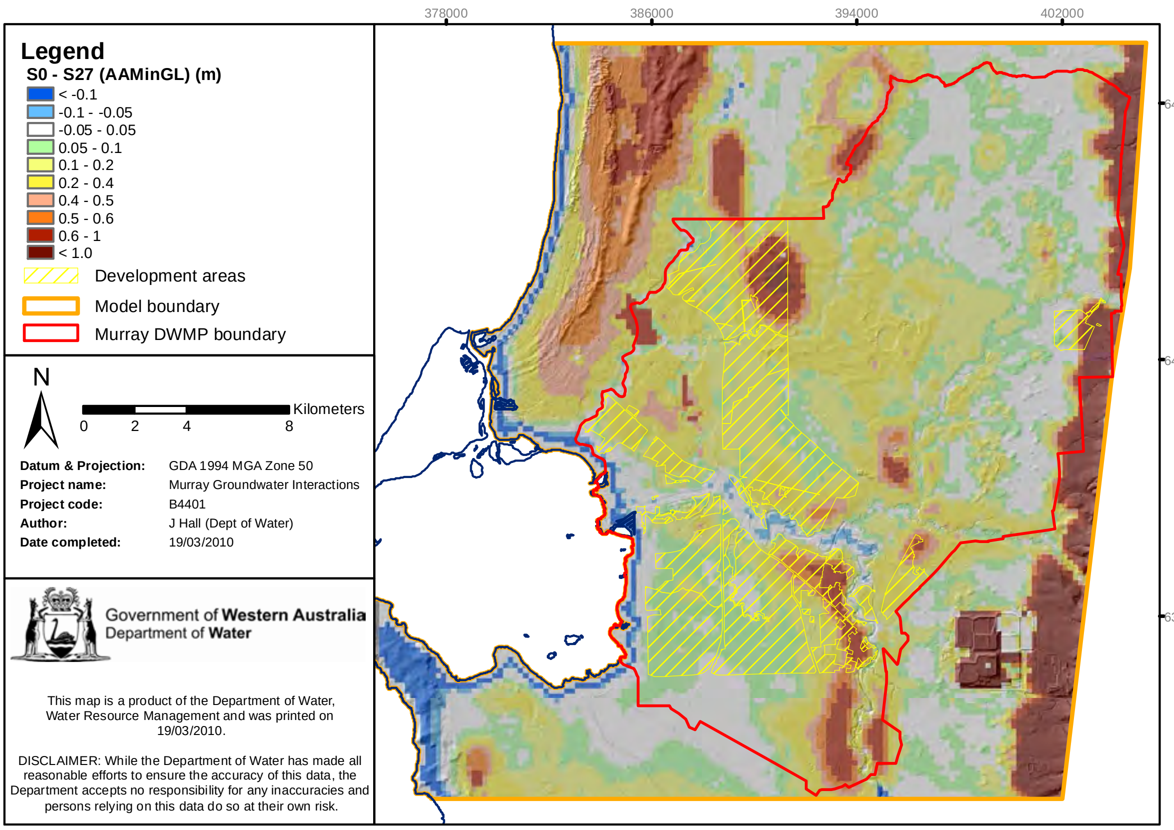


***Figure 3-7:** Difference between current and future dry climate scenario (AAMinGL)*

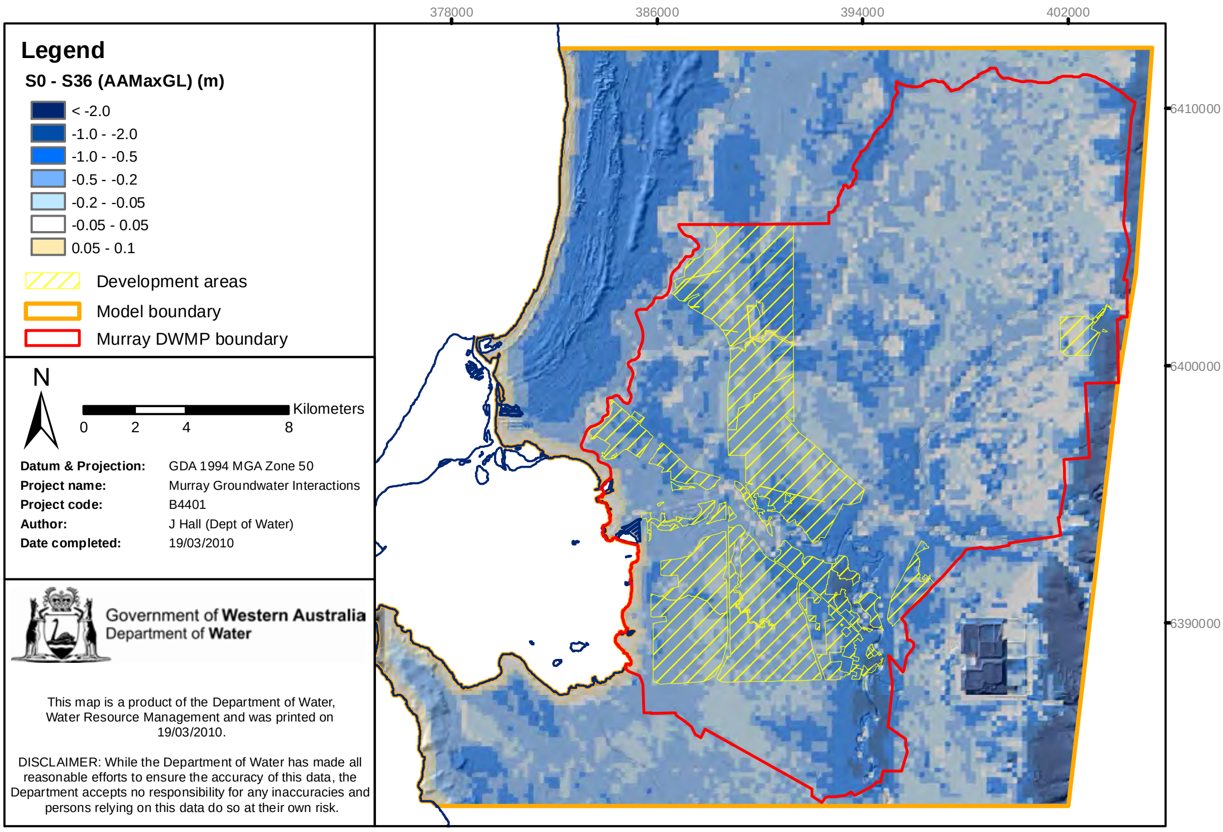


***Figure 3-8**: Difference between current and historical wet climate scenarios (AAMaxGL)*

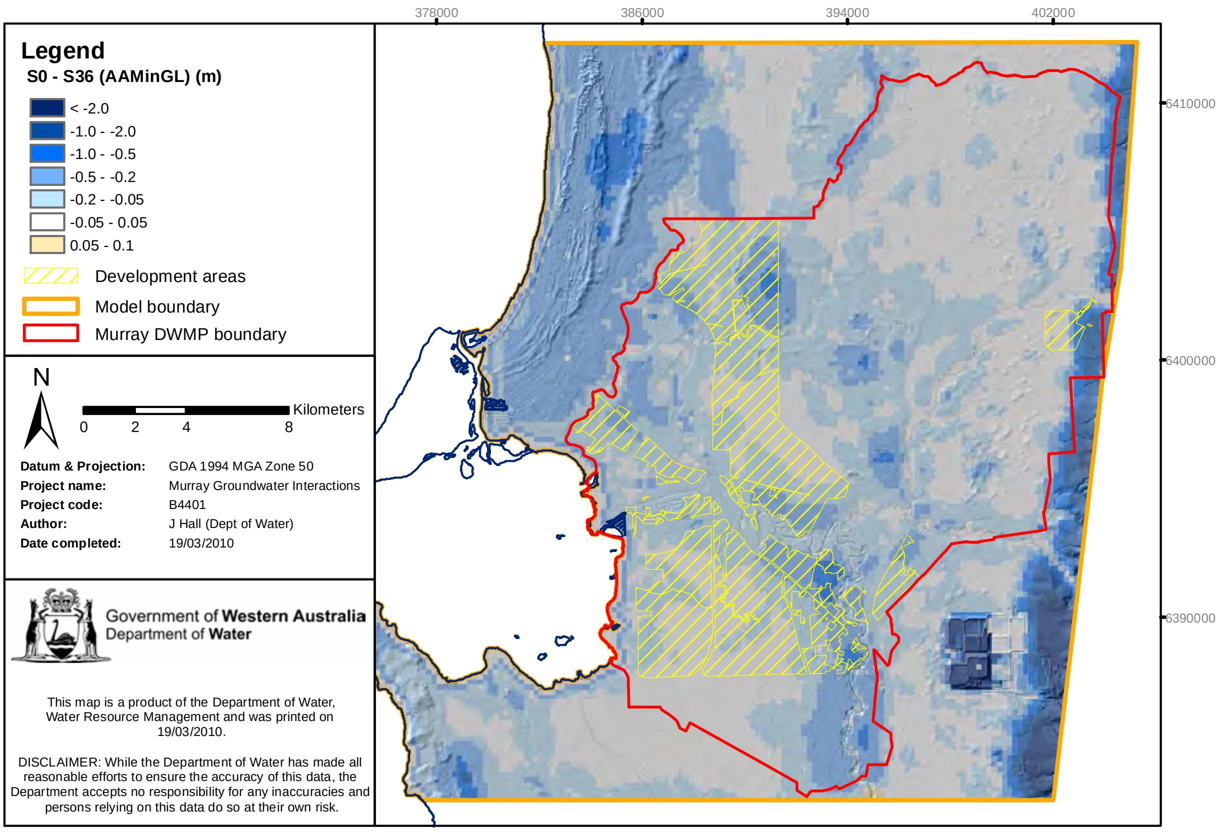


***Figure 3-9**: Difference between current and historical wet climate scenarios (AAMinGL)*

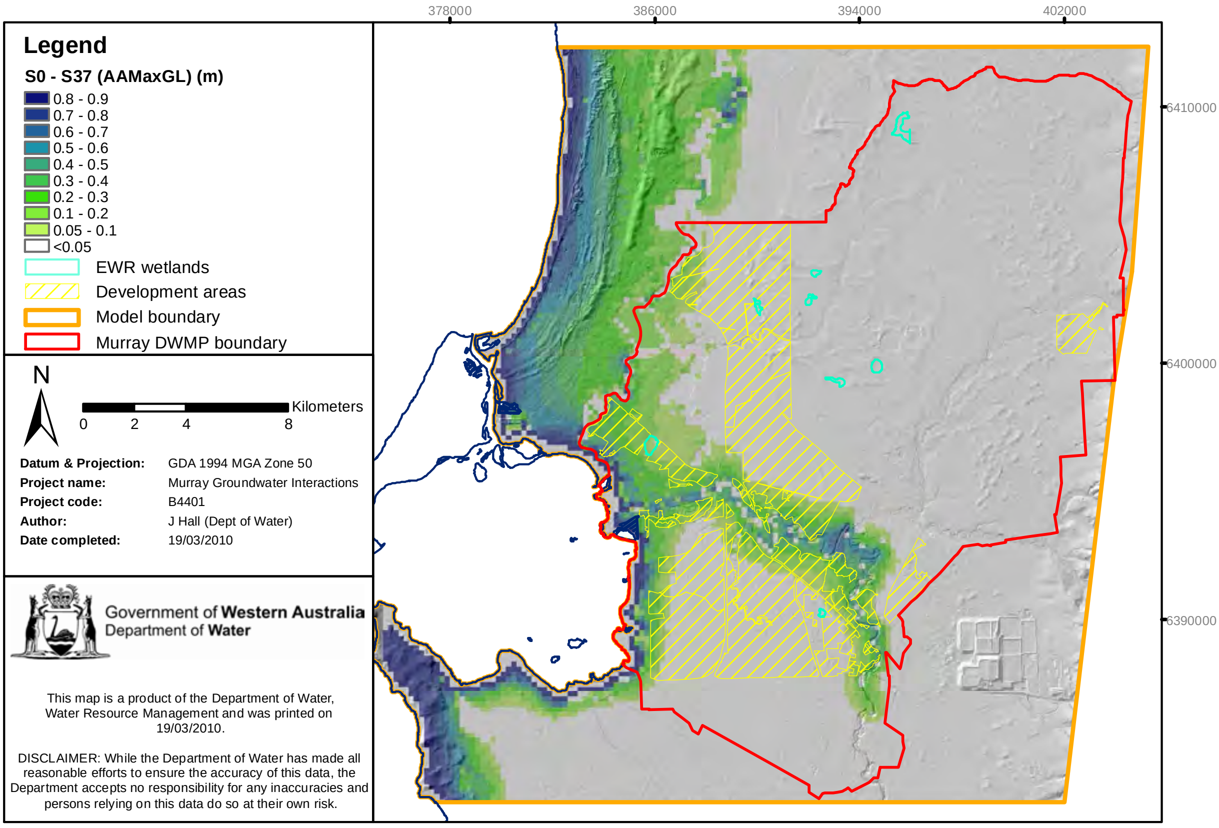


Figure 3-10: *0.9 m sea-level rise, change in AAMaxGL*

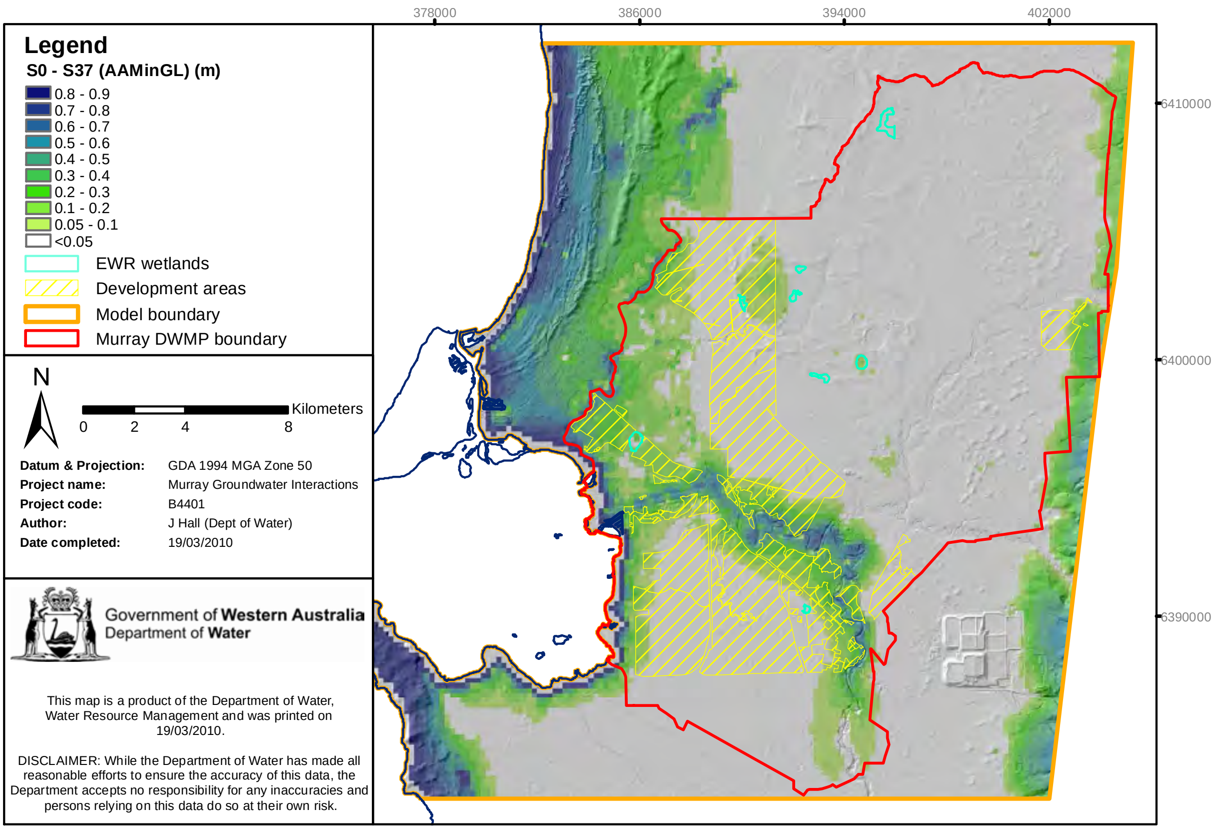


Figure 3-11: *0.9 m sea-level rise, change in AAMinGL*

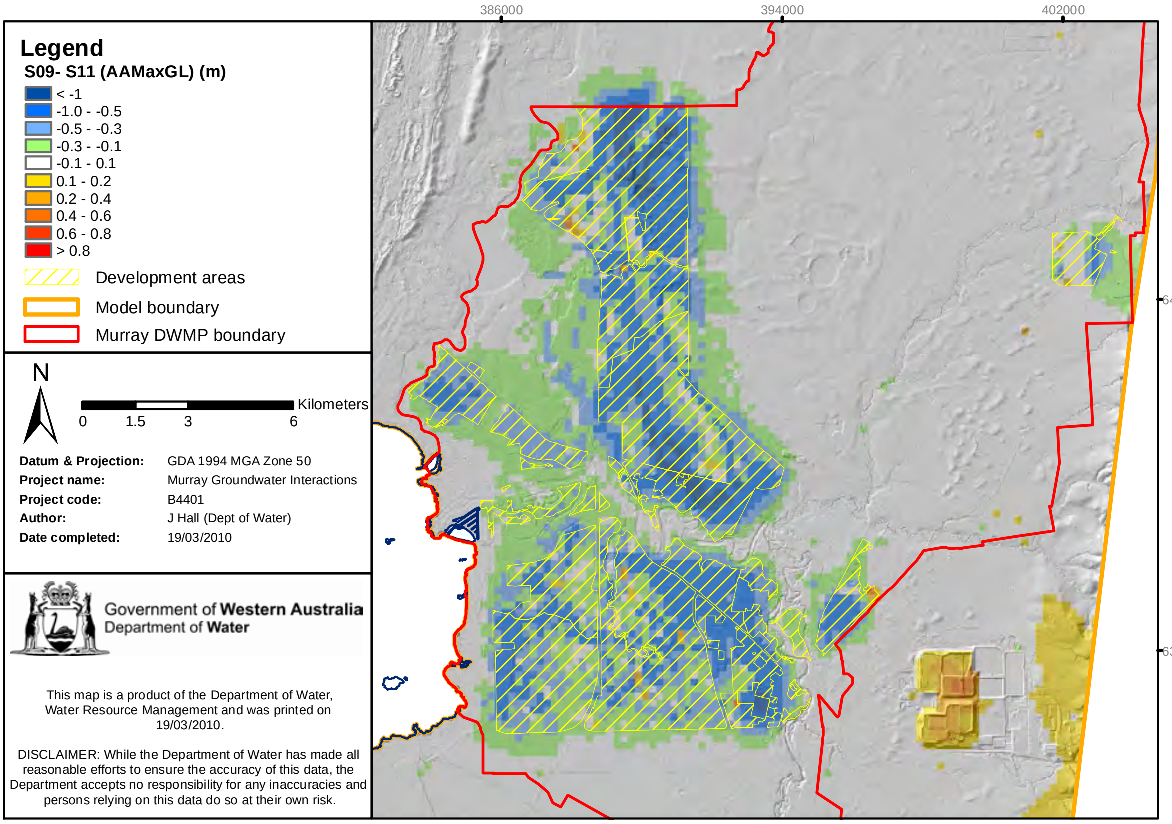


Figure 3-14: *Future wet scenario: change in AAMaxGL for drains at ground level and 1.0 m fill.*

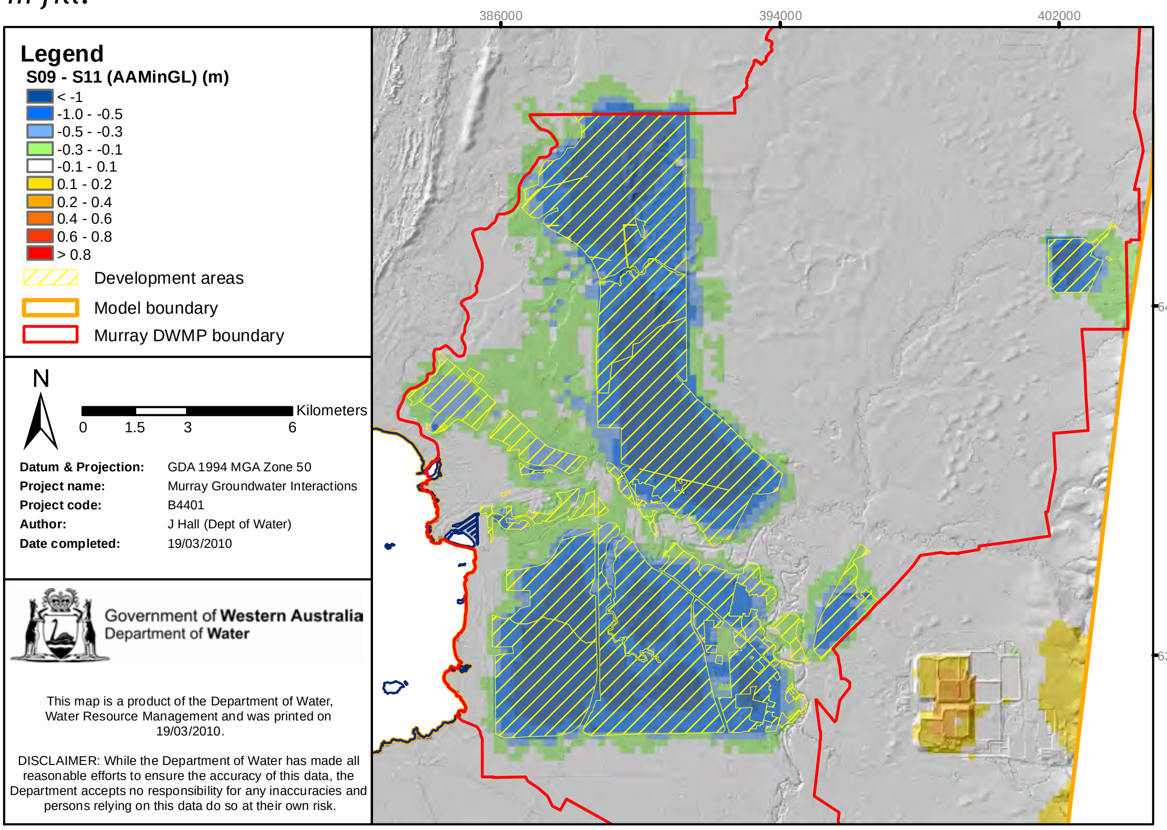


Figure 3-15: *Future wet scenario: change in AAMinGL for drains at ground level and 1.0 m fill*

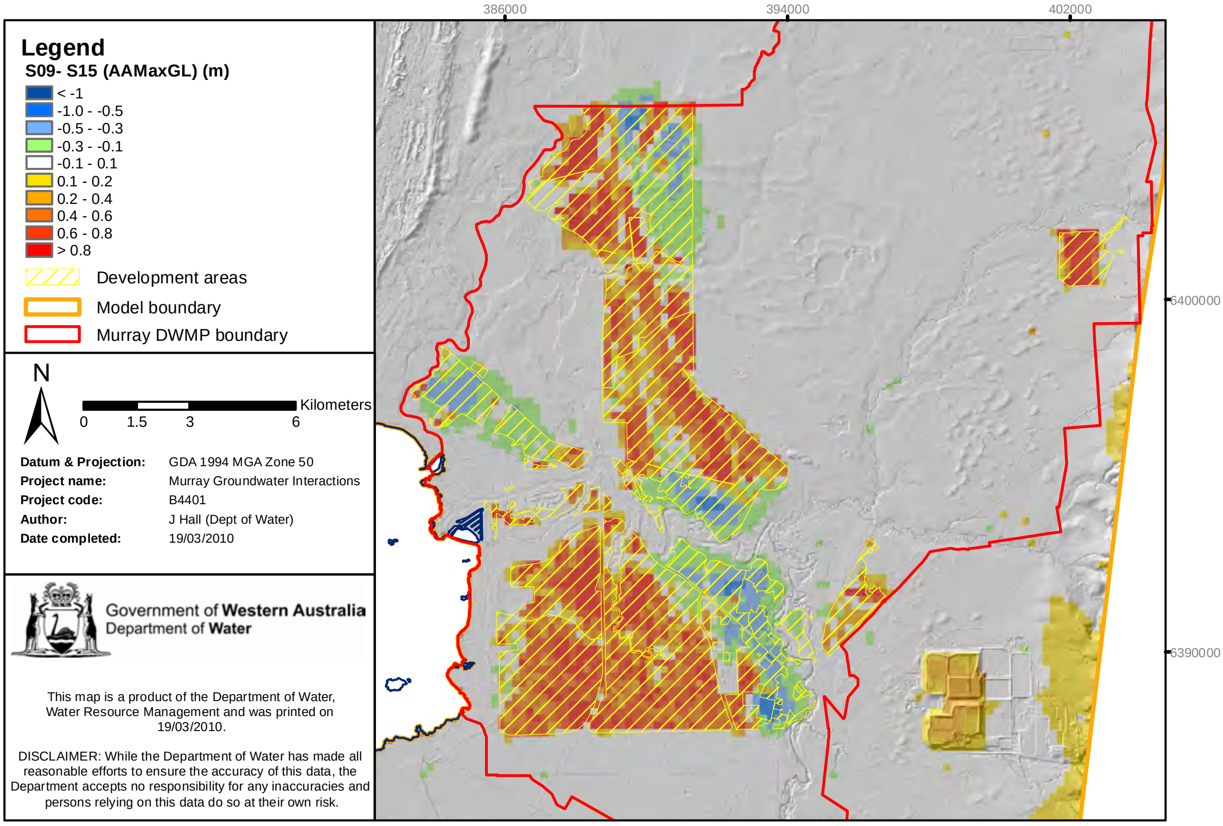


Figure 3-16: *Future wet scenario: change in AAMaxGL for drains at 1.0 m bgl (no fill)*

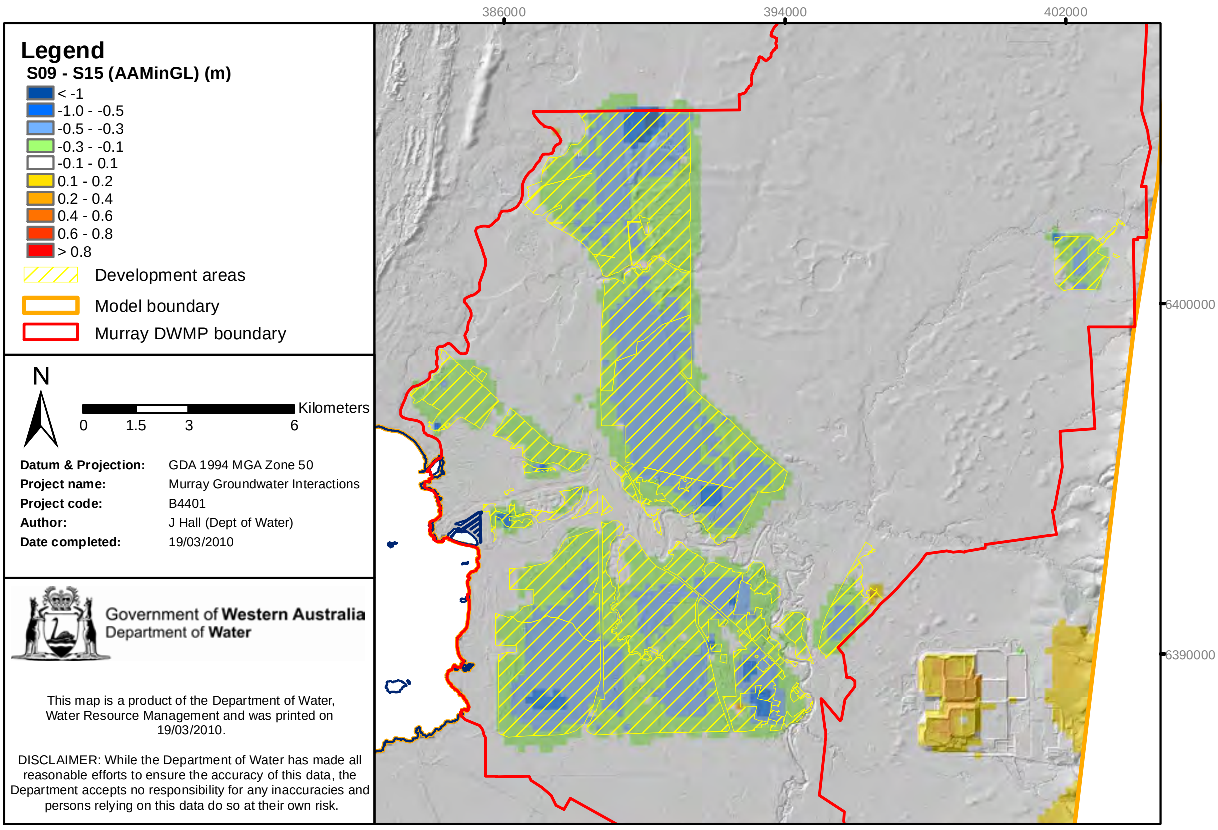


Figure 3-17: *Future wet scenario: change in AAMinGL for drains at 1.0 m bgl (no fill)*

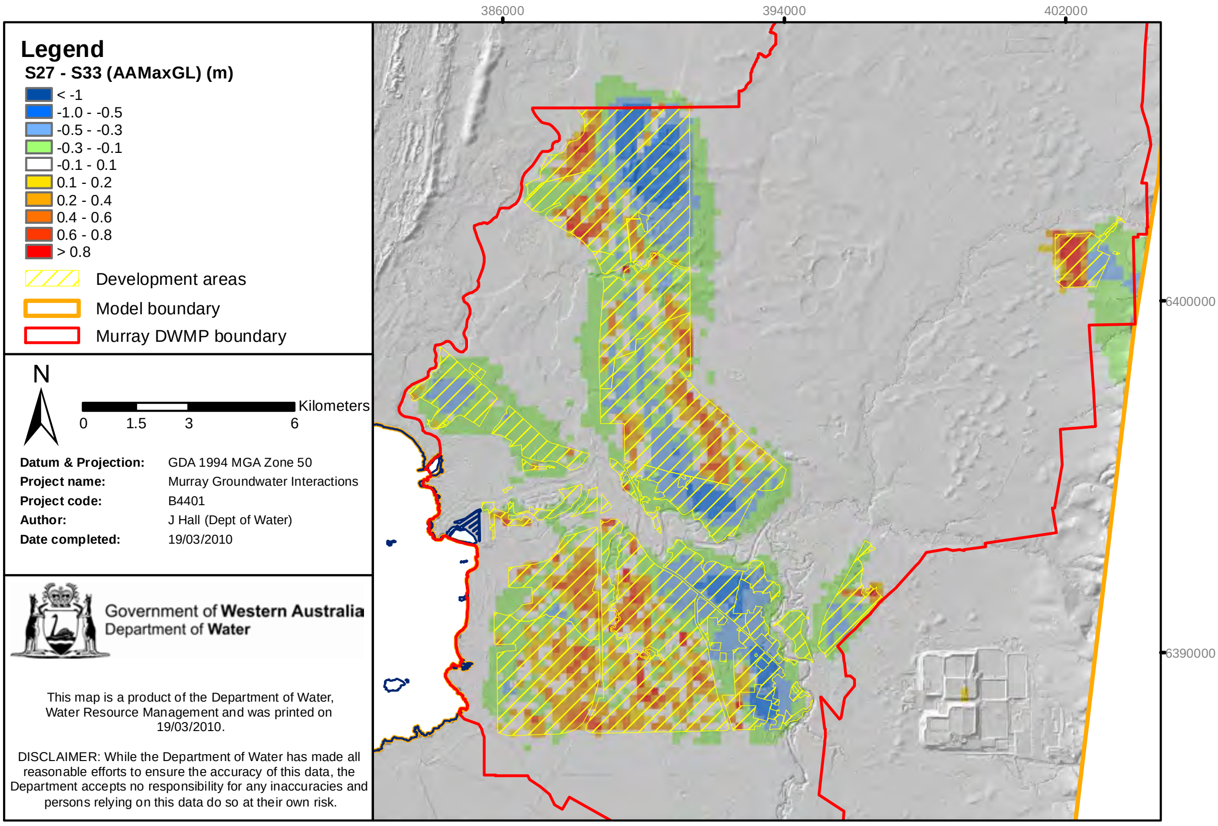


Figure 3-19: *Future dry scenario: change in AAMaxGL for drains at 1.0 m bgl (no fill)*

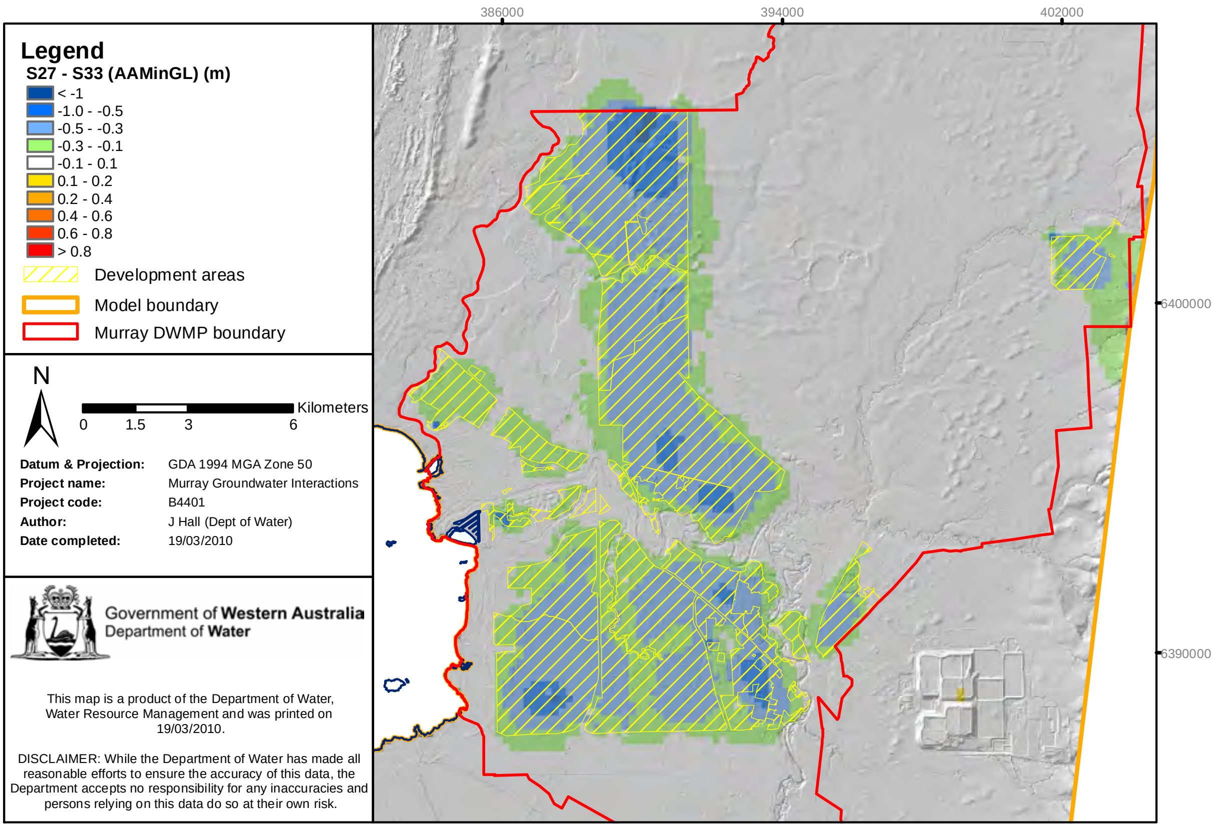


Figure 3-20: *Future dry scenario: change in AAMinGL for drains at 1.0 m bgl (no fill)*

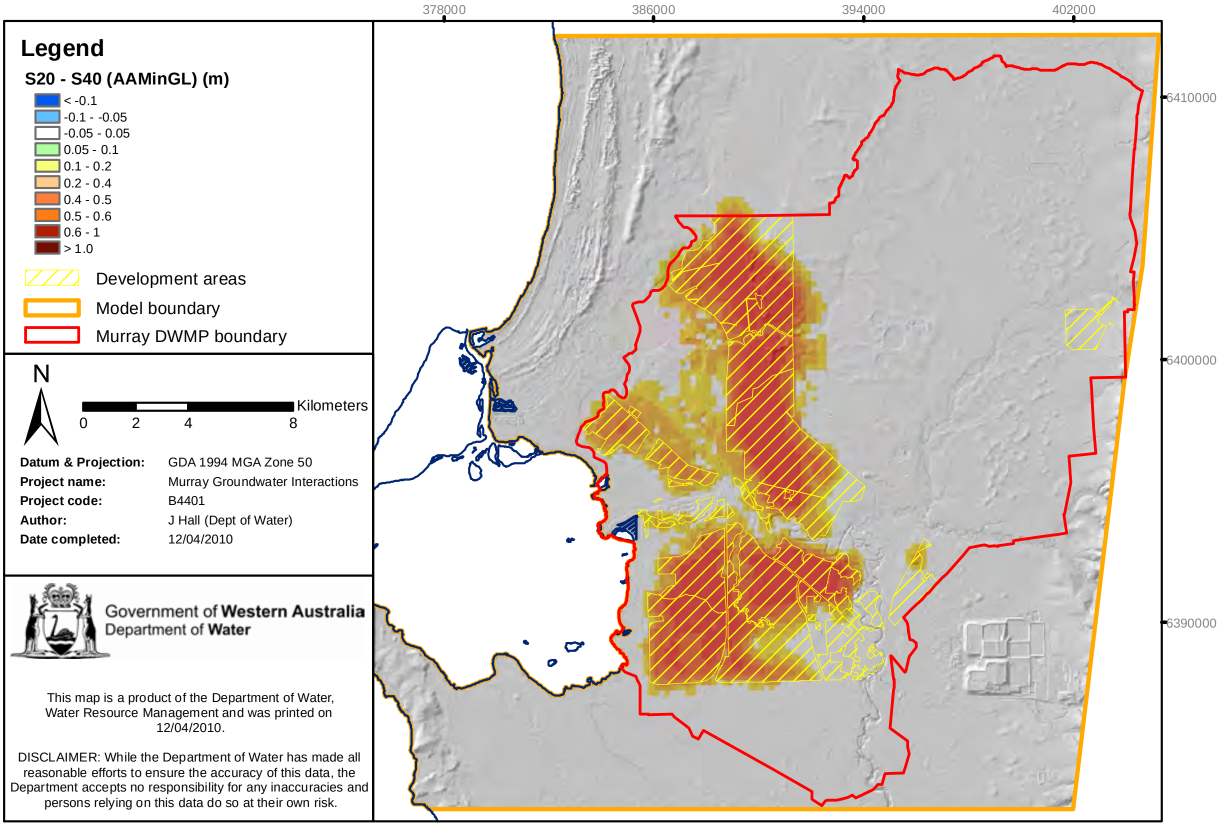


Figure 3-25: *Change in AAMinGL due to the implementation of domestic bores*

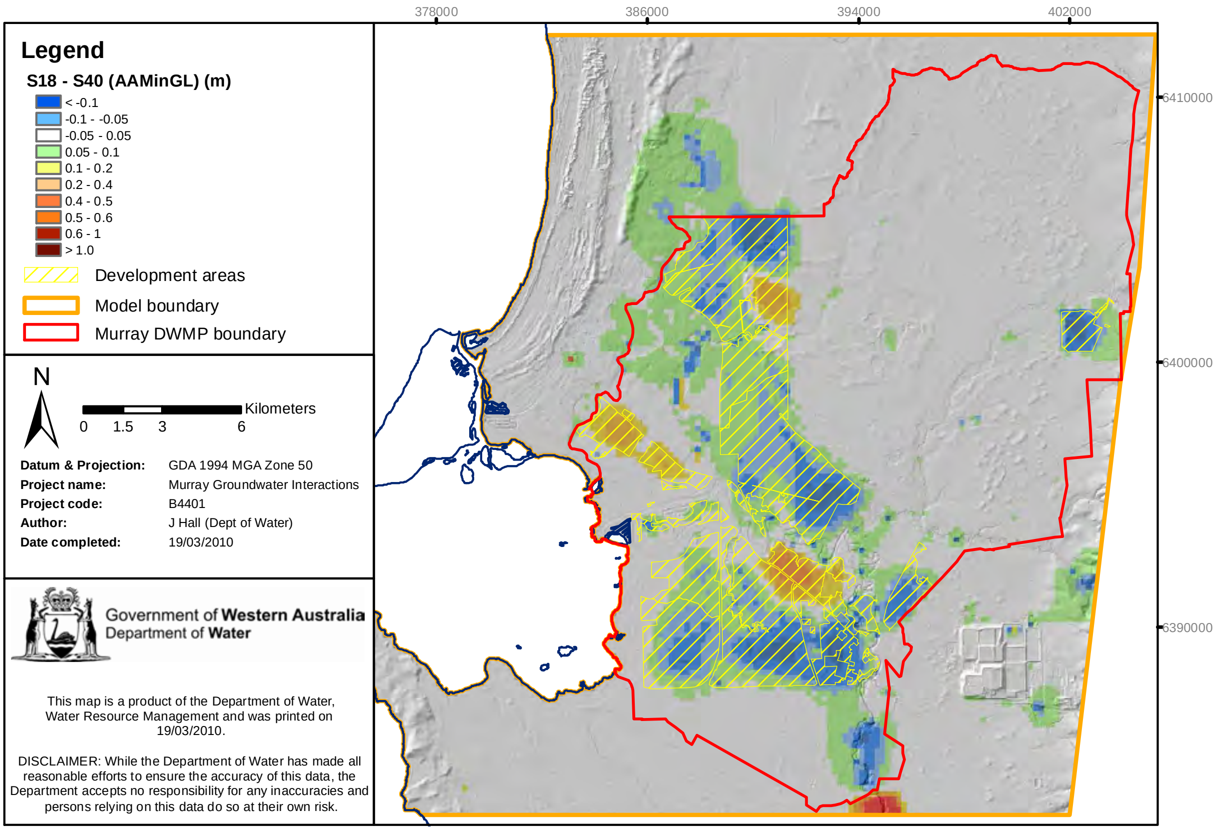


Figure 3-26: *Domestic bore scenario compared with no development scenario (AAMinGL)*

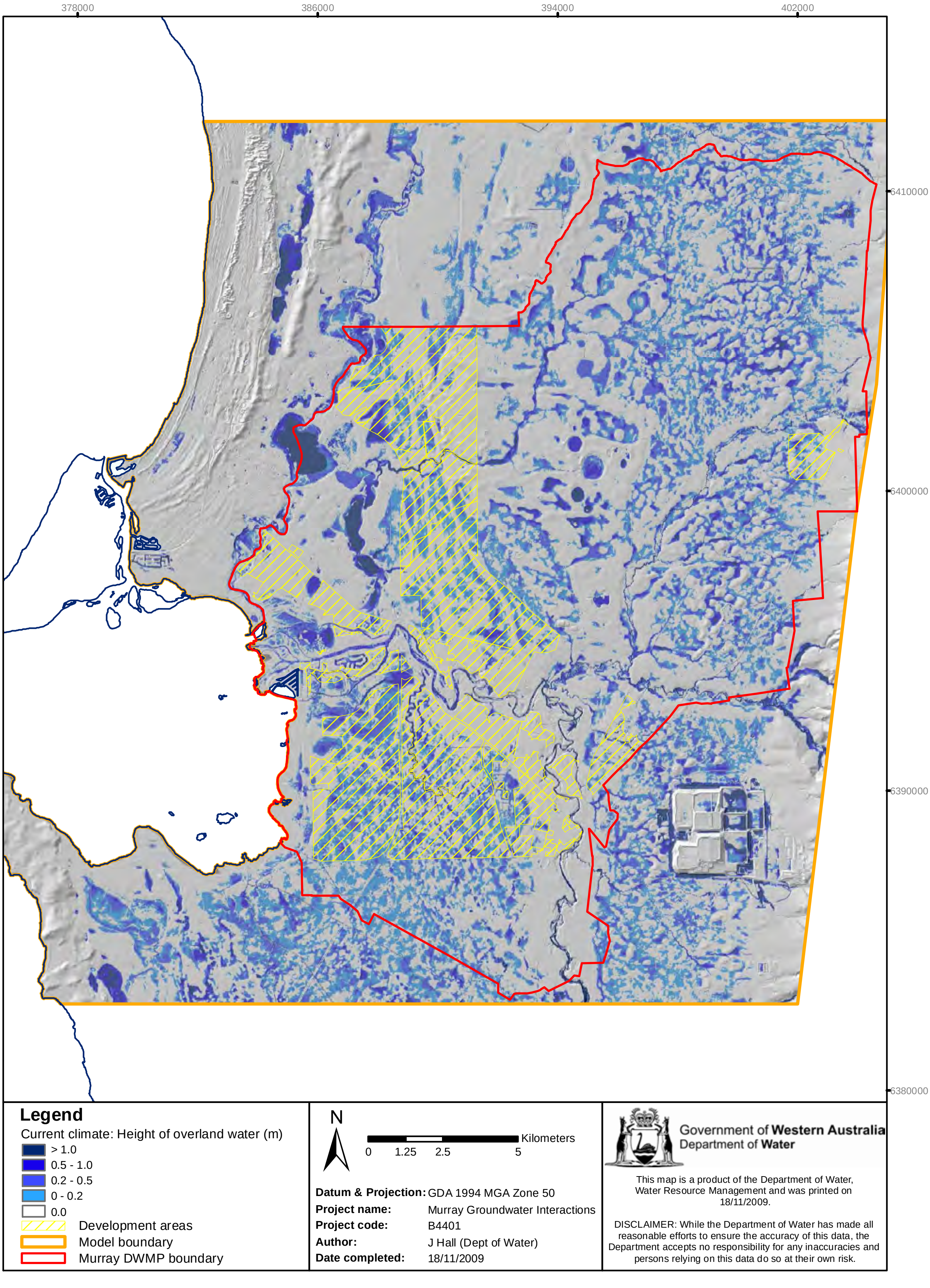


***Figure 3-27**: Maximum depth of overland water: base-case scenario (S0)*

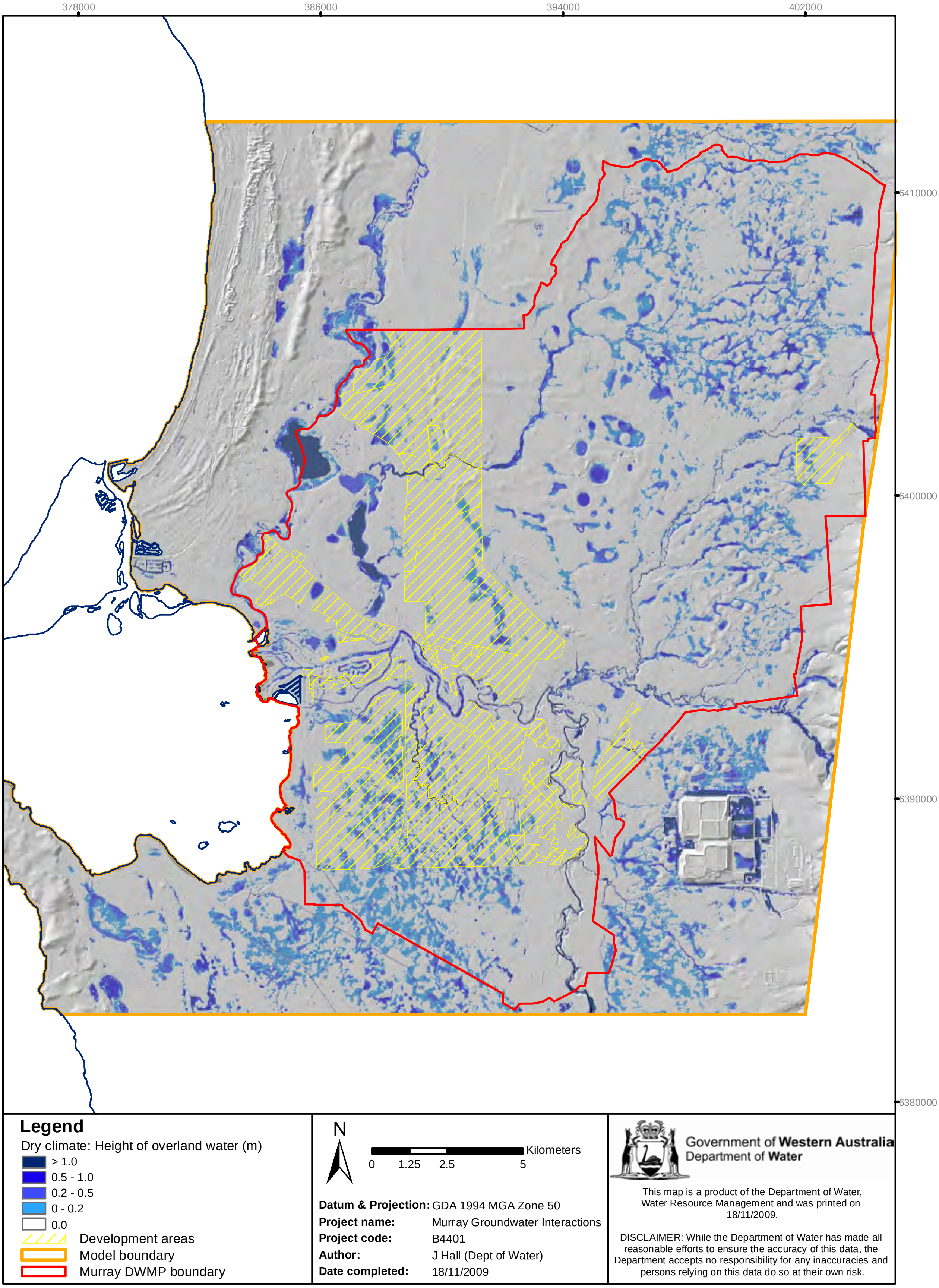


Figure 3-28*: Maximum depth of overland water: future dry climate scenario (S27)*

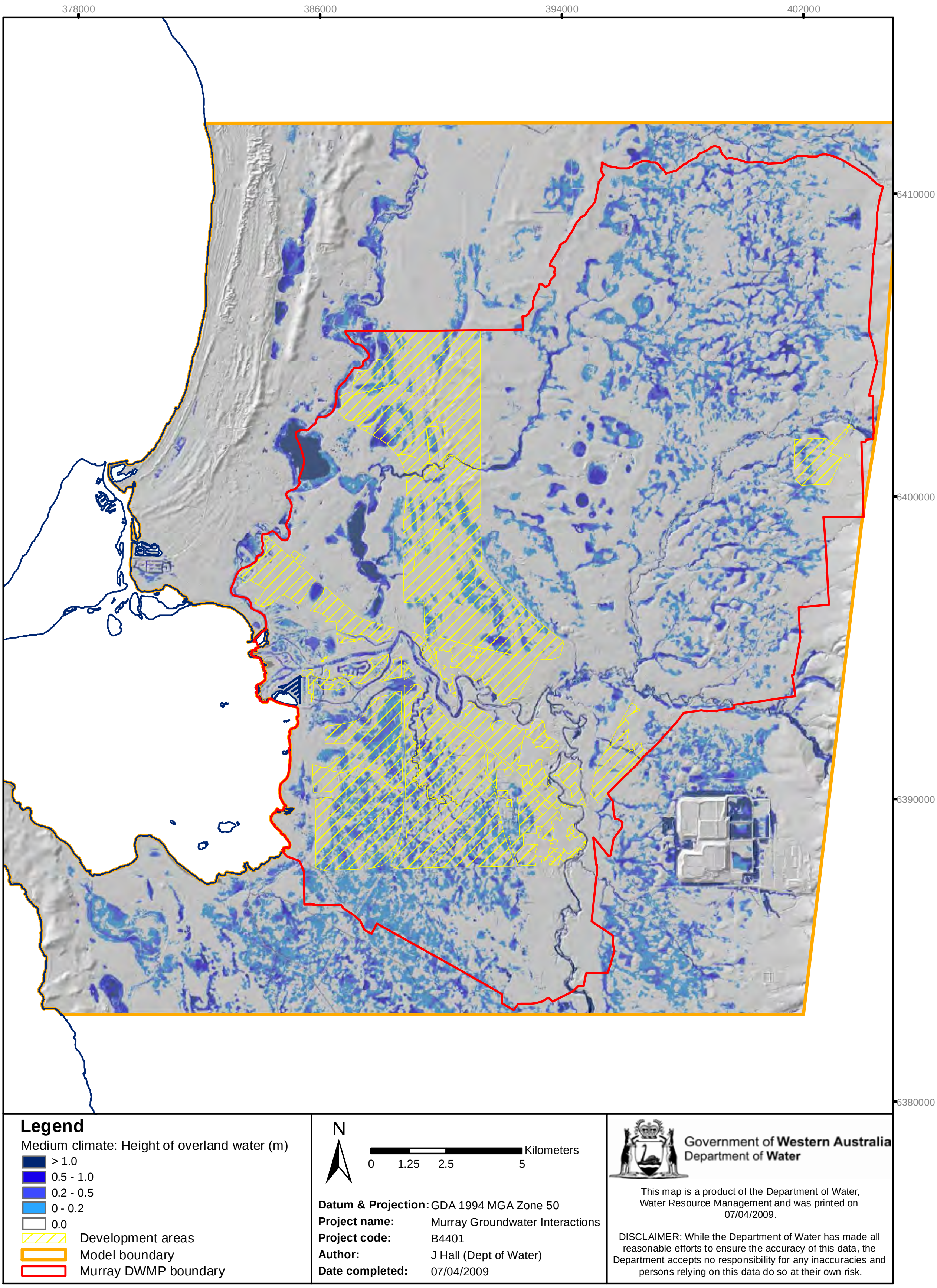


***Figure 3-29**: Maximum depth of overland water: future medium climate scenario (S18)*

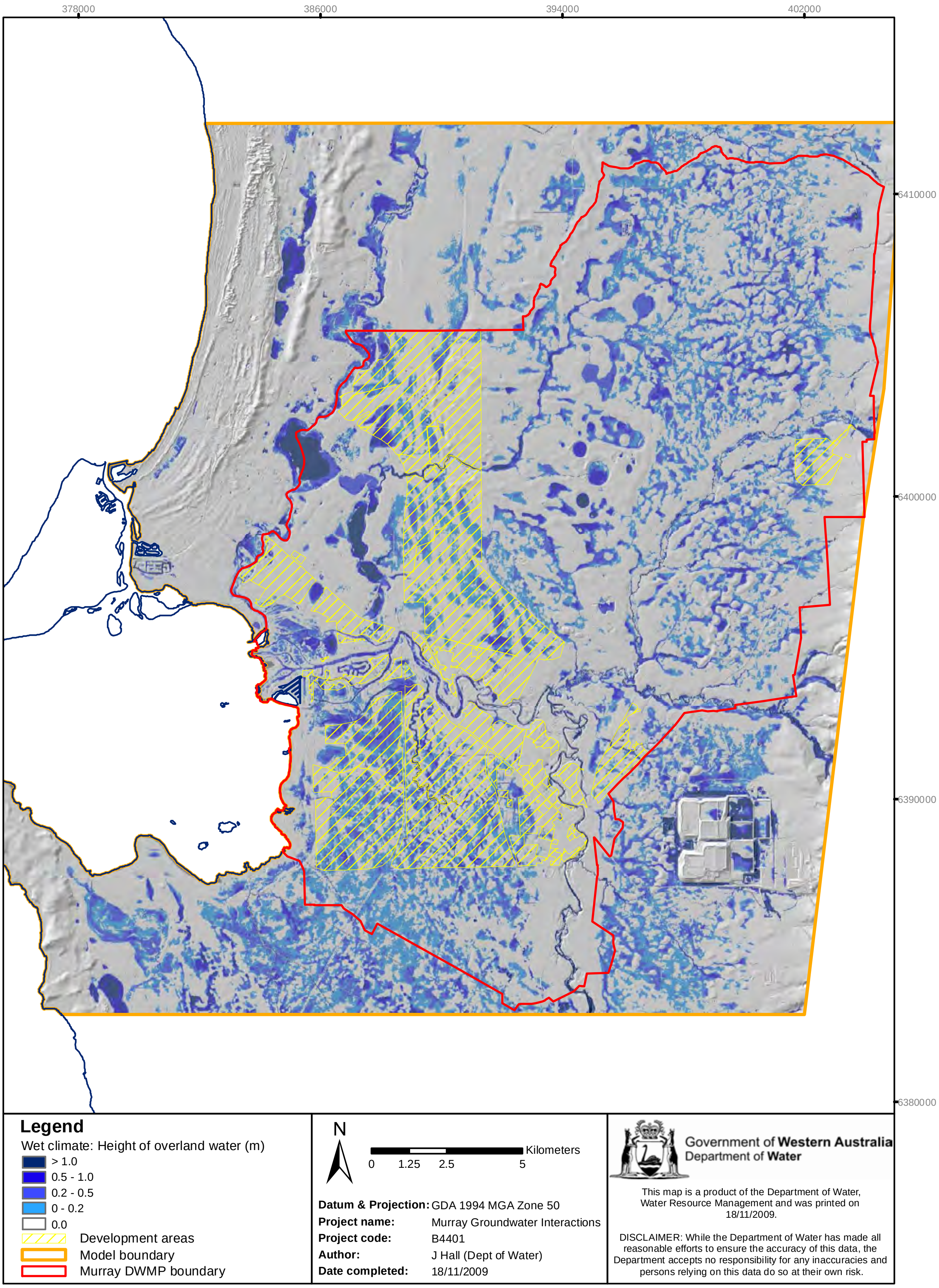


Figure 3-30*: Maximum depth of overland water: future wet climate scenario (S09)*

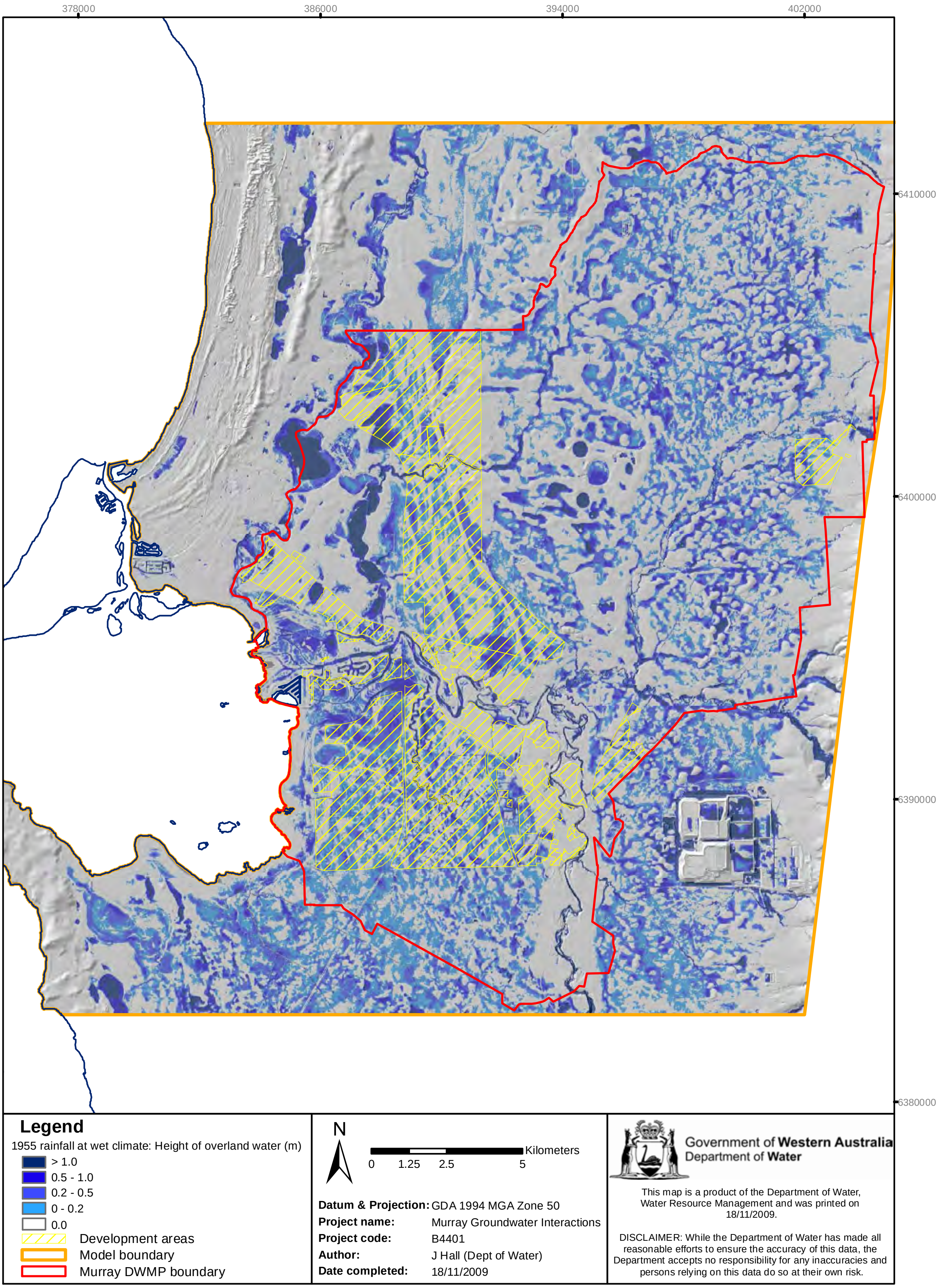


Figure 3-31*: Maximum depth of overland water: future wet climate scenario with 1955 rainfall (S38)*

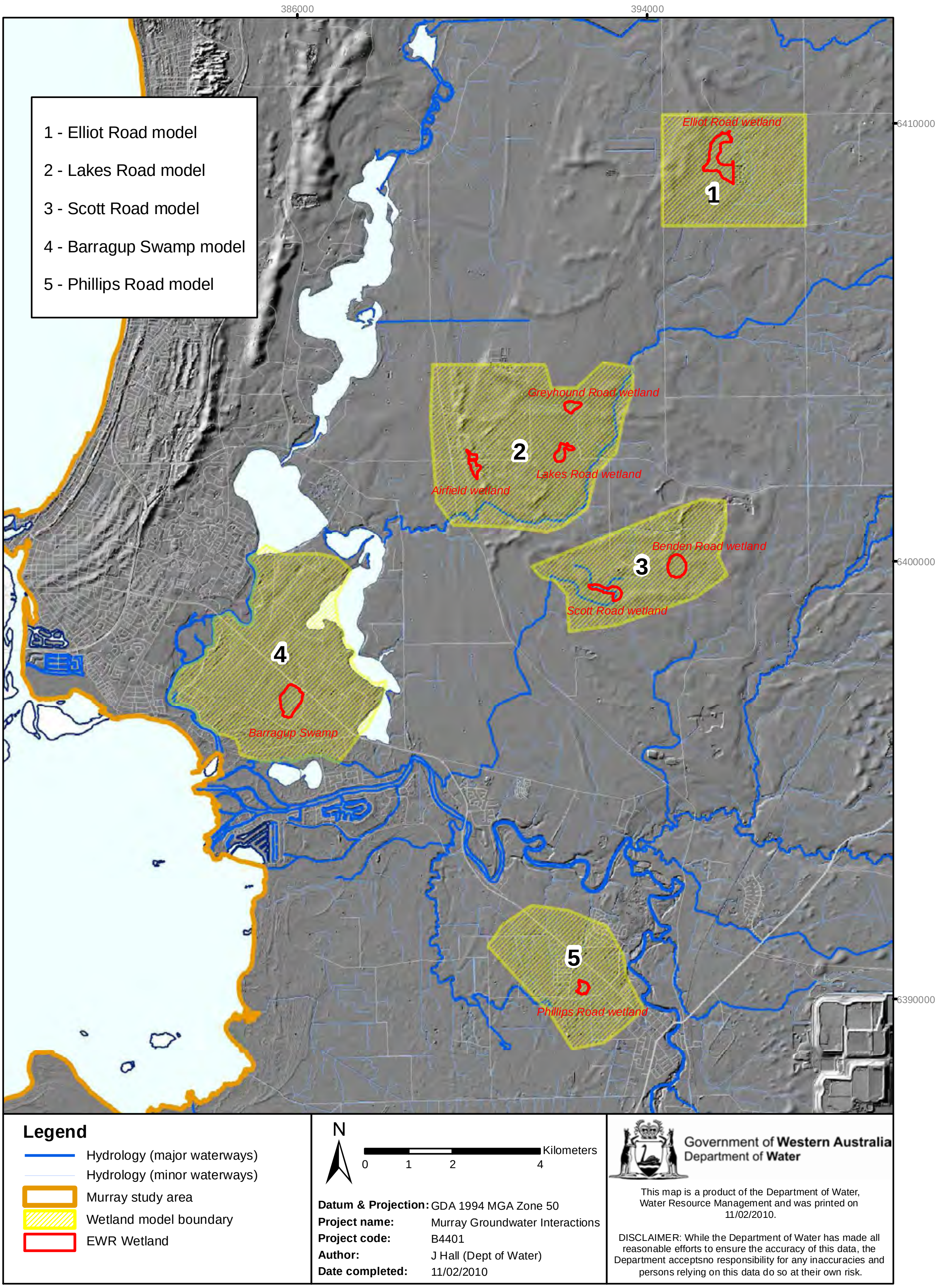


***Figure 4-1:** Key wetland locations and model boundaries*

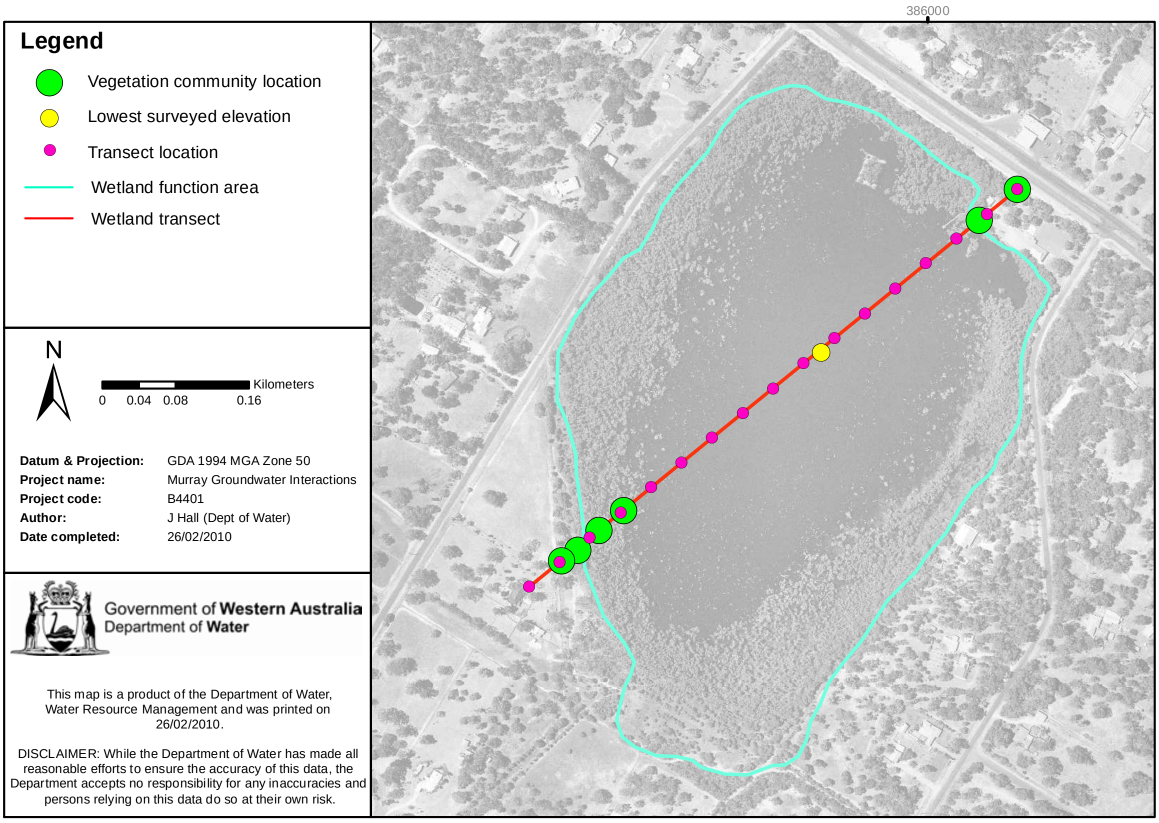


Figure 4-2: *Barragup wetland transect and vegetation community locations*

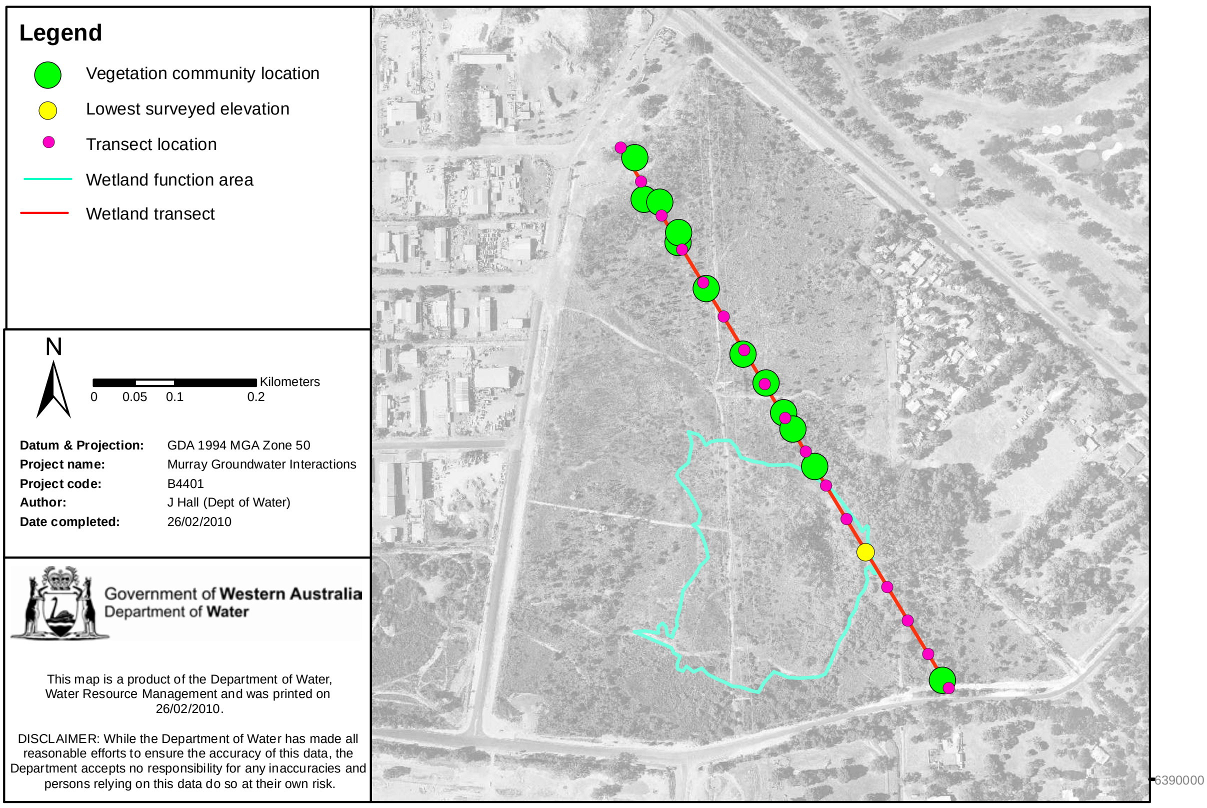


Figure 4-3: *Phillips Road wetland transect and vegetation community locations*

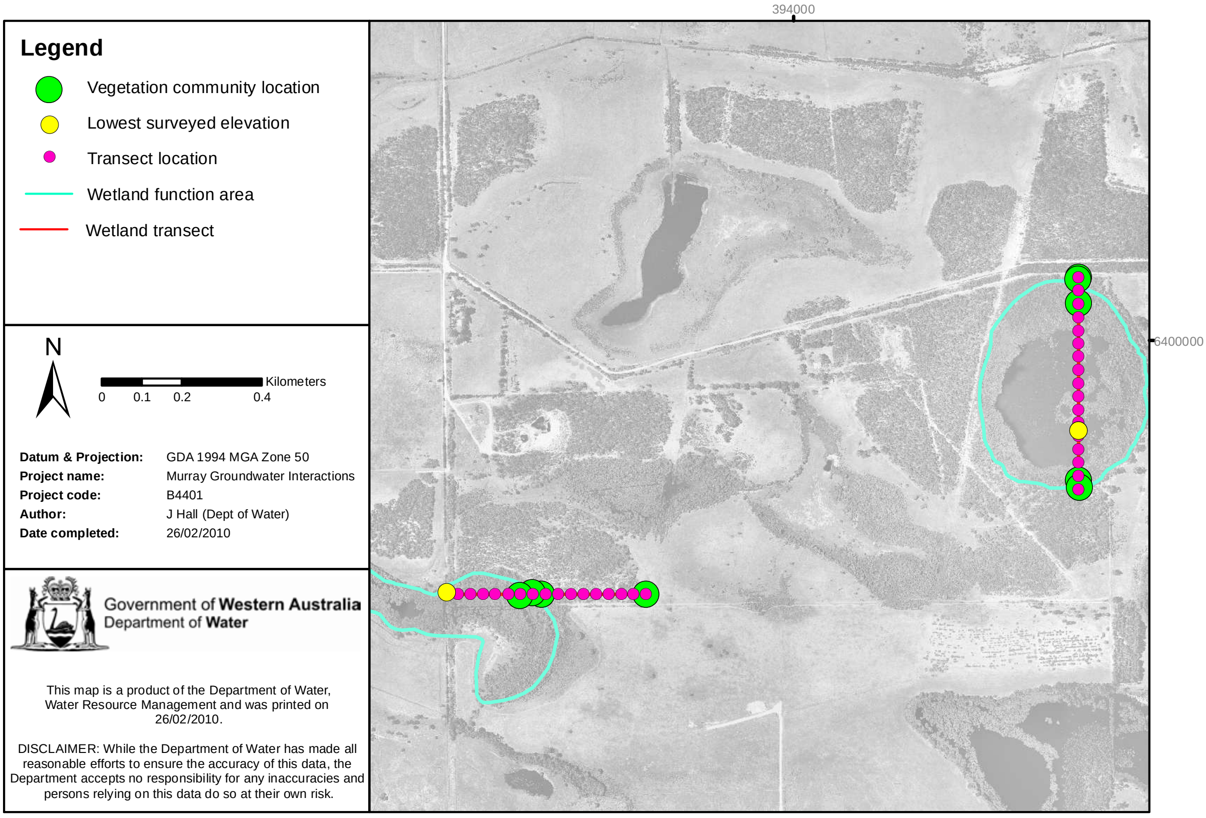


Figure 4-4: *Scott Road and Benden Road wetland transect and vegetation community locations*

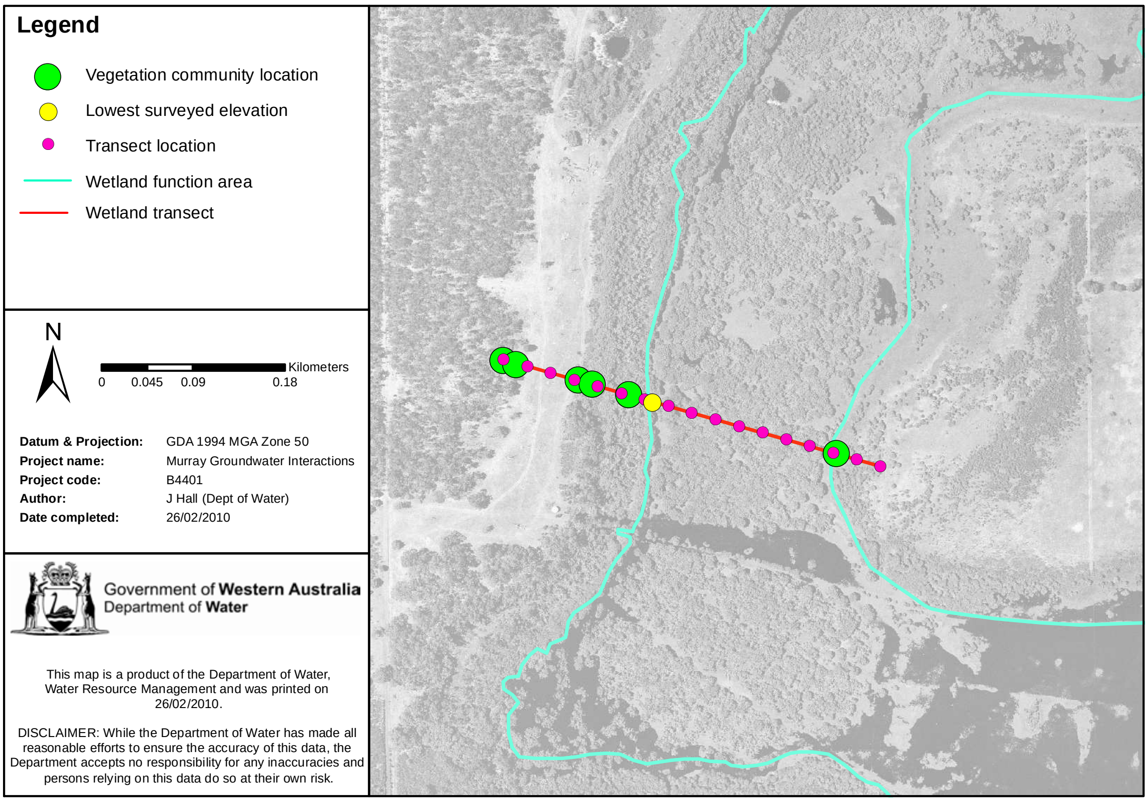


Figure 4-5: *Elliot Road wetland transect and vegetation community locations*

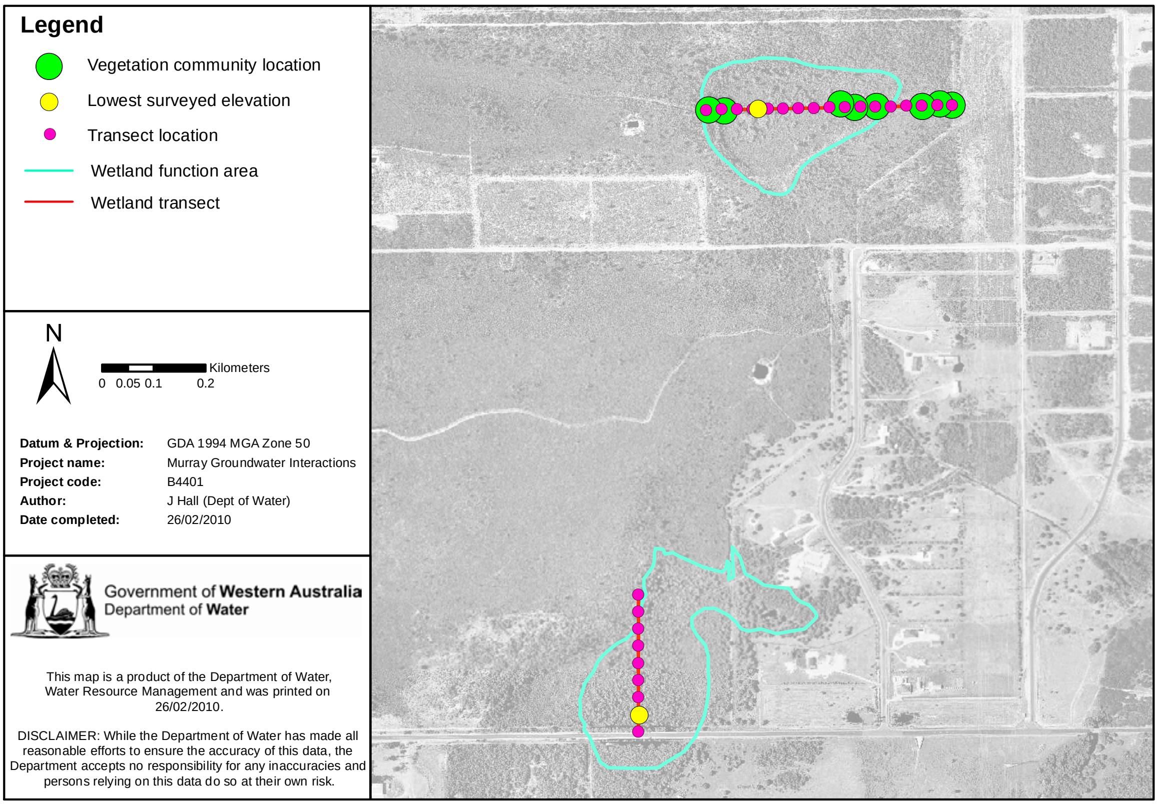


Figure 4-6: *Greyhound Road and Lakes Road wetland transect and vegetation community locations*

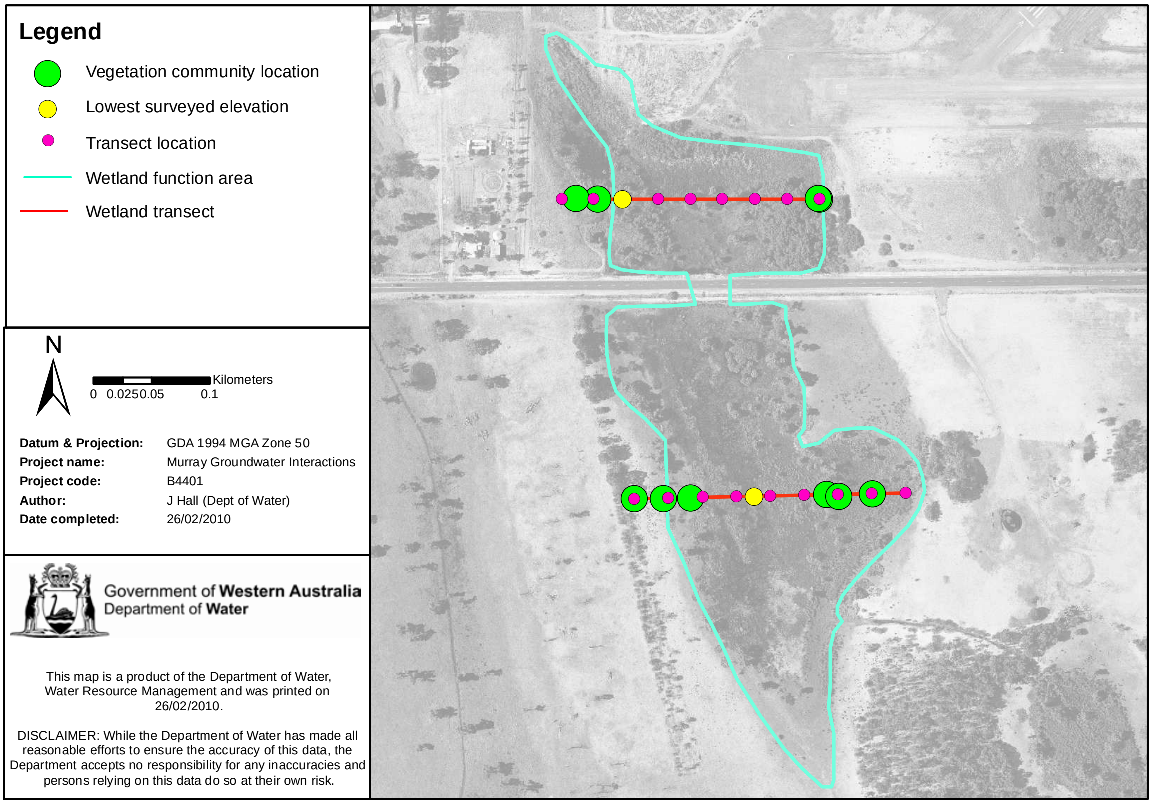


Figure 4-7: *Airfield wetland transect and vegetation community locations*

Appendix A: Water balance fluxes for development scenarios

Development	Area	Flux	Average annual flux quantity (mm)												
			S0	S09	S11	S15	S18	S20	S26	S39	S40	S27	S29	S33	S36
South Yunderup	1.22	Rainfall	812	800	800	800	740	740	740	740	740	680	680	680	913
		Recharge	279	245	332	336	143	287	287	287	287	88	235	236	728
		Horizontal flow (IN)	182	196	70	230	192	65	78	60	102	191	67	148	201
		Horizontal flow (OUT)	189	187	366	260	178	337	304	343	280	169	298	246	203
		Total SW (OUT)	10	9	37	301	6	15	62	4	10	3	5	138	65
		EVT (GW)	135	138	0	0	121	0	0	0	0	104	0	0	169
		EVT (Total)	794	798	465	465	748	452	452	452	452	698	443	443	842
		Abstraction	0	0	0	0	0	0	0	0	100	0	0	0	0
		Total error	0	0	0	0	0	0	0	0	0	0	0	0	0
Austin Cove	4.92	Rainfall (mm)	827	815	815	815	755	755	755	755	755	693	693	693	962
		Recharge(mm)	375	343	345	347	207	298	297	297	298	117	247	247	688
		Horizontal flow (IN)	32	31	30	49	31	28	26	26	27	30	25	38	35
		Horizontal flow (OUT)	64	63	157	75	61	159	140	171	100	59	132	81	66
		Total SW (OUT)	23	15	220	325	6	169	187	155	57	1	140	204	125
		EVT (GW)	309	284	0	0	166	0	0	0	0	86	0	0	556
		EVT (Total)	770	768	468	468	718	454	454	454	454	663	445	445	805
		Abstraction	0	0	0	0	0	0	0	0	171	0	0	0	0
		Total error	0	0	0	0	0	0	0	0	0	0	0	0	1
Nerimma	8.7	Rainfall (mm)	818	806	806	806	746	746	746	746	746	685	685	685	958
		Recharge(mm)	234	215	343	346	148	297	296	296	297	99	246	246	410
		Horizontal flow (IN)	48	48	33	55	47	31	33	30	35	46	45	45	49
		Horizontal flow (OUT)	55	52	106	63	50	104	85	106	69	48	63	64	58
		Total SW (OUT)	38	27	256	320	11	209	229	207	78	3	212	211	139
		EVT (GW)	179	170	0	0	118	0	0	0	0	78	0	0	285
		EVT (Total)	759	759	461	461	715	448	448	448	447	664	438	438	794
		Abstraction	16	16	16	16	16	16	16	16	187	16	16	16	16
		Total error	1	1	0	0	0	0	0	0	0	0	0	0	2
Buchanans	17.8	Rainfall (mm)	839	829	829	829	767	767	767	767	767	704	704	704	991
		Recharge(mm)	234	219	357	359	169	310	310	310	310	128	258	258	423
		Horizontal flow (IN)	44	44	37	61	42	34	39	34	39	40	48	44	50
		Horizontal flow (OUT)	97	96	146	100	92	143	126	148	121	88	110	99	105
		Total SW (OUT)	70	56	251	321	33	203	225	198	122	17	197	204	212
		EVT (GW)	140	126	0	0	93	0	0	0	0	65	0	0	264
		EVT (Total)	727	726	466	466	685	453	453	453	453	638	444	444	767
		Abstraction	2	2	2	2	2	2	2	2	111	2	2	2	2
		Total error	14	8	0	0	2	0	0	0	0	0	0	0	47
Pinjarra	1.48	Rainfall (mm)	839	829	829	829	768	768	768	768	768	705	705	705	995
		Recharge(mm)	324	310	368	368	262	320	320	768	320	207	266	266	460
		Horizontal flow (IN)	541	528	597	550	497	567	534	561	546	454	516	492	591
		Horizontal flow (OUT)	605	589	668	636	535	617	560	612	521	470	548	534	730
		Total SW (OUT)	260	249	298	282	224	271	295	267	266	193	236	225	313
		EVT (GW)	0	0	0	0	0	0	0	0	0	0	0	0	2
		EVT (Total)	514	519	461	461	505	447	447	447	447	497	438	438	537
		Abstraction	0	0	0	0	0	0	0	0	81	0	0	0	0
		Total error	0	0	0	0	0	0	0	0	0	0	0	0	0
South Murray	2.31	Rainfall (mm)	838	827	827	827	766	766	766	766	766	703	703	703	981
		Recharge(mm)	292	280	364	364	244	316	316	316	316	200	262	262	387
		Horizontal flow (IN)	129	128	117	117	129	121	127	123	141	132	118	119	136
		Horizontal flow (OUT)	394	383	451	406	357	420	362	410	282	321	370	362	445
		Total SW (OUT)	13	10	41	75	10	19	82	30	10	8	12	21	41
		EVT (GW)	16	14	0	0	8	0	0	0	0	4	0	0	53
		EVT (Total)	561	562	463	463	526	449	449	449	168	506	440	540	633
		Abstraction	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	7
Barragup	4.79	Rainfall (mm)	798	785	785	785	727	727	727	727	727	668	668	668	895
		Recharge(mm)	215	201	323	324	175	278	279	278	278	142	228	229	296
		Horizontal flow (IN)	158	161	114	144	161	117	130	117	182	163	122	133	162
		Horizontal flow (OUT)	255	246	343	288	230	309	269	307	209	209	270	254	279
		Total SW (OUT)	4	2	17	103	0	8	62	12	4	-2	3	30	37
		EVT (GW)	37	38	0	0	28	0	0	0	0	20	0	0	104
		EVT (Total)	619	621	461	461	580	448	448	448	447	545	439	439	678
		Abstraction	78	78	78	78	78	78	78	78	248	78	78	78	78
		Total error	1	1	0	0	0	0	0	0	0	0	0	0	21
Ravenswood	16.6	Rainfall (mm)	834	822	822	822	762	762	762	762	762	699	699	699	940
		Recharge(mm)	267	244	353	355	177	305	305	305	306	129	253	253	477
		Horizontal flow (IN)	71	70	46	73	69	43	49	43	53	67	63	62	74
		Horizontal flow (OUT)	143	141	188	143	136	185	160	185	156	131	145	143	151
		Total SW (OUT)	27	21	205	276	13	157	188	157	14	8	164	165	94
		EVT (GW)	159	142	0	0	89	0	0	0	0	50	0	0	307
		EVT (Total)	730	725	469	469	675	455	455	455	455	620	446	446	760
		Abstraction	5	5	5	5	5	5	5	5	138	5	5	5	5
		Total error	0	0	0	0	0	0	0	0	0	0	0	0	1
Nambeelup	21.4	Rainfall (mm)	827	817	817	817	757	757	757	757	757	695	695	695	923
		Recharge(mm)	276	252	346	346	186	299	287	299	299	140	247	247	530
		Horizontal flow (IN)	104	104	91	106	103	91	78	91	101	101	96	99	105
		Horizontal flow (OUT)	196	194	244	185	189	245	304	248	202	183	216	193	205
		Total SW (OUT)	47	38	185	260	20	138	162	134	55	8	120	147	138
		EVT (GW)	187	163	0	0	97	0	0	0	0	51	0	0	435
		EVT (Total)	704	700	470	470	653	457	457	457	456	602	447	447	731
		Abstraction	7	7	8	7	6	7	7	7	144	5	6	6	7
		Total error	24	20	0	0	10	0	0	0	0	3	0	0	57
Carcoola	2.8	Rainfall (mm)	839	829	829	829	768	768	768	768	768	704	704	704	993
		Recharge(mm)	245	237	348	360	201	303	303	302	303	164	249	252	379
		Horizontal flow (IN)	131	130	112	133	0	109	113	105	112	123	107	118	139
		Horizontal flow (OUT)	242	241	301	251	230	288	262	290	283	216	265	240	268
		Total SW (OUT)	102	91	169	240	76	132	164	126	131	58	99	134	197
		EVT (GW)	39	38	0	0	28	0	0	0	0	20	0	0	59
		EVT (Total)	626	627	470	470	588	456	456	456	456	554	447	447	666
		Abstraction	0	0	0	0	0	0	0	0	10	0	0	0	0
		Total error	0	0	0	0	0	0	0	0	0	0	0	0	2
North Dandalup	2.07	Rainfall (mm)	902	894	894	894	829	829	829	829	829	761	761	761	1030
		Recharge(mm)	256	247	396	398	200	344	344	344	344	150	285	285	373
		Horizontal flow (IN)	241	240	219	254	207	188	189	188	189	179	161	185	301
		Horizontal flow (OUT)	166	165	271	158	155	262	256	265	259	144	246	150	180
		Total SW (OUT)	169	154	348	495	108	274	281	271	272	65	206	326	324
		EVT (GW)	171	170	0	0	149	0	0	0	0	127	0	0	199
		EVT (Total)	807	814	493	493	771	480	480	480	480	150	471	471	826
		Abstraction	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

Development	Area	Flux	Average annual flux quantity (ML)												
			S0	S09	S11	S15	S18	S20	S26	S39	S40	S27	S29	S33	S36
South Yunderup	1.22	Rainfall	991	975	975	975	903	903	903	903	903	830	830	830	1113
		Recharge	340	299	405	409	174	350	350	350	350	107	287	288	889
		Horizontal flow (IN)	222	239	85	281	235	79	95	73	124	233	82	180	245
		Horizontal flow (OUT)	230	228	447	318	217	411	371	419	341	206	364	300	248
		Total SW (OUT)	12	11	45	367	8	19	75	5	12	4	6	168	80
		EVT (GW)	165	168	0	0	148	0	0	0	0	126	0	0	206
		EVT (Total)	968	974	567	567	912	551	551	551	551	851	540	540	1027
		Abstraction	0	0	0	0	0	0	0	0	121	0	0	0	0
		Total error	0	0	0	0	0	0	0	0	0	0	0	0	0
Austin Cove	4.92	Rainfall (mm)	4068	4011	4011	4011	3714	3714	3714	3714	3714	3409	3409	3409	4731
		Recharge(mm)	1844	1689	1696	1709	1021	1467	1461	1464	1468	575	1213	1217	3387
		Horizontal flow (IN)	155	153	150	242	150	139	130	130	134	149	123	186	174
		Horizontal flow (OUT)	317	312	773	367	302	781	688	843	493	290	649	398	326
		Total SW (OUT)	115	75	1084	1599	29	834	919	765	280	7	690	1004	617
		EVT (GW)	1519	1398	0	0	817	0	0	0	0	424	0	0	2735
		EVT (Total)	3790	3776	2301	2302	3532	2235	2234	2234	2234	3260	2190	2190	3958
		Abstraction	0	0	0	0	0	0	0	0	840	0	0	0	0
		Total error	1	0	0	0	0	0	0	0	0	0	0	0	5
Nerimma	8.7	Rainfall (mm)	7118	7014	7014	7014	6492	6492	6492	6492	6492	5958	5958	5958	8338
		Recharge(mm)	2032	1868	2981	3010	1290	2580	2576	2577	2581	860	2142	2142	3568
		Horizontal flow (IN)	414	414	287	478	407	269	283	263	302	403	387	387	423
		Horizontal flow (OUT)	480	454	921	550	436	906	743	920	597	418	548	556	502
		Total SW (OUT)	334	231	2223	2785	97	1817	1994	1799	682	27	1841	1833	1211
		EVT (GW)	1559	1477	0	0	1030	0	0	0	0	681	0	0	2475
		EVT (Total)	6607	6602	4012	4012	6223	3894	3893	3893	3893	5774	3813	3813	6910
		Abstraction	143	143	143	143	143	143	143	143	1628	143	143	143	143
		Total error	6	5	0	0	2	0	0	0	0	1	0	0	16
Buchanans	17.8	Rainfall (mm)	14943	14759	14759	14759	13667	13667	13667	13667	13667	12541	12541	12541	17652
		Recharge(mm)	4169	3897	6357	6396	3016	5525	5513	5516	5526	2281	4586	4589	7534
		Horizontal flow (IN)	787	777	651	1085	742	598	692	606	701	710	855	787	882
		Horizontal flow (OUT)	1735	1703	2593	1783	1637	2546	2242	2641	2157	1561	1954	1766	1866
		Total SW (OUT)	1246	998	4471	5715	579	3615	4014	3528	2177	294	3509	3626	3779
		EVT (GW)	2489	2242	0	0	1649	0	0	0	0	1164	0	0	4694
		EVT (Total)	12947	12938	8303	8304	12199	8061	8061	8061	8061	11369	7901	7901	13663
		Abstraction	36	36	36	36	36	36	36	36	1979	36	36	36	36
		Total error	243	142	0	0	44	0	0	0	0	4	0	0	836
Pinjarra	1.48	Rainfall (mm)	1242	1227	1227	1227	1136	1136	1136	1136	1136	1043	1043	1043	1473
		Recharge(mm)	480	459	544	544	387	474	474	1136	474	306	393	393	681
		Horizontal flow (IN)	800	781	884	814	735	840	791	830	808	672	764	728	875
		Horizontal flow (OUT)	896	872	988	942	792	914	829	906	771	696	812	791	1080
		Total SW (OUT)	385	368	441	418	332	401	436	395	394	286	349	333	463
		EVT (GW)	0	0	0	0	0	0	0	0	0	0	0	0	3
		EVT (Total)	761	768	682	682	748	661	661	661	661	735	648	648	795
		Abstraction	0	0	0	0	0	0	0	0	119	0	0	0	0
		Total error	0	0	0	0	0	0	0	0	0	0	0	0	0
South Murray	2.31	Rainfall (mm)	1936	1911	1911	1911	1770	1770	1770	1770	1770	1624	1624	1624	2266
		Recharge(mm)	674	647	840	841	564	730	731	730	730	461	605	606	894
		Horizontal flow (IN)	299	295	270	270	298	279	294	285	325	304	272	275	313
		Horizontal flow (OUT)	909	886	1041	937	824	969	837	948	651	742	855	836	1027
		Total SW (OUT)	29	24	94	174	23	43	189	69	23	19	28	48	95
		EVT (GW)	36	33	0	0	19	0	0	0	0	8	0	0	124
		EVT (Total)	1296	1297	1069	1069	1215	1037	1037	1037	388	1169	1016	1247	1462
		Abstraction	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	17
Barragup	4.79	Rainfall (mm)	3821	3760	3760	3760	3481	3481	3481	3481	3481	3198	3198	3198	4289
		Recharge(mm)	1031	964	1548	1552	838	1332	1334	1333	1332	681	1092	1096	1419
		Horizontal flow (IN)	757	772	544	692	770	559	623	559	871	780	582	636	774
		Horizontal flow (OUT)	1224	1178	1641	1378	1101	1482	1290	1472	1001	1003	1293	1214	1337
		Total SW (OUT)	21	10	82	493	0	40	297	56	18	-9	15	145	178
		EVT (GW)	179	183	0	0	136	0	0	0	0	96	0	0	499
		EVT (Total)	2963	2974	2207	2207	2777	2144	2144	2144	2143	2612	2101	2101	3248
		Abstraction	372	372	372	372	372	372	372	372	1190	372	372	372	372
		Total error	6	5	0	0	0	0	0	0	0	0	0	0	103
Ravenswood	16.6	Rainfall (mm)	13842	13642	13642	13642	12635	12635	12635	12635	12635	11596	11596	11596	15588
		Recharge(mm)	4425	4041	5851	5895	2944	5068	5066	5067	5069	2146	4191	4192	7918
		Horizontal flow (IN)	1181	1169	755	1206	1142	709	812	707	877	1108	1039	1027	1220
		Horizontal flow (OUT)	2366	2333	3111	2376	2263	3076	2660	3061	2590	2176	2401	2372	2507
		Total SW (OUT)	440	351	3394	4587	209	2597	3122	2609	226	135	2727	2742	1567
		EVT (GW)	2636	2357	0	0	1481	0	0	0	0	835	0	0	5097
		EVT (Total)	12105	12019	7778	7778	11194	7553	7553	7553	7552	10284	7399	7399	12607
		Abstraction	91	91	91	91	91	91	91	91	2287	91	91	91	91
		Total error	2	2	0	1	1	0	0	0	0	0	0	0	13
Nambeelup	21.4	Rainfall (mm)	17682	17470	17470	17470	16182	16182	16182	16182	16182	14857	14857	14857	19752
		Recharge(mm)	5899	5398	7405	7410	3988	6404	6132	6401	6405	2987	5280	5284	11340
		Horizontal flow (IN)	2227	2217	1950	2271	2193	1945	1673	1948	2160	2153	2052	2109	2256
		Horizontal flow (OUT)	4190	4148	5221	3958	4040	5236	6502	5310	4313	3910	4625	4120	4376
		Total SW (OUT)	1002	817	3954	5554	431	2945	3460	2871	1182	165	2572	3137	2947
		EVT (GW)	3993	3489	0	0	2064	0	0	0	0	1081	0	0	9303
		EVT (Total)	15053	14977	10056	10055	13967	9766	9765	9765	9764	12873	9563	9564	15642
		Abstraction	144	142	163	152	130	153	143	151	3072	111	137	128	158
		Total error	514	421	0	0	214	0	0	0	0	56	0	0	1219
Carcoola	2.8	Rainfall (mm)	2350	2321	2321	2321	2149	2149	2149	2149	2149	1972	1972	1972	2780
		Recharge(mm)	685	664	974	1007	562	847	847	847	847	460	698	707	1061
		Horizontal flow (IN)	368	364	312	371	0	305	318	295	314	344	299	330	389
		Horizontal flow (OUT)	679	675	843	703	644	805	733	812	791	606	742	673	751
		Total SW (OUT)	285	253	474	672	212	371	460	353	366	161	278	376	553
		EVT (GW)	110	106	0	0	79	0	0	0	0	56	0	0	165
		EVT (Total)	1753	1756	1315	1316	1647	1278	1278	1278	1278	1550	1252	1253	1865
		Abstraction	0	0	0	0	0	0	0	0	27	0	0	0	0
		Total error	0	0	0	0	0	0	0	0	0	0	0	0	5
North Dandalup	2.07	Rainfall (mm)	1867	1850	1850	1850	1716	1716	1716	1716	1716	1575	1575	1575	2131
		Recharge(mm)	530	512	819	824	414	711	711	711	711	311	590	591	772
		Horizontal flow (IN)	500	498	453	525	428	389	391	388	390	371	333	382	622
		Horizontal flow (OUT)	343	342	561	328	320	542	529	548	536	299	509	311	372
		Total SW (OUT)	350	319	720	1024	223	567	581	560	562	135	426	674	672
		EVT (GW)	353	352	0	0	309	0	0	0	0	263	0	0	411
		EVT (Total)	1670	1685	1021	1021	1597	993	993	993	993	311	974	974	1709
		Abstraction	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

Glossary

AAMaxGL	average annual maximum groundwater level: the average of each of the modelled maximum groundwater levels over the 30-year simulation
AAMinGL	average annual minimum groundwater level: the average of each of the modelled annual minimum groundwater levels over the 30-year simulation
Abstraction	pumping groundwater from an aquifer
Australian height datum (AHD)	height datum used within the study. Where Level (AHD) = mean seal level (MSL) + 0.026m
Alluvium	detrital material which is transported by streams and rivers and deposited
aquifer	a geological formation or group of formations able to receive, store and transmit significant quantities of water
AveGL	average groundwater level: the average groundwater level taken from daily results for the entire 30 year modelling simulation
unconfined aquifer	a permeable bed only partly filled with water and overlying a relatively impermeable layer. Its upper boundary is formed by a free watertable or phreatic level under atmospheric pressure
confined aquifer	a permeable bed saturated with water and lying between an upper and a lower impermeable layer
semi-confined	a permeable bed saturated with water and lying between an upper and a lower impermeable layer
baseflow	that portion of a river and streamflow coming from groundwater discharge
basin (geological)	a depression of large size, which may be of structural or erosional origin (contains sediments)
beds (geological)	a subdivision of a formation: smaller than a member
bore	small-diameter well, usually drilled with machinery

coffee rock	colloquial term for iron oxide (limonite)-cemented sand grains
confining bed	sedimentary bed of very low hydraulic conductivity
density	the mass of water per unit volume, usually stated in g/cm^3
discharge (groundwater)	all water leaving the saturated part of an aquifer
effective porosity	drainable pore space, considered synonymous with specific yield of unconfined aquifer
estuary (estuarine)	the seaward or tidal mouth of a river where fresh water comes into contact with seawater
evapotranspiration	a collective term for evaporation and transpiration
fault	a fracture in rocks or sediments along which there has been an observable displacement
flux	outflow
formation (geological)	a group of rocks or sediments which have certain characteristics in common and which were deposited about the same geological period and constitute a convenient unit for description
Geographical Information Systems (GIS)	An arrangement of computer hardware, software and geographic data that people interact with to integrate, analyse and visualise the data; identify relationships, patterns and trends; and find solutions to problems. Such a system is designed to capture, store, update, manipulate, analyse and display the geographic information. A GIS is typically used to represent maps as data layers that can be studied and used to perform analyses.
hydraulic	pertaining to groundwater motion
conductivity (permeability)	ease with which water is conducted through an aquifer
global climate model (GCM)	Computer models designed to help understand and simulate global and regional climate, in particular the climatic response to changing concentrations of greenhouse gases. GCMs aim to include mathematical descriptions of important physical and chemical

	processes governing climate, including the role of the atmosphere, land, oceans, and biological processes. The ability to simulate subregional climate is determined by the resolution of the model.
gradient	the rate of change of total head per unit of distance of flow at a given point and in a given direction
head	the height of the free surface of a body of water above a given subsurface point
infiltration	movement of water from the land surface to below ground level
Inundation	to cover completely with water
leaf area index (LAI)	The ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows. LAI is a dimensionless value, typically ranging from 0 for bare ground to 6 for a dense forest.
MaxGL	maximum groundwater level: the maximum groundwater level for each of the modelling cells for the entire 30-year modelling simulation
MinGL	minimum groundwater level: the minimum groundwater level for each of the modelling cells for the entire 30-year modelling simulation
member (geological)	a lithostratigraphic unit of subordinate rank, comprising some specially developed part of a formation
model (modelling system)	a simplified version of the hydrological system that approximately simulates the excitation-response relations of the real system
permeable	ability to permit water movement
pH	the negative decimal logarithm of hydrogen ion concentration. For example, pure water at 25℃ contains 10^{-7} g/L of H+ ion; its pH is 7.00
phreatic surface	The level at which the groundwater pressure is equal to atmospheric pressure. It may be conveniently visualised as the ‘surface’ of the groundwater in a given vicinity

plain	tract of flat or level terrain
potentiometric surface	an imaginary surface representing the total head of groundwater and defined by the level to which water will rise in a bore. The watertable is a particular potentiometric surface
recharge (groundwater)	all water reaching the saturated part of an aquifer (artificial or natural)
salinity	a measure of the concentration of total dissolved solids (TDS) in water 0 – 500 mg/L, fresh 500 – 1500 mg/L, fresh to marginal 1500 – 3000 mg/L, brackish 3000 mg/L and greater, saline
scarp	a line of cliffs (steep slopes) produced by faulting or by erosion
SILO data-drill	Synthetic daily rainfall data on grids of data interpolated from point observations by the Bureau of Meteorology. Interpolations are calculated by splining and Kriging techniques. The data-drill provides meteorological variables interpolated to 0.05° spatial resolution
specific yield	the volume of water that an unconfined aquifer releases from storage per unit surface area of the aquifer per unit decline in the watertable
stratigraphy	The science of rock strata. Concerned with original succession and age relations of rock strata and their form, distribution, lithology, fossil content, geophysical and geochemical properties
throughflow (groundwater)	groundwater flow within an aquifer
transmissivity	the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient
watertable	the surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere

References

CSIRO 2009, *Groundwater yields in south-west Western Australia,* a report to the Australian government from the CSIRO South-West Western Australia Sustainable Yields Project, Water for a Healthy Country, National Research Flagships.

Davidson, WA & Yu, X 2006, Perth regional aquifer modelling system (PRAMS) model development: hydrogeology and groundwater modelling, Department of Water, Western Australia, HG20.

Department of Water 2009, *Strategic policy 2.03 – Managing unlicensed groundwater use,* Department of Water, Perth.

DoW – see Department of Water

Hall, J, Kretschmer, P, Quinton, B & Marillier, B 2010a, *Murray hydrological studies: surface water, groundwater and environmental water – conceptual model report,* Water Science Technical Series, report no. 16, Department of Water, Western Australia.

— 2010b, *Murray hydrological studies: surface water, groundwater and environmental water – model construction and calibration report,* Water Science Technical Series, report no. 25, Department of Water, Western Australia.

Intergovernmental Panel on Climate Change 2007, *Climate Change 2007: the physical science basis,* contributions of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

— 2000, *Special report on emissions scenarios*, Nakicenovic N & R Swart (eds.), Cambridge University Press, Cambridge, UK, 612 pp.

IPCC – see Intergovernmental Panel on Climate Change

Kelsey, P, Hall, J, Kretschmer, P, Quinton, B & Shakya D 2010, *Hydrological and nutrient modelling of the Peel-Harvey catchment*, Water Science Technical Series, report no. 33, Department of Water, Western Australia.

Kretschmer, P, Wallace-Bell, P & Hall, J 2010, *Murray hydrological studies: surface water, groundwater and environmental water – acid sulfate soil risk assessment,* Water Science Technical Series, report no. 30, Department of Water, Western Australia.

Research Solutions 2009, *Incidence of bores in the Perth metropolitan area,* a report prepared for the Department of Water, Western Australia from Research Solutions Pty Ltd, 15 pp.

WAPC – see Western Australian Planning Commission

Western Australian Planning Commission 2009, *Draft south metropolitan and Peel sub-regional structure plan,* June.

— 2007, *Liveable Neighbourhoods: a Western Australian Government sustainable cities initiative*, Western Australian Planning Commission, Perth, Western Australia

— 2005, *Guideline for the determination of wetland buffer requirements for public comment,*, December

Xu, C, Canci, M, Martin, M, Donnelly, M & Stokes, R 2009, Perth regional aquifer modelling system (PRAMS) model development: application of the vertical flux model, Hydrogeological record series, Report no. 27, Department of Water, Western Australia

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