Department of
Sustainability and
Environment

ecoMarkets
VALUING OUR ENVIRONMENT

North East CMA Groundwater Model

Transient model development report

HYDRO GEO ENVIRONMENTAL SERVICES
HOCKING ET AL PTY LTD

A Victorian Government initiative

Victoria
The Place To Be

Produced by Hocking et al on behalf of the Victorian Government Department
of Sustainability and Environment Melbourne, 2010.

Please cite this report as;
Hocking et al. (2010). North East CMA – Transient model development report.
Written for DSE Victoria, Environmental Economics Unit. Unpublished report

Authorised by the Victorian Government, 8 Nicholson Street, East Melbourne.

www.dse.vic.gov.au/ecomarkets

Summary

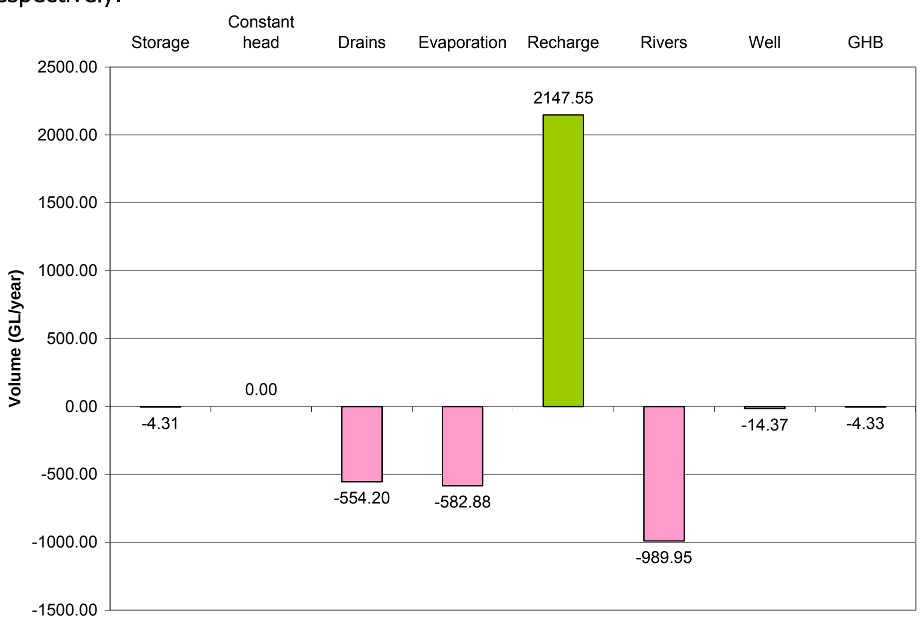
The groundwater model described in this report has been developed within the context of DSE requirements consistent with the ecoTender approach. That is, it provides a tool for assessing the impacts of land use change on catchment water balances. The model predicts changes in the volume of base flow, areas of land subject to a shallow watertable and, by inference, areas subject to land salinity.

This report describes the second stage of a two-part project; the first stage was a multilayer steady-state groundwater model, and this stage presents a simulated multilayer transient groundwater model of the North East Catchment Management Authority (CMA) region.

The North East CMA model attempts to simulate groundwater movement within each of the principal aquifers of the region. The following model layers and geology groups have been aligned in a six-layer framework. The model has been developed in finite difference format (regular gridding). It features a cell size of 200m, totalling 496 214 solution points occupying 769 rows and 932 columns, and comprises of 6 layers and 2 977 284 active cells.

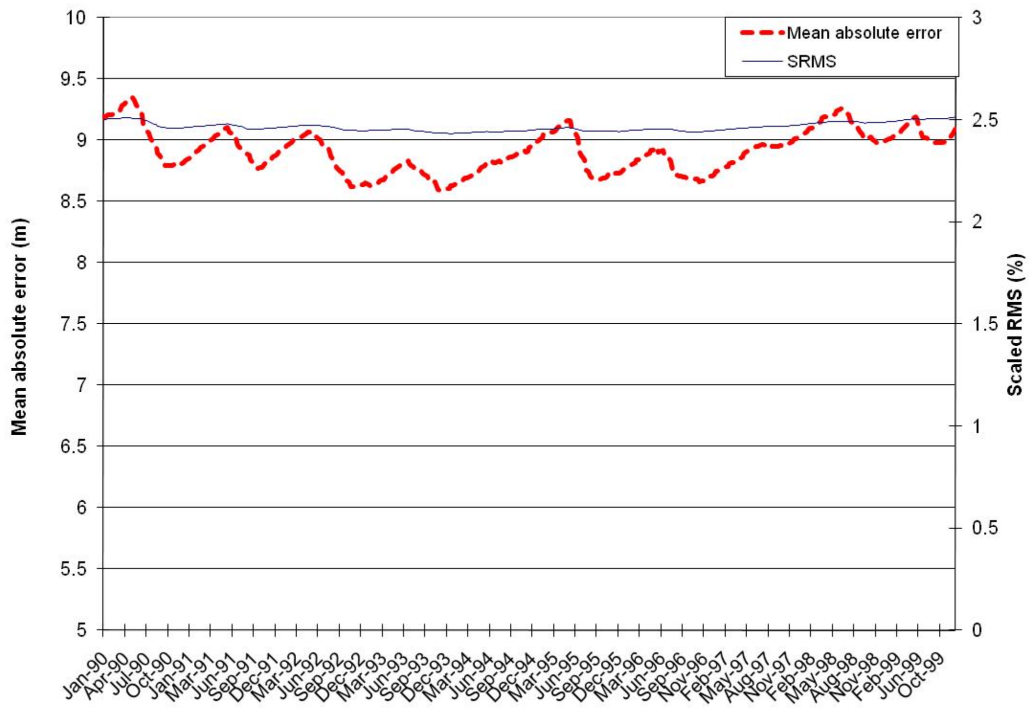
Model calibration was achieved by attempting to match observed groundwater level with simulated groundwater levels in monthly time steps over the calibration period between 1990 and 1999. The transient calibration follows-on from a calibrated steady-state simulation (Hocking et al. 2010).

Annual average calibrated time-varying water balance between1990 and 1999 is presented below. Results suggest the main export of groundwater from the catchment is groundwater base flow, evaporation, groundwater pumping and groundwater outflow respectively.



Simulated versus observed groundwater level data statistics determined a scaled Root Mean Square (RMS) over time generally remained less than 3 % across the calibration (1990–1999) and validation (2000–2005) periods. The simulated depth to watertable (below) is considered a reasonable representation of the region when considering the scale, assumptions and time limitations of the project. Results show the model simulation

generally agrees with observed water level data, at least within the criteria required for this project.



Considerable discussion and debate has occurred with the hydrogeological conceptualisation of the region, namely the depth to watertable in the uplands of the North East CMA region. The model developer considers the application of the North East CMA region groundwater model has the capacity to predict changes in the water balance, however there are a number of potential limitations which should be kept in mind, they are;

- There should be no long-term scenario prediction of the transient model (e.g. > 15 years), as no data validation has been undertaken beyond this period. Also, underlying groundwater trends may impact model prediction capacity beyond this period.
- Only relative water balance changes should be considered, not absolute changes. That is, due to scale, complexity, availability of calibration data and project time limitations, model calibration is not at sufficient detail to warrant absolute values.
- The application of the North East CMA region steady-state groundwater model may be used for impact assessment of land use change as calibrated recharge rates provided reasonable recharge estimates, and therefore redistribute the groundwater balance proportionately.
- When considering land use change scenarios, the area of change should be no less than, say 10 hectares, as scale generalisations and solver tolerance is unlikely to accurately identify changes in the catchment groundwater balance.

Contents

List of Figures

List of Tables

1 Introduction

This report has been prepared by Hocking et al Pty Ltd in conjunction with Phil Dyson and Associates on behalf of the Department of Sustainability and Environment (DSE) and describes the conceptualisation, attribution and calibration of the multi-layer spatial groundwater model for the entire North East Catchment Management Authority (CMA) region.

1.1 ecoMarkets project background

The North East CMA groundwater model represents part of a statewide program aimed at producing groundwater models for each of Victoria's eight CMA regions. The groundwater models for each CMA region will be used to assess the impacts of land use change on the water balance, and in particular the influence on depth to watertable and base flow volume. This information is intended to inform DSE market-based approaches to land management that are designed to reward landholders for environmental improvements in their properties. This DSE program is generally known as 'ecoTender'

EnSym (Environmental Systems Modelling Platform) is a computer program designed by the Victorian Government to provide:

- simple and intuitive access to complex science that helps prioritise natural resource investment
- an understanding of the environmental benefits delivered by actions undertaken in the landscape; and
- a framework for scientists and researchers to test and apply empirical and process based scientific models.

Ensym employs scientific models to improve understanding about the impacts that actions such as revegetation, weed control and riparian management, have on the landscape. Users can visualise, test and interpret results of changes in climate, land use and land management practices through a single interface. Models are grouped into 5 toolboxes that relate to different sections of the landscape and analytical capabilities. The toolbox that simulates surface water dynamics and thus provides the recharge values is known as Biosym.

Biosym (biophysical systems toolbox) is the name given the biophysical modelling toolbox within the Ensym model. BioSym originated from the Catchment Analysis Tool, also known as CAT1D (Beverley, 2007) which was jointly developed by DSE and DPI. From December 2008 onward, DSE and DPI followed different paths in further developments and modifications of the CAT1D module, thus to distinguish and to reflect the divergence of the simulation codes, BioSym was the name adopted as the computer program for biophysical modelling within the Ensym model.

BioSym solves for physical processes conceptually by using simplified analytical solutions and empirical equations. The code for BioSym was written with the objective of simulating all major hydrologic components as simply and realistically as possible, and to use inputs readily available over large spatial scales to enhance the likelihood that the model would become routinely used in planning and water resource decision making.

The model components of BioSym can be placed into eight major categories - hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, agricultural management, and pesticides.

Water entering the soil profile is initially determined by subtracting the calculated surface runoff from the total daily precipitation and irrigation. Once in the soil profile, water can be removed by evapotranspiration, lateral flow, downward movement if soil capacity is

exceeded. Water fills up lower soil layers until it exits the soil profile and becomes drainage. Drainage is then portioned into sub surface lateral flow and recharge.

The Biosym modelling approach, results in several limitations in regards to recharge calculations, the most major of which are:

- no recharge time lags are taken account of, thus it is assumed that water partitioned for recharge instantly hits the water table. This limitation is of most concern in areas of deeper water tables and of little concern in shallow water table areas.
- surface runoff does not cascade from upstream modelling cells to downstream modelling cells, thus no pooling can be modelled or accumulation of water in low lying areas. This may result in the underestimation of recharge is low lying areas.
- similarly floods are not modelled thus recharge events caused by flood waters will be missed. Obviously recharge still tends to peak during flood events as a result of high rainfall however recharge will be underestimated in areas where flood waters contribute to recharge.
- all biophysical processes are simulated on a daily time-step thus processes that occur on a smaller time-step may be poorly accounted for, such as short high intensity storm events.
- any influence that underlying geology has on impeding or aiding recharge is not taken into account, for example in some areas of upland Victoria the deeper regolith is suspected to throttle recharge depending on it's water content.
- the soil mapping used is the best currently available across the state however it is primarily a landsystem map thus large variations in soil types can exist within each of the Biosym soil units.
- Biosym assumes no temporal changes in landuse, thus for example, recharge changes from afforestation are not modelled during the groundwater model time period.
- Biosym doesn't take into account areas where the soil profile is saturated due to groundwater discharge.

It is important that these recharge modelling limitations are taken into account when assessing the overall limitations of a groundwater model using Biosym recharge values.

For further detail on the Biosym toolbox please refer to the CAT1D technical manual (Beverley, 2007) and to the Programmer's Guide for BioSym (Ha, in preparation)

1.2 Model objectives and context

The groundwater model described in this report has been developed within the context of DSE requirements consistent with the Ensym approach. That is, it provides a tool for assessing the impacts of land use change on catchment water balances. The model predicts changes in the volume of base flow, areas of land subject to a shallow watertable and, by inference, areas subject to land salinity.

The groundwater modelling project has been undertaken in two parts: the first phase involved the calibration of a multi-layer steady-state groundwater model. This work was independently reviewed before stage two (this stage) was commissioned. The second stage aims at further refinement and expansion of the phase 1 outputs. It builds on the conceptualisation and the datasets used in the steady state model and lead to the construction of a calibrated multi-layer transient groundwater model for the North East CMA region.

1.3 Model specifications

Specifications for this modelling exercise are:

- finite difference/element gridding at 200 metre cell size
- multi-layer groundwater model (representing major geological units) consistent with existing models
- common boundary conditions and relatively consistent aquifer parameters with adjacent models
- a scaled (normalised) RMS of less than 10% for the transient model based upon time-series observation data
- a transient calibration/validation period of 10 years
- a sensitivity analysis to assess the variability of modelled outputs to variations in key model input parameters
- catchment water balance error of less than 2%
- all catchment water balance features to be considered and reported
- the source and statement of quality of all input datasets to be reported
- at least 500 groundwater observation bores used for calibration (if more than 500 present)
- the model domain represents at least the entire extent of the North East CMA region
- groundwater recharge layers to be developed by DSE and be incorporated into the groundwater model, unless demonstrated to be erroneous.

1.4 External review and workshops

Independent external review of the key project outputs forms an integral part of the project. External review was achieved via a series of five workshops, held at key stages during the project, combined with regular informal communication and review by the appointed reviewers. The following workshops were conducted:

- ✓ Informal review workshop – to be held following the collation of all the relevant datasets and the development of the preliminary aquifer conceptualisation.
- ✓ Statewide groundwater modelling workshop – will be conducted following the preliminary conceptualisation. The workshop will ensure the biophysical processes being considered are consistent across each CMA region.
- ✓ Formal Phase 1 model review workshop – formal presentation of final aquifer conceptualisation and a calibrated multi-layer, steady-state groundwater model for review.
- ✓ Final model workshop – formal presentation of a calibrated multi-layer transient groundwater model and report for review.
- ✓ Final audit workshop – formal audit of the final groundwater model including handover and review of the model input and output data files.

Alan Wade and Brian Rask (of Parsons Brinckerhoff Pty Ltd) was appointed as external reviewers for the North East CMA region model, with sub-contractor Phillip Macumber of Phillip Macumber consulting providing expert hydrogeological review.

2 Hydrogeological setting

2.1 Study area

This investigation covers the North East Catchment Management Authority (CMA) region in Victoria (Figure 1). The region encompasses some 2.0 million hectares of land and the major population centres of Wodonga, Wangaratta, Bright, Omeo, Tallangatta, Rutherglen and Corryong.

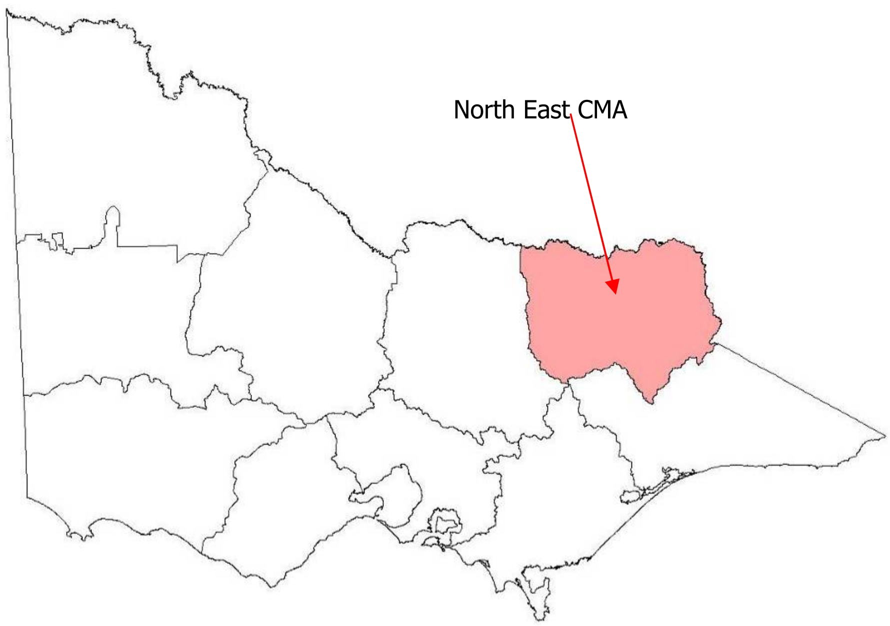


Figure 1 Location of North East CMA region

2.2 Climate

The region is made up from three main river catchments: the Upper Murray, the Ovens and the Kiewa. In each of these rainfall varies in sympathy with elevation.

Climate plays an important role in the hydrologic processes that drive the catchment water balance. The mean annual rainfall distribution over the North East CMA region varies markedly, ranging from more than 2600 mm/year at Falls Creek to around 500 mm/year at Rutherglen (Figure 2).

Over the past ten years there has been a major change in monthly rainfall volume. Figure 3 presents the cumulative residual rainfall for the Bright Bureau of Meteorology (BOM) climate station. It demonstrates a strong decline in rainfall since 1998.

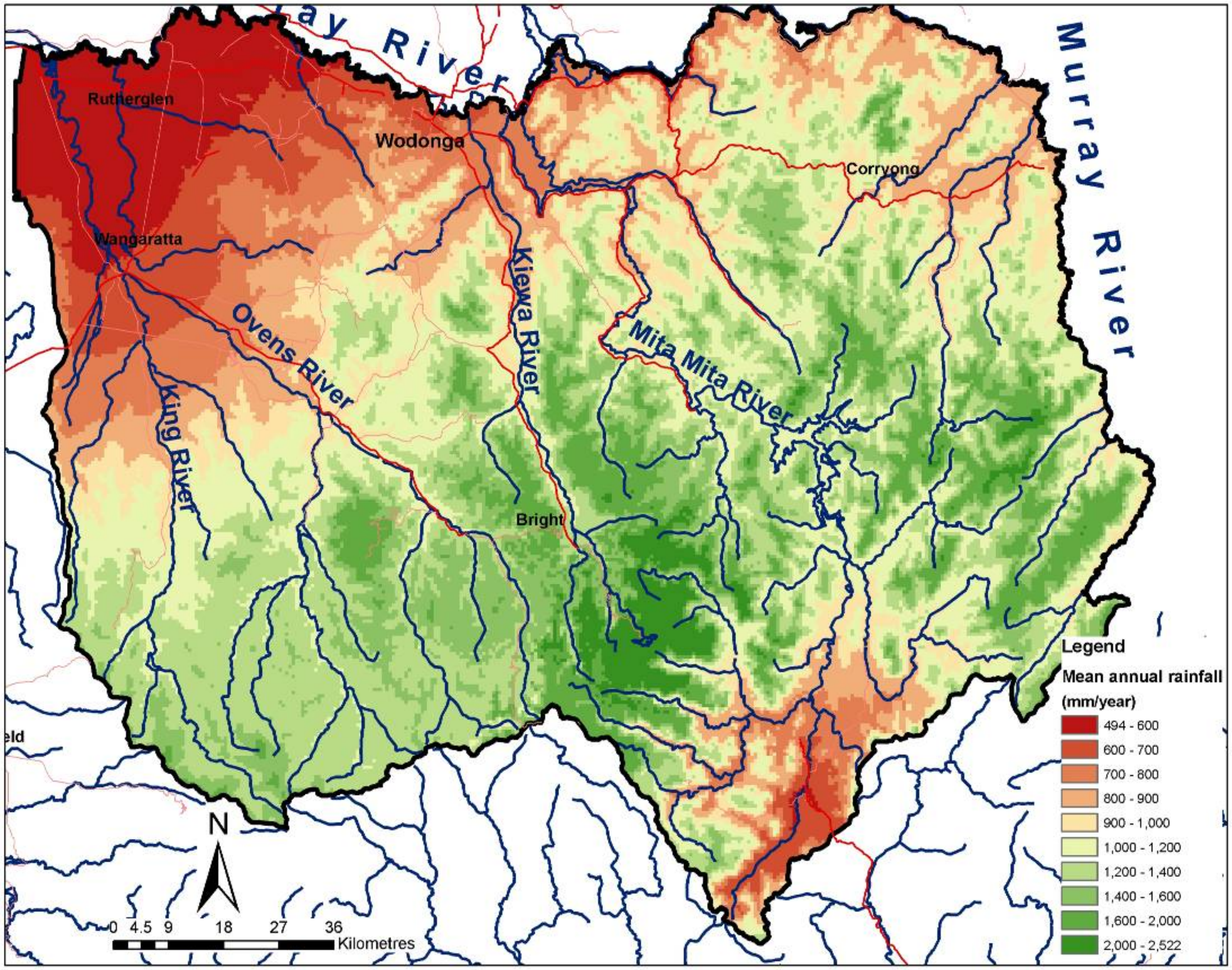


Figure 2 Distribution of mean annual rainfall across the region

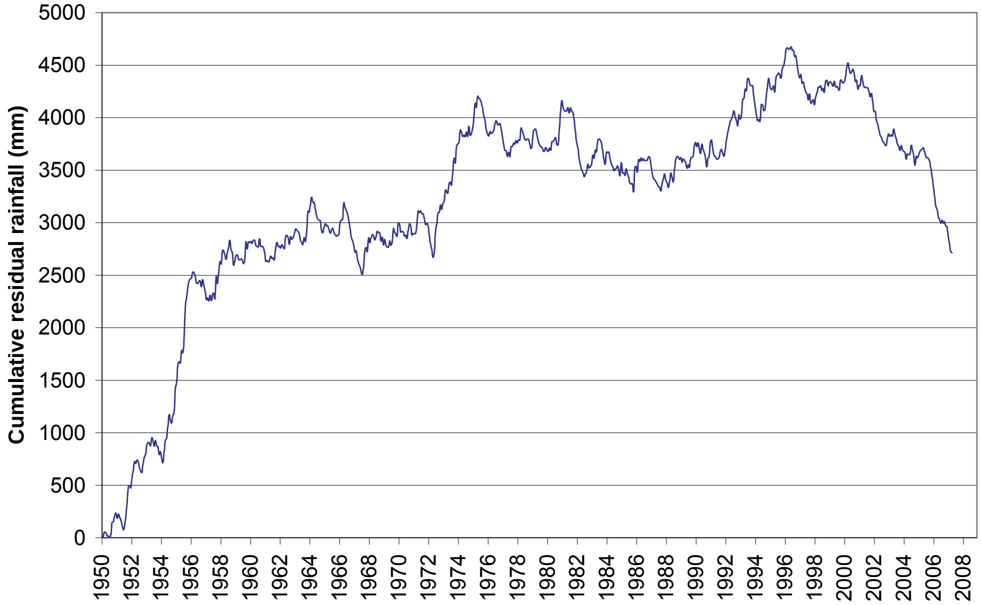


Figure 3 Cumulative residual rainfall at Bright

2.2.1 Regional groundwater trends

Groundwater recharge in southern Australia is strongly correlated with annual rainfall. This is particularly true when the seasonal rainfall pattern follows that established by the long-term trend. In this condition most rainfall occurs during cold wet winters and least in hot dry summers.

Hekmeijer et al (2008) selected 68 bores in the DPI groundwater trend review across Northern Victoria (including the North East region), only 7 bores recorded a rising groundwater trend. Eighteen (18) were relatively stable (especially in recent years), and 43 had a falling trend. Of the latter group, 32 were recording their lowest water levels. Many of the selected bores were recording their lowest groundwater level (Reid, et al 2009). The declines in levels have mostly occurred since 1996 or 1997 but there are examples of declines occurring since 1994 and also only as recently as from 2002. Upper landscape bores show the most significant change in level, with declines most commonly being 4 to 8 metres (Reid, et al 2009).

Average rainfall trend should be used to select a representative year for recharge as individual groundwater monitoring bore have site specific factors which obscure an average annual climate sequence.

2.3 Topography

The landscapes of North East Victoria are diverse. In the south and the east the land is mountainous but in the north the Great Dividing Ranges give way to gentler foothills and Riverine Plains particularly in the Ovens and King valleys in the north and west.

The region can be considered to comprise two major geomorphic zones; the uplands and the plains. The uplands terrain ranges from gentle undulating lands in the mid reaches through to steep hills and mountains in the headwaters and along the catchment margins. The river valleys of the uplands are narrow compared with the much broader and less defined valleys in the lowland plains. Significant topographic features in the region include the Great Dividing Ranges, Warby Range, Snowy Range, Mount Hotham and Mount Buffalo.

Digital elevation data for the North East CMA region was sourced via the DSE corporate geospatial library at 20 m cell size. The Digital Elevation Model (DEM) was re-sampled to 200 m using bilinear interpolation (Figure 5). It is acknowledged re-sampling the landscape into 200m cells causes elevation generalisations, and is likely to produce an underlying error which may distort model calibration data statistics. In attempt to quantify the likely error, a comparison of available surveyed bore elevation with the DEM used for this modelling exercise was undertaken. Results show the mean sum of residuals is 3.74 m (Figure 5), this underlying elevation variation should be kept in mind when reviewing measured versus simulated groundwater level data.

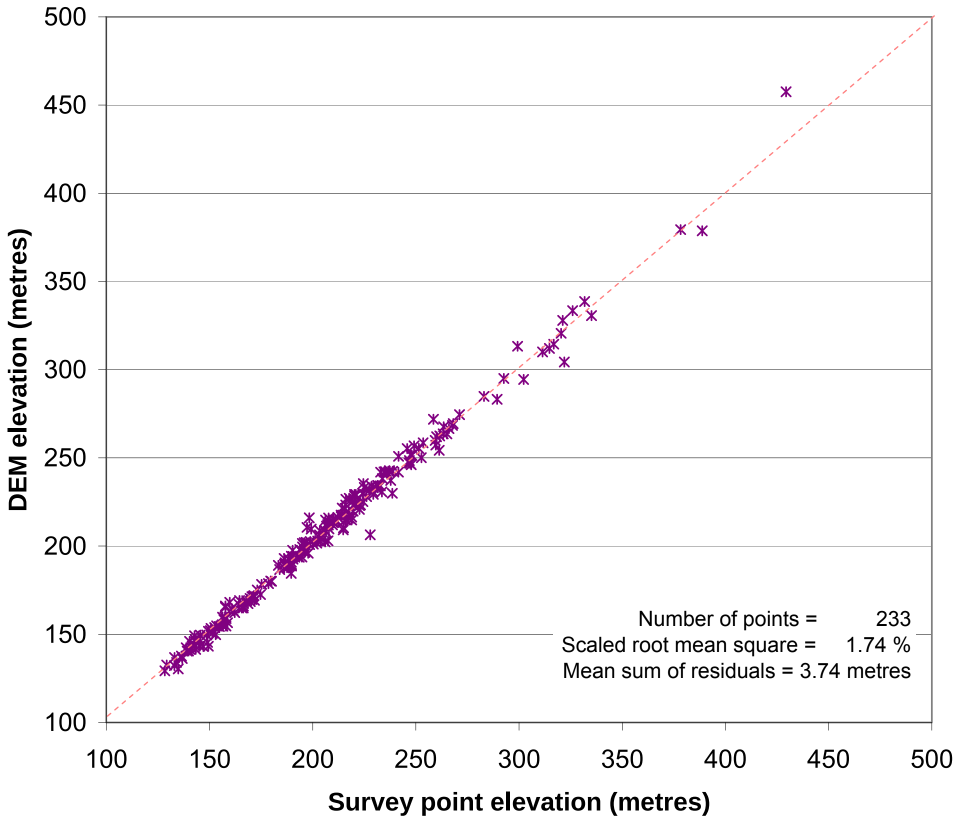


Figure 4 Surveyed versus digital elevation data

2.4 Landuse

The North East Region of Victoria comprises the land extending from the Murray River and the New South Wales border in the north and east through to the Victorian Alps in the south. To the west, the Warby Ranges separate the North East CMA region from the adjoining Goulburn-Broken catchment.

Most of the steeper mountainous terrain is public land (59%). There are approximately 700 000 hectares of state forest, 400 000 hectares of national and state parks including the Mount Buffalo National Park, the Chiltern Mount Pilot Park and a substantial area of the Alpine National Park.

Figure 6 presents the distribution of broad land use classes in the North-East CMA region. The dominant land uses are native vegetation (59%), grazing (29%), forestry (2%), residential (2%) and cropping (1%).

2.5 Hydrology

The network of surface streams in the North East is well defined and provides relatively reliable flows annually (Figure 7). The majority of the region has more than 1000 mm of annual rainfall, and hence a well organised drainage network. The main drainage feature is the Murray River, where all surface water flow within the region eventually reaches. Major river networks of the North East CMA region include, the King, Ovens, Kiewa, Mita Mita and upper Murray. Many other smaller drainage networks exist. All river networks flow to the Murray River.

North East Victoria is particularly significant from a water harvesting perspective. About 38% of the flow in the Murray-Basin comes from the region's catchments. Lake Hume on the Murray at Albury/Wodonga and Dartmouth Reservoir on the Mitta Mitta River are particularly important storages. When full they hold (collectively) approximately 7,000 giga litres of water. The Ovens River is also a particularly significant source of environmental water for the Murray Valley, and for South Australia in times of drought. It is one of the few rivers that remain unregulated and, accordingly, it affords opportunities for important flood flows realised from storm activity.

2.6 Groundwater interactions

This section provides insight into of the various surface water and groundwater interactions known to occur within the region.

2.6.1 Recharge

Spatially varying groundwater recharge was provided by DSE via 'Ensym' (Figure 8). The Ensym framework utilises a number of one-dimensional farming system models to estimate the impact of variations in soil, water and vegetation on certain components of the water balance, including estimates of groundwater recharge and surface runoff.

Spatially varying groundwater recharge over 30.4 day time steps supplied for the 1990 – 2005 period. Appendix 3 presents monthly groundwater recharge rates over the model calibration (0-120 time steps) and validation (121-192 time step) periods.

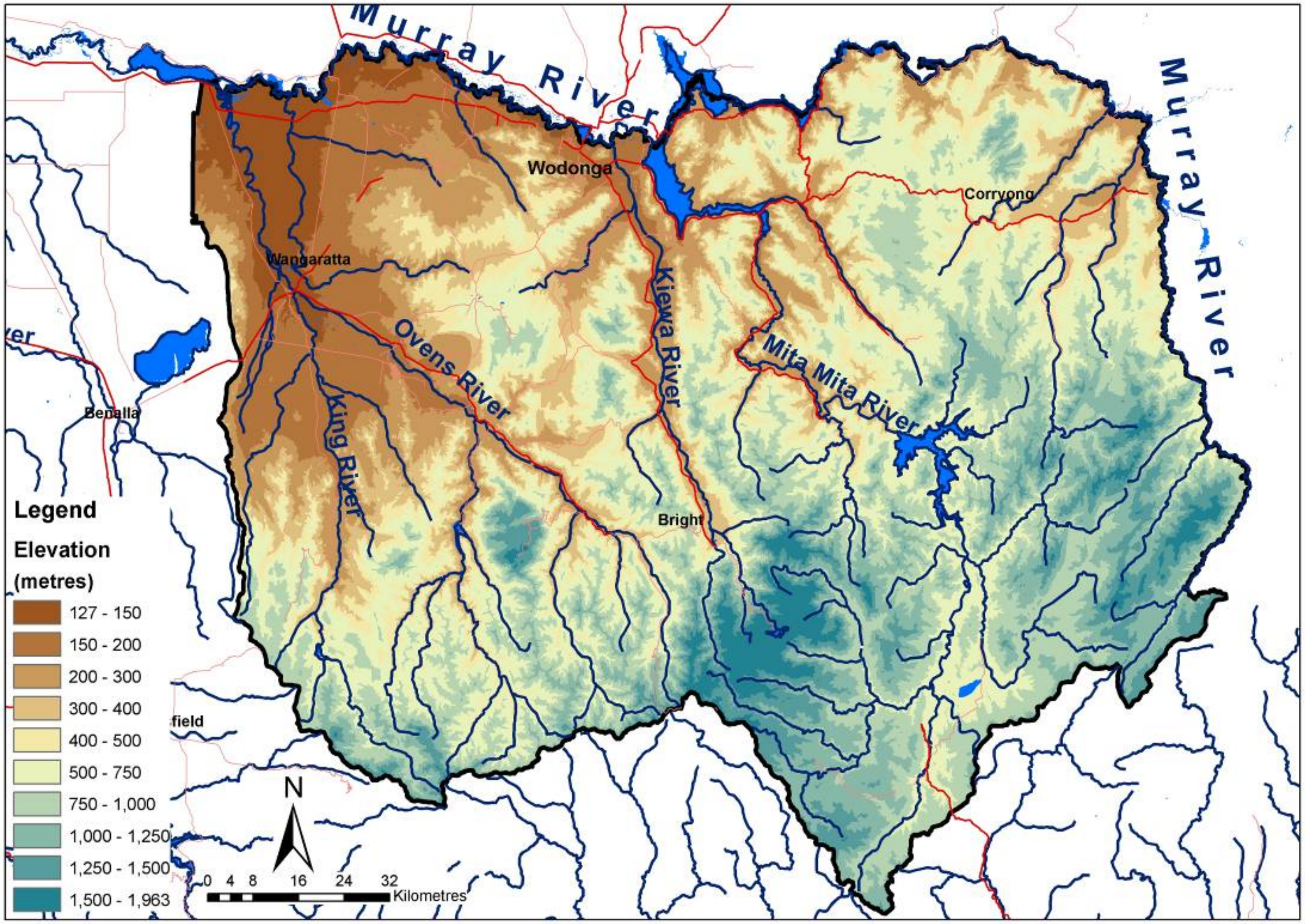


Figure 5 Topography of the North East CMA region

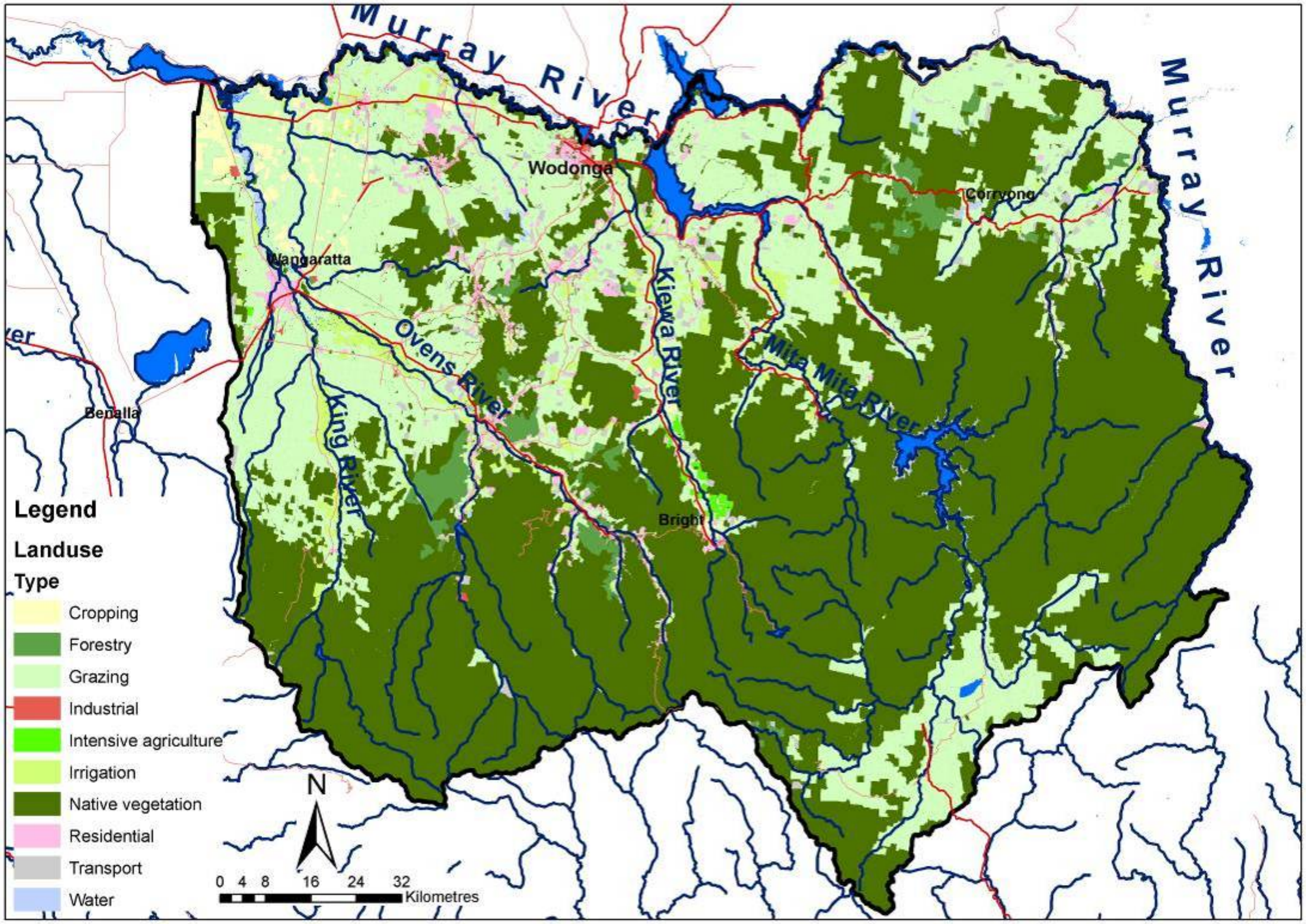


Figure 6 Land use classes of the North East CMA region

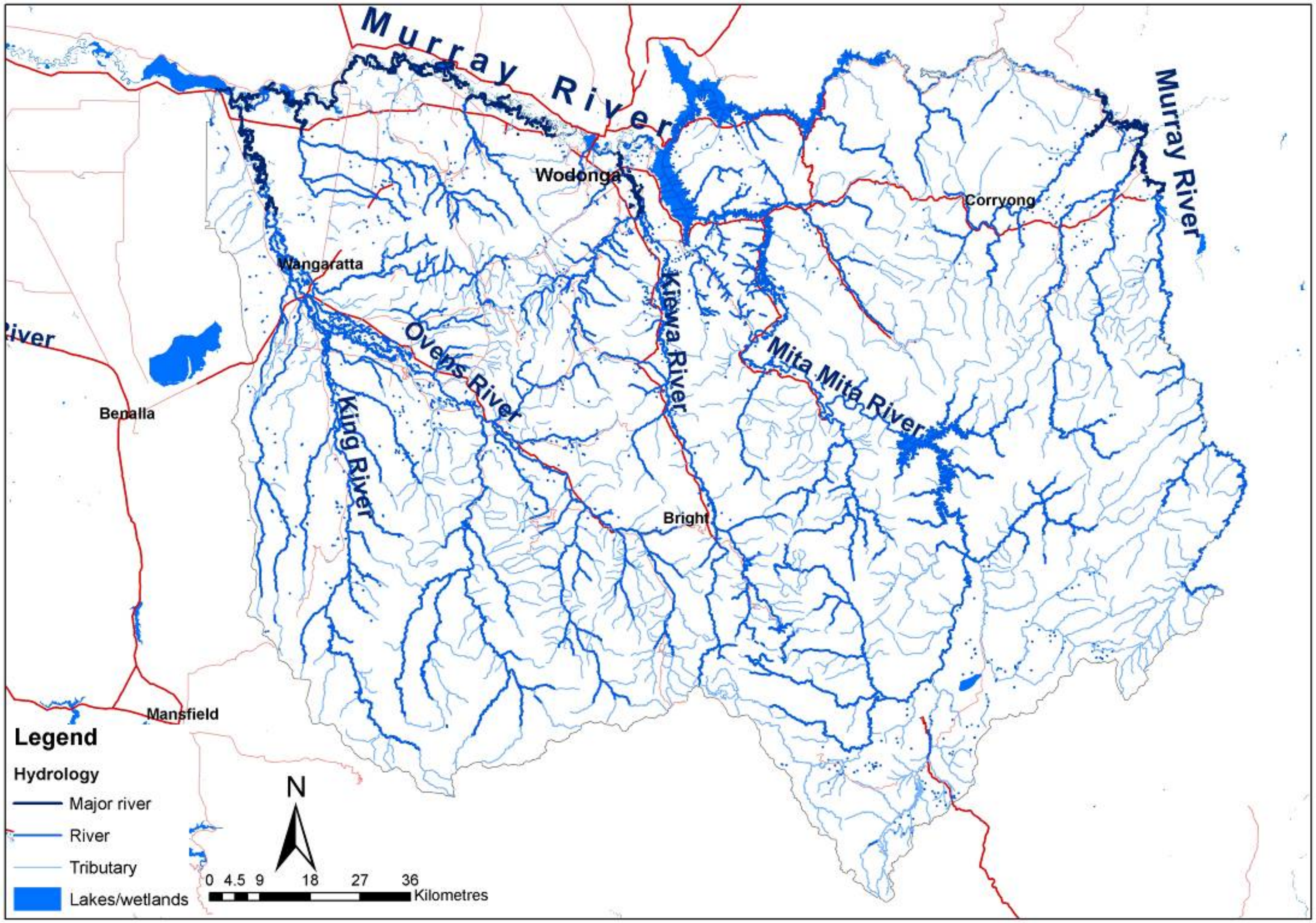


Figure 7 Drainage networks of the North East CMA region

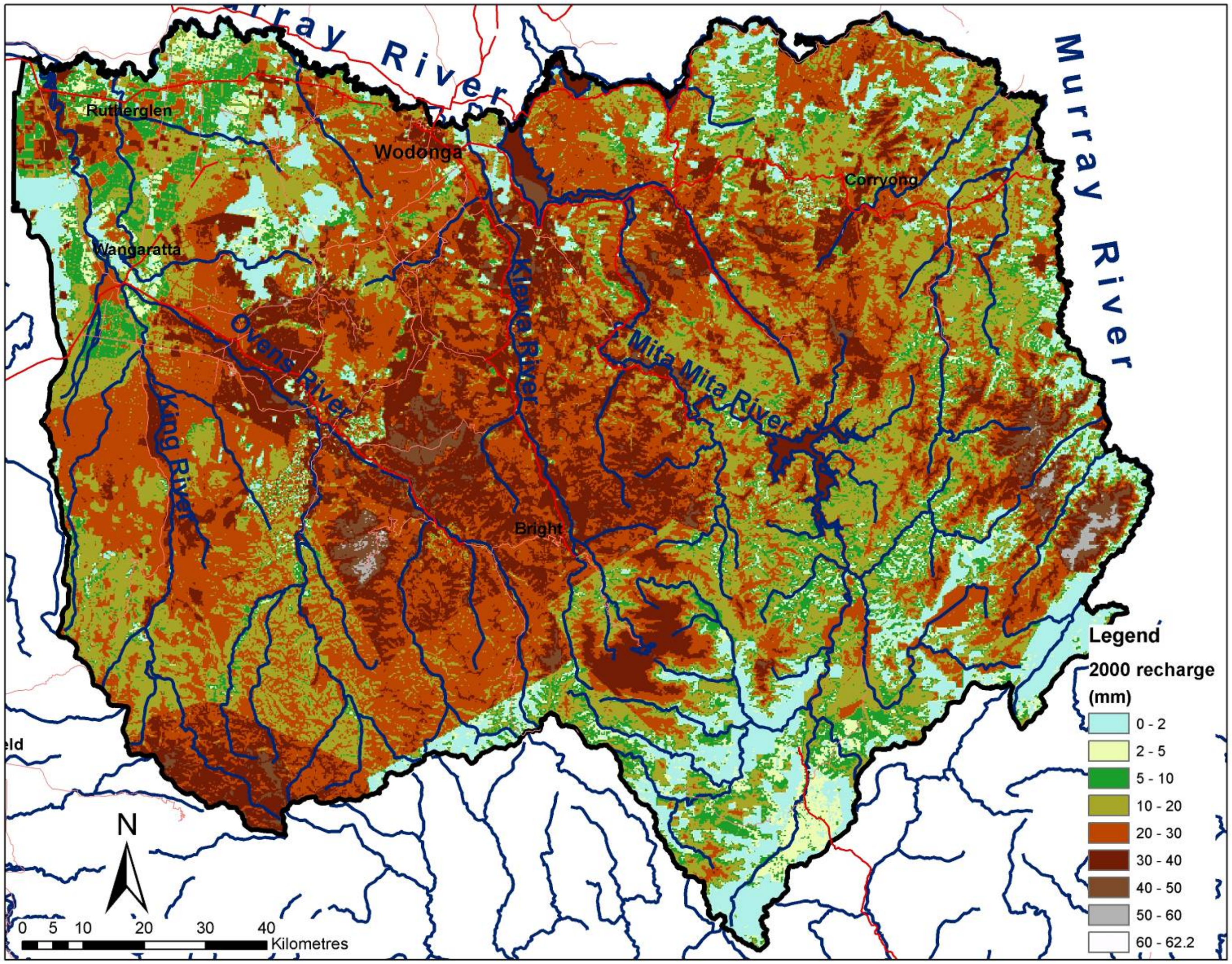
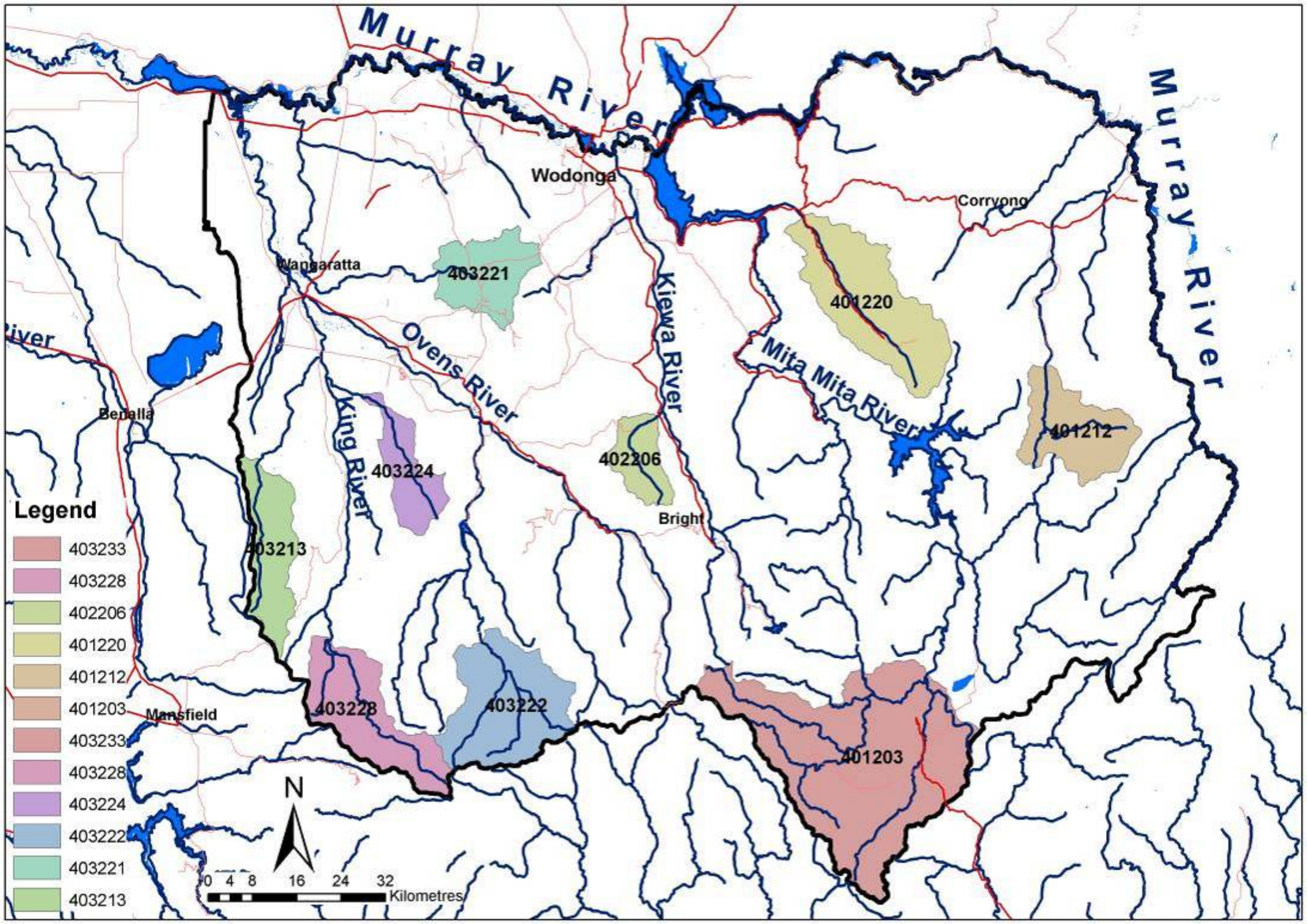


Figure 8 DSE provided groundwater recharge layer



Murray River
Murray River
Wodonga
Corryong
Wangaratta
Benalla
Mansfield
Bright
Ovens River
Kiewa River
King River
Mita Mita River
403221
401220
401212
403224
402206
403213
403228
403222
401203
Legend
403233
403228
402206
401220
401212
401203
403233
403228
403224
403222
403221
403213
N
0 4 8 16 24 32
Kilometres

Figure 9 Gauged catchments considered for baseflow analysis

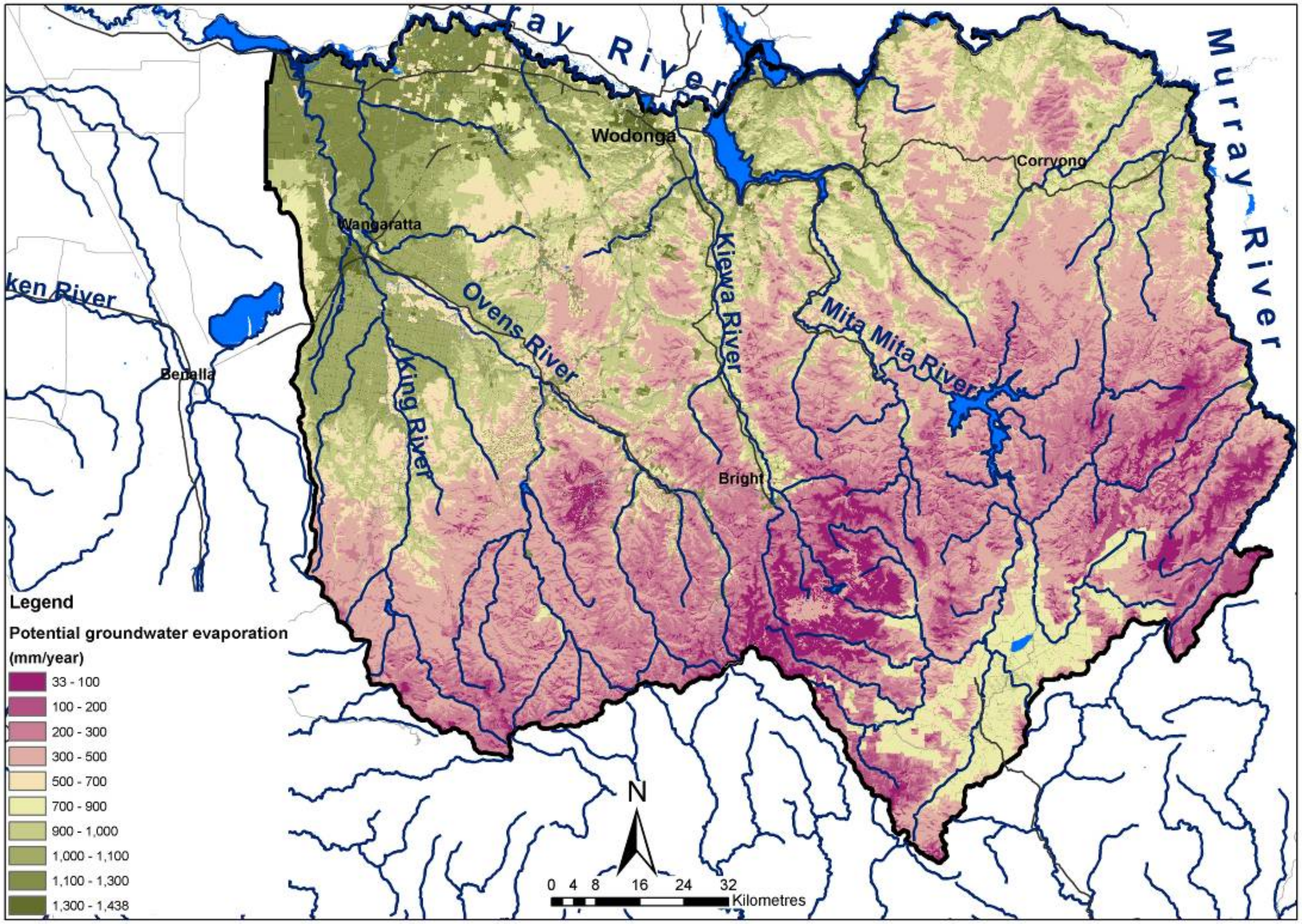

Murray River
Murray River
Wodonga
Corryong
Wangaratta
ken River
Ovens River
Kiewa River
Mita Mita River
King River
Benalla
Bright
Legend
Potential groundwater evaporation
(mm/year)
33 - 100
100 - 200
200 - 300
300 - 500
500 - 700
700 - 900
900 - 1,000
1,000 - 1,100
1,100 - 1,300
1,300 - 1,438
N
0 4 8 16 24 32
Kilometres

Figure 10 Potential groundwater evaporation across the North East CMA region

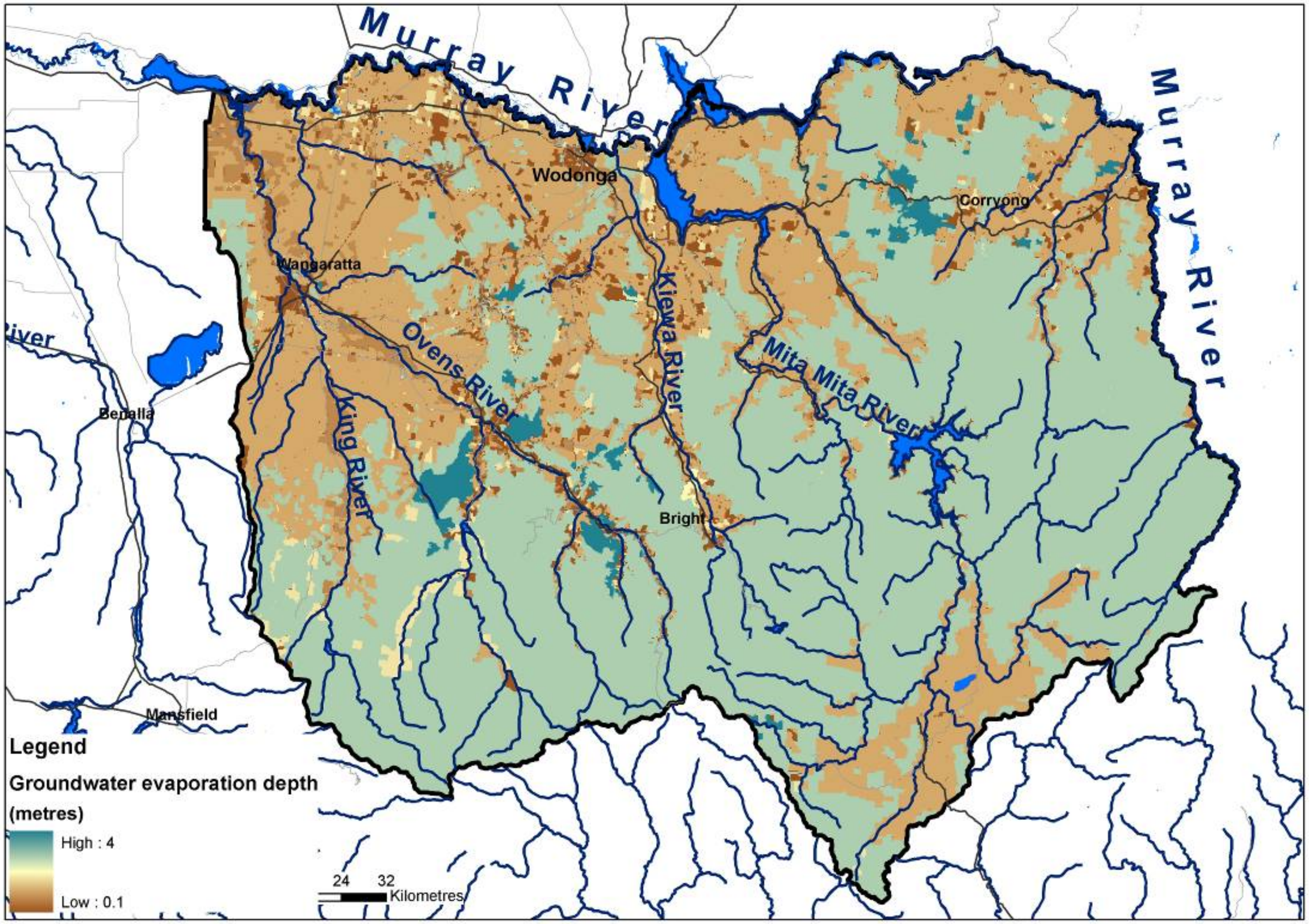

Murray River
Murray River
Wodonga
Corryong
Wangaratta
Ovens River
Kiewa River
Mita Mita River
King River
Benalla
Bright
Mansfield
River
Legend
Groundwater evaporation depth
(metres)
High : 4
Low : 0.1
24 32
Kilometres

Figure 11 Simulated groundwater evaporation depth

2.6.2 River interaction

Estimates of surface water and groundwater interactions have been made by selecting stream gauges for base flow analysis.

Figure 9 presents stream gauges and contributing catchment areas analysed for base flow, these locations were selected primarily based upon flow data availability and spatial spread. Base flow was estimated using the automated analysis technique described by Arnold and Allen (1999).

The equation for the filter is:

$$q_t = \beta\, q_{t-1} + (1 + \beta)/2 * (Q_t - Q_{t-1})$$

Where;

q_t	=	filtered surface run off
t	=	time-step
Qt	=	original stream flow data
β	=	filter parameter (0.95)

The recursive digital filter technique is described by Nathan and McMahon (1990). The technique has no real physical basis, however it is objective and replicatable (Arnold, et, al., 1995). The digital base flow filtering can be passed up to three times, where each pass effectively reduces base flow percentage. Nathan and McMahon (1990) compared a manual and the recursive digital filtering base flow analysis and found the automated filtering method was comparable in accuracy to that of manual base flow separation. Arnold, et. al., (1995) recommend in the absence of on-site conditions that the one filter pass (first pass) be the default value used.

Appendix 1 presents individual base flow data for each stream gauge and this information is summarised in Table 1 for 2000. Significant variation and perhaps error exists in baseflow volumes calculated or the groundwater recharge rates provided. Data suggests in some catchments more than 100% of the catchment groundwater recharge volume discharges via groundwater.

Table 1 Baseflow estimates of selected catchments in 2000

Stream Gauge	Baseflow calculation (ML)	Catchment recharge (ML)	Recharge volume percentage (%)
402206	25 300	51 621	49
401220	81 030	156 027	52
401212	126 400	100 750	125
401203	270 500	159 980	169
403228	127 800	61 519.9	208
403224	16 800	52 224.0	32
403222	97 400	95 882.9	102
403221	19 250	44 845.76	43
403213	36 330	53 596.74	68
Average of recharge values less than 100% = 49 %			

2.6.3 Evapotranspiration

Potential mean annual evaporation increases by more than half from south to north across the region.

Spatially varying groundwater evapotranspiration at 30.4 day time steps in MODFLOW format was supplied via Ensym (Figure 10). Spatially varying groundwater evapotranspiration depth was determined based upon the Catchment Analysis Tool (CAT) DSE (2008).

Spatially varying groundwater evaporation depth (Figure 11) was determined based upon differing land use and associated estimated evaporation depth.

Surface water – groundwater interaction

Investigation of groundwater – surface water interaction, specifically along the Murray River was undertaken to determine if groundwater level is controlled, or controls surface water level. . Figure 12 presents the location of stream gauges considered in the surface water –groundwater interaction in the lower North East. On the Victorian Riverine Plain groundwater – surface water interaction generally increases down stream of Barmah.

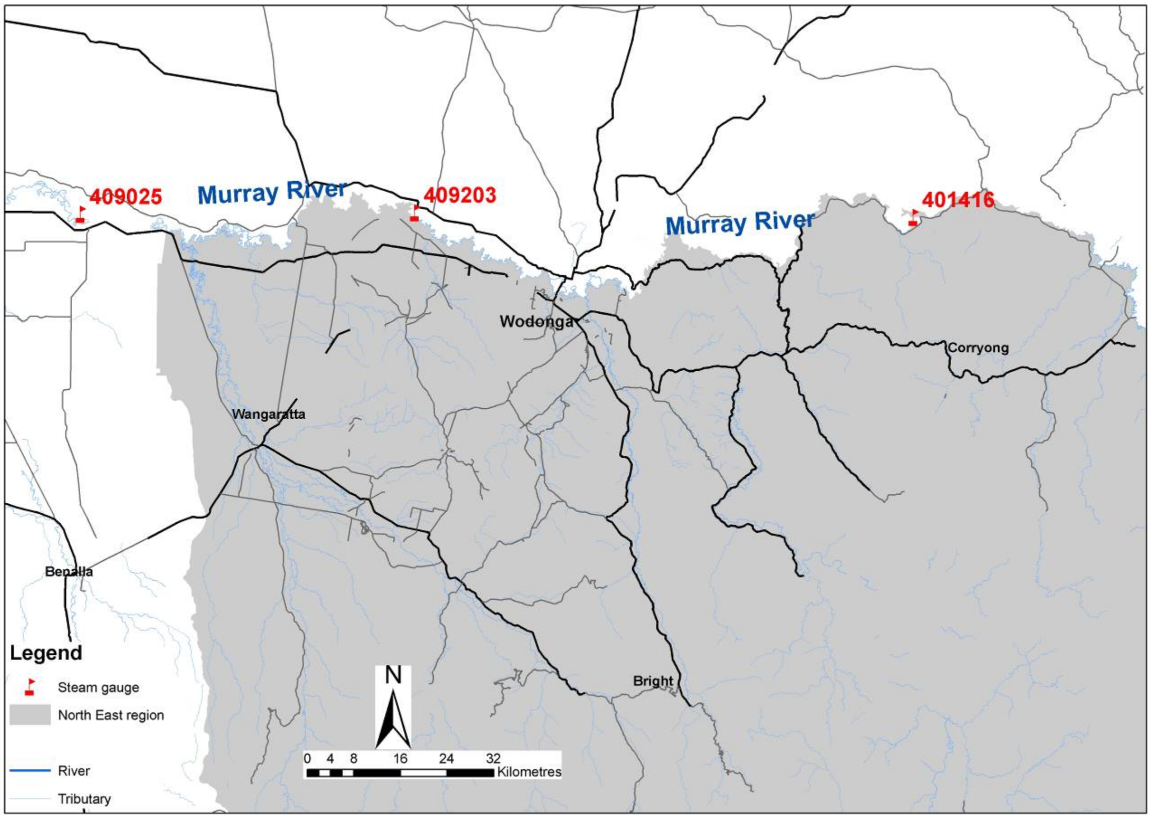


Figure 12 Location of stream gauges along the Murray River considered in the North East

Murray River @ Yarrawonga (gauge 409025)

At Yarrawonga, comparison of shallow aquifer water level (Shepparton Formation) and surface water levels shows free water levels remain relatively stable, whereas groundwater level fluctuate and trend independently confirming there is no groundwater – surface water interaction in the area.

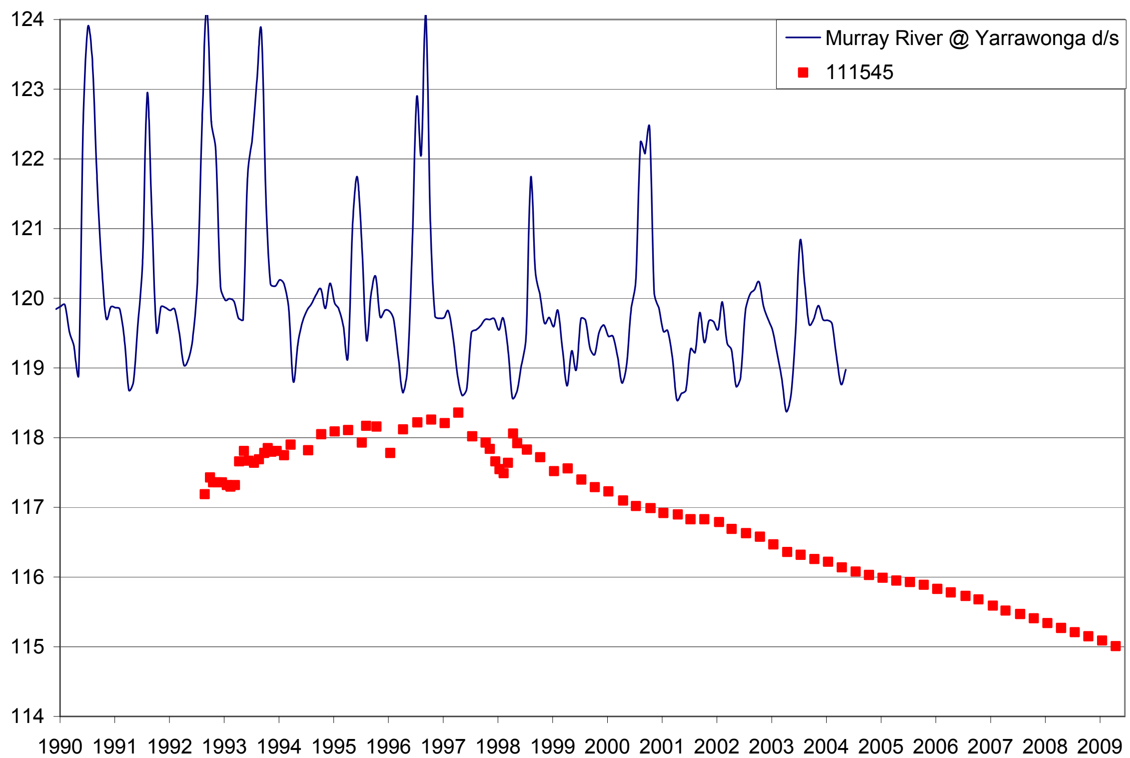


Figure 13 Groundwater levels versus river levels at Yarrawonga weir.

2.6.4 Groundwater usage

Within the North East CMA region groundwater is sourced via a number of aquifers in various locations, with most groundwater pumping occurring within the Ovens River Valley (Figure 14). Sixty per cent of the licensed groundwater pumping was considered to represent a reasonable estimation of mean annual groundwater pumping volume (source: GMW pers comm.[1]). Across the region 663 pumping wells, extracting a total of approximately 13 GL/year (60% of licensed) was considered representative for 2000 – 2001 (Table 2).

A groundwater pumping season was assumed to occur between November – April annually and was incorporated into the model groundwater pumping simulation on monthly intervals.

Table 2 Goulburn Murray Water mean annual pumping volumes

Aquifer	Mean annual volume (ML/year)
Shepparton Formation (upper & lower)	11 447
Palaeozoic basement	1 644
TOTAL	13 091

[1] Brendan Cossens, Water Resources Officer, Goulburn Murray Water, April 2008.

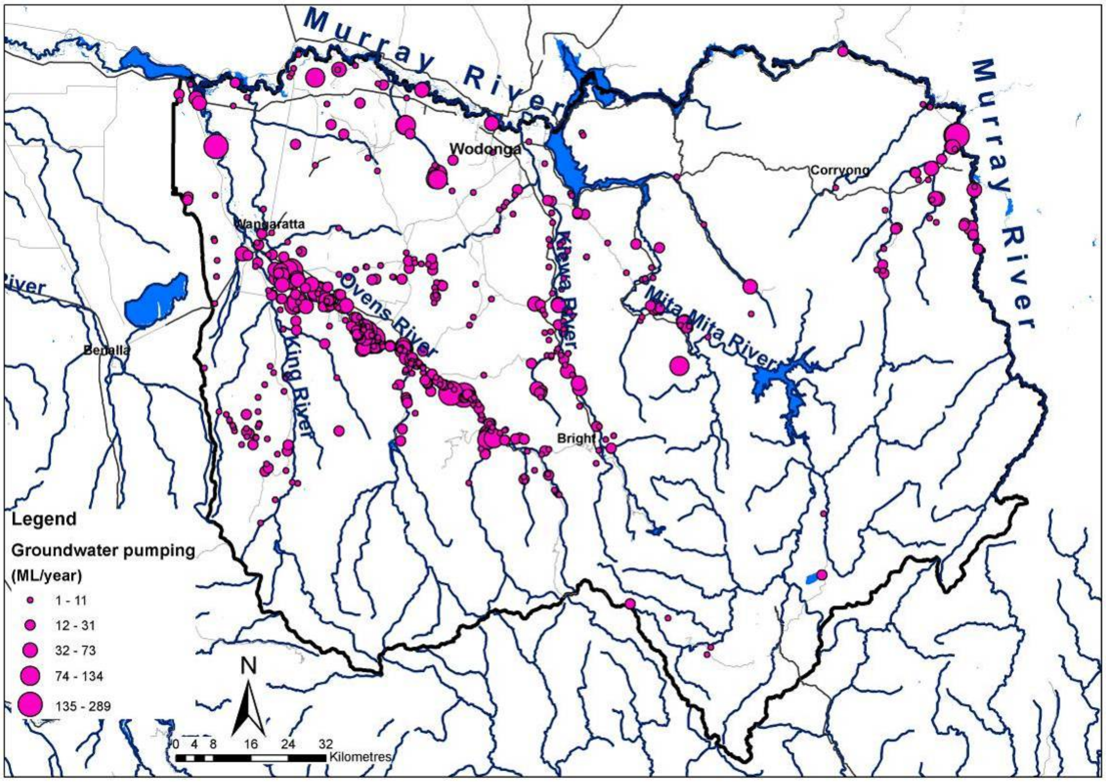


Figure 14 Groundwater pumping locations of the North East CMA region

2.6.5 Surface water bodies

A number of natural and artificially filled water bodies exist in the region. To date, there has been little quantification of any surface water and groundwater interactions at these locations. It is considered the magnitude of any interaction is insignificant relative to the scale and magnitude of the overall catchment water balance and is a fixed feature in the landscape.

Water features such as lakes and reservoirs are not enforced in the groundwater model. That is, a shallow watertable is not enforced in the groundwater model by setting fixed head conditions. Instead groundwater recharge was allocated by recharge as a function of land use (eg. lake, reservoir, wetland, etc.) was considered an adequate rate of lake/wetland leakage. Fixed heads boundaries can enforce an artificially high zone of shallow watertable expanding well beyond the extent of the water body, producing an unrealistic potentiometric surface and water balance at each location.

2.7 Geology and landscape evolution

The surface and subsurface geology of the North East is extremely diverse (Figure 16), ranging from the Palaeozoic meta-sediments and Devonian granites in the uplands through to recent geological formations of the Murray Basin along the Murray River.

2.7.1 Geology and hydrogeology

The hydrogeology of the region is summarised using a groundwater flow system context in an attempt to provide scale and detail relevant information within the scope of this report. For further information on the geology and hydrogeology of the North East CMA region refer to sources such as Douglas and Ferguson (1988), Heislers (1993) and area specific reports.

Groundwater systems in fractured rock aquifers

Most of the mid to upper catchments of the North East CMA region comprise local groundwater systems that function in fractured rock aquifers in the hilly or mountainous areas of the Great Dividing Ranges. They belong to the suite of consolidated Palaeozoic sedimentary and metamorphic rocks of the Lachlan Fold Belt in south-eastern Australia.

In some instances, the fractured rock aquifers comprise groundwater systems that are capable of sub-regional scale groundwater flow over 20 km or more. These occur where relief is low and where weathering is not intense. Groundwater flow systems in the high relief mountainous headwaters, however, favour much more localised flows at small scales. Here, groundwater typically migrates from steep sloping lands to the immediate valley floors and discharges as groundwater baseflow to streams. The timing of these localised high relief systems generally occurs intermittently and is not considered a perennial feature of the landscape.

On a broader scale, groundwater depth in the elevated parts of the landscape is considered to be deep (e.g. > 100 metres). The concept of a deep watertable in high parts of the landscape and shallower watertable in low parts of the landscape follows-on from Salama et al. (1996) and Salama, Hatton, and Dawes (1996). It is acknowledged local scale variations may contradict this generalisation, however any local scale watertable 'highs' are not considered representative of the regions groundwater conditions and would require detailed conceptualisation to represent this occurrence in the landscape. No published information suggests a contrary conceptualisation of groundwater in upland landscapes, however there is no published information which supports this conceptualisation either.

For the most part the fractured rock aquifers contain fresh groundwater that becomes brackish or moderately saline as both rainfall and relief decrease and the extent of rock weathering increases. Extensive weathering surfaces dating from early Tertiary times have been almost entirely removed during periods of uplift and erosion. Remnants of the weathering surface comprising saprolite and saline groundwater are, however, present in the Rutherglen area and along the eastern foot-slopes of the northern Warby Ranges. In several areas brackish or saline groundwater discharges from the fractured rock aquifers causing localised outbreaks of dryland salinity. Notable examples occur in weathered rocks at Rutherglen, and in less weathered rocks at Everton in the southeast Ovens catchment. Similar salinity issues are also apparent at the break-of-slope in the metamorphic aureole that defines the western sector of the Indigo Valley.

Figure 15 Saline groundwater discharging from fractured rock at Everton

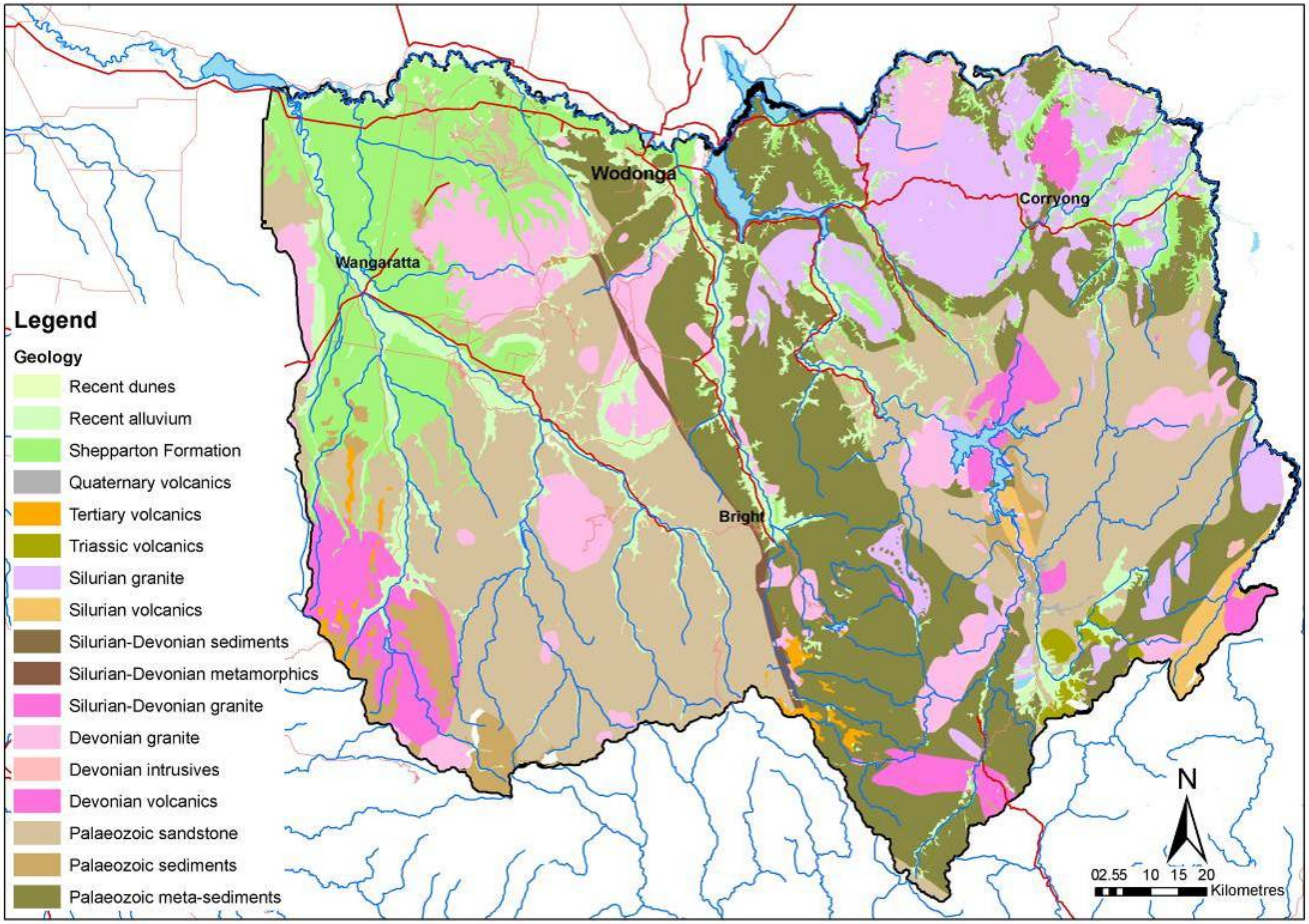


Figure 16 Surface geology of the North East CMA region

Groundwater systems in granitic rocks

Smaller localised groundwater systems also function within the coarser-grained colluvium and alluvium that forms as fans on the slopes in the valley floors of granites and coarse-grained metamorphic rocks. The scale of groundwater flow is generally quite small. In most instances flow is simply from steeper sloping lands to the adjacent valley floors, with limited down valley transfers.

The salinity of the groundwater in granitic terrain, in common with the fractured rock aquifers, is a function of rainfall, weathering and relief. Total dissolved salt concentration tends to be in the low to brackish range and generally less than 3 000 mg/l. This is sufficient to cause significant saline seeps to occur in and around spring zones that occur along breaks of slope.

Saline seeps are common within the granitic terrain comprising the eastern sector of the Indigo Valley and within the coarse-grained metamorphic rocks that form the Lady William Ranges east of the Hume Highway.

Regional groundwater systems in the Riverine Plains

The larger groundwater systems that have value as a groundwater resource occur within the alluvium of the Riverine Plains and within the larger floodplains along the upland rivers. The most significant aquifers occur in the Ovens and King valleys within alluvial plains that extend from the Murray River south to the region of Greta, and from the Warby Ranges in the west to Springhurst and Everton in the east.

The down-faulted block known geologically as the Ovens graben defines the Ovens Valley. The bedrock trough established by this structure is in-filled with unconsolidated Quaternary sediments of the Shepparton Formation, and the basal sands and gravels of the Tertiary Calivil Formation. Together the two unconformably overlie semi-consolidated Permian sediments.

Whilst the Calivil Formation deep lead is the main regional aquifer shoe-string sand deposits are inter-bedded with clays in the overlying Shepparton Formation and are also exploited for groundwater. North of Wangaratta the stratigraphic sequence appears to be a classical Shepparton Formation overlying a basal deep lead Calivil Formation. South of Wangaratta high-energy streams coming from the mountainous region to the immediate south have deposited a repetitious poorly sorted sequence of coarser-grained sediments comprising inter-bedded sands and gravels that in some areas extend from the land surface to bedrock.

In the plains north of Wangaratta the Shepparton Formation is typically 100m thick in the central parts of the Ovens Valley. In contrast the underlying deep lead (Calivil Formation) ranges in thickness from 10m through to about 30m.

Most groundwater recharge to the Ovens deep lead occurs south of Wangaratta through the alluvial fans comprising the coarse-grained sediments along the highland front. The rivers are bound to contribute to recharge where they pass across this geomorphic unit. Upon passing beyond the highland front into the Ovens floodplains passes beyond Wangaratta and continues to flow northward beneath the Murray River into the Deniliquin area of NSW. Groundwater also flows from NSW in a south-westerly direction into the Katunga Water Supply Protection Area of the Goulburn-Broken catchment (Macumber pers. comm[2]).

---

[2] Phillip Macumber, Phillip Macumber Consulting Services, April 2008

2.8 Hydrogeology

The main aquifers of the North East CMA region are summarised as;

- Shepparton Formation - alluvial sediments with significant textural variation both spatially and vertically. Permeability ranges from low to high.
- Calivil Formation - moderate permeability aquifer restricted to the ancestral tributaries of the Murray Plains.
- Palaeozoic meta-sediments - fractured rock aquifers in fresh rock with variable permeability depending on the density of fracturing.

There are no well defined aquitards in the region; however there is evidence of confining layers between the upper and lower Shepparton Formation water bearing zones, and also between the Calivil Formation and parts of the Shepparton Formation.

2.9 Hydrogeological conceptual models

A number of differing hydrogeolgical conceptualisations for the North East CMA region was considered in the development of the steady state model before the accepted conceptual model was selected. This particularly relates to the conceptualisation of groundwater movement in the Palaeozoic basement aquifer. The following conceptualisations were attempted (Table 3), where it became evident that unless either vast tracts of artesian heads or dry cells were acceptable, the depth to watertable in the uplands were required to be deep (eg.>100m) for model stability.

Table 3 Hydrogeological conceptualisations considered

Conceptualisation for basement	Reason why not used
Constant transmissivity between 1-100 m^2/day	Tight model convergence, but scaled RMS of > 5% could not be achieved
Smoothed basement thickness between 50-200 metres and ≈0.5 m/day hydraulic conductivity plus ADDITIONAL 20 metre thickness <0.5 m/day hydraulic conductivity layer (e.g. 7 layer model)	Good model convergence, no DRY cells but scaled RMS >5%,
Smoothed basement thickness between 50-200 metres and a low transmissivity layer (e.g. 7 layer model)	Good model convergence, no DRY cells but scaled RMS >5%,

2.10 Proposed layering system

2.10.1 Model layers

The North East CMA model attempts to simulate groundwater movement within each of the principal aquifers of the region. The following model layers and geology groups have been aligned in a six-layer framework (Table 4).

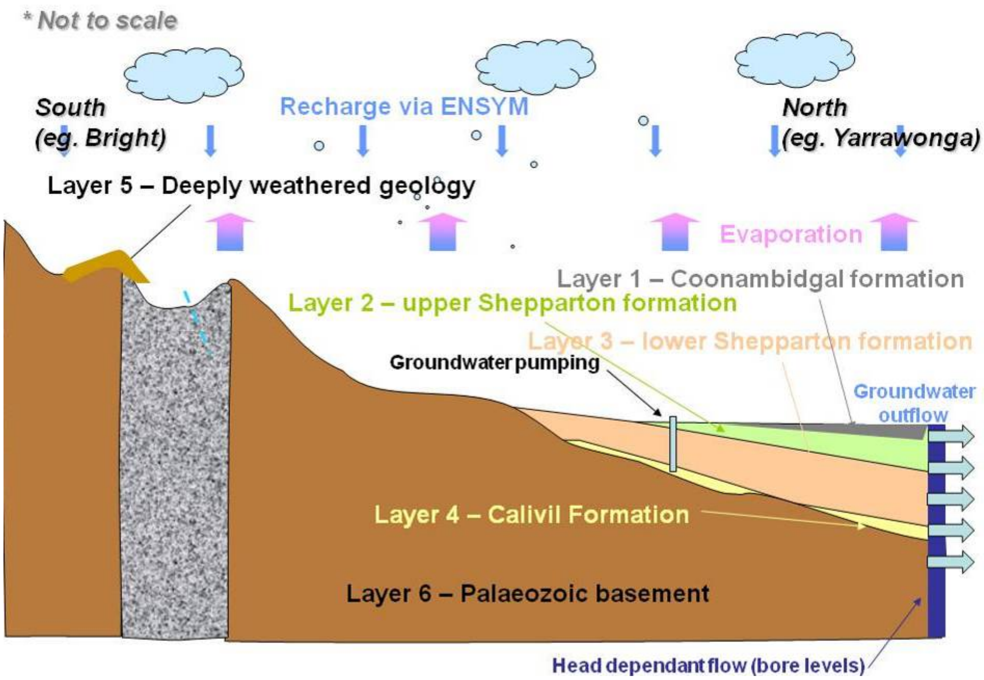
Table 4 Model layers and associated geology groups

Model layer	Geology group
Layer 1 – Coonambidgal Formation	Coonambidgal Formation (Recent – Quaternary sediments)
Layer 2 – upper Shepparton Formation	Shepparton Formation thickness up to 35m thick
Layer 3 – lower Shepparton Formation	Shepparton Formation where entire Shepparton Formation thickness is greater than 35m.
Layer 4 – Calivil Formation	Calivil Formation
Layer 5 – Deeply weathered geology	White Hills gravel / Deeply Weathered & Deeply weathered Granite GFS mapping units
Layer 6 – Palaeozoic basement	Palaeozoic metasediments, Silurian - Devonian granite

2.11 Schematic conceptual model

A schematic conceptual understanding of the water balance and hydrogeology within the North East CMA region is presented in Figure 17. The important water balance features considered within the model include:

- groundwater recharge
- groundwater inflow and outflow
- groundwater abstraction
- groundwater evaporation
- groundwater – surface water interaction



*Note: Layer structure does not illustrate the minimum thickness approach used

Figure 17 Conceptualisation of hydrogeology and model layers

It is beyond the scope of this modelling project to document the variety of previous hydrogeological pump test investigations in the region. Table 5 present ranges and mean of hydraulic conductivity values of model layers, this information will be used as a guide to reasonable ranges of hydraulic conductivity during model calibration. Much information complied below is sourced from Heislers (1989) or literature cited within and should be sought if further detail is required. Note there are no generalised estimates of transmissivity in the region considered relevant for model comparison.

Table 5 Hydraulic conductivity ranges of model layers

Model layer	Hydraulic conductivity range (m/day)	Mean hydraulic conductivity (m/day)
Layer 1 (Coonambidgal Formation)	0.5 - 1	0.7
Layer 2 (upper Shepparton Formation)	0.5 - 3	1.5
Layer 3 (lower Shepparton Formation)	1 – 100	12
Layer 4 (Calivil Formation)	5 - 100	30
Layer 5 (Deeply weathered geology)	0.1 – 0.5	0.2
Layer 6 (Palaeozoic basement)	0.2 – 1.5	0.8

Appendix 2 presents data sources and extents of individual model layers.

3 Numerical model design

3.1 Groundwater modelling software

Groundwater flow through the North East CMA region was simulated using MODFLOW-96, a widely used modular finite-difference groundwater flow code written by USGS k This code was selected because of;

- its documented capabilities to simulate regional scale groundwater processes,
- its documentation and wide use (McDonald and Harbaugh, 1998; Anderson and Woessner, 1992),
- the availability of a number of third-party pre- and post-processors,
- its easily available public domain software.

This model was developed and run on a Hewlett Packard ProLiant ML350 with an Intel Xeon 2.50 GHz processors with 24.0 GB of RAM running Windows XP 64 bit software.

All model development was undertaken by Mark Hocking of Hocking et. al. MODFLOW used in this exercise has been benchmarked with MODFLOW96 provided by DSE.

3.2 Groundwater model complexity

The complexity of the North East CMA groundwater model is consistent with the 'Impact Assessment' class described in MDBC (2000). It has moderate complexity and is suitable for predicting the impacts of proposed developments or management policies.

The model has been developed in finite difference format (regular gridding). It features a cell size of 200m, totalling 496 214 solution points occupying 769 rows and 932 columns, and comprises of six layers and 2 977 284 active cells.

3.3 Boundary conditions and spatial extent

The groundwater model has been developed with time varying head dependant flow boundary conditions (third type) to simulate lateral groundwater outflow to the north and north-west. Investigation of data for groundwater interaction with the Murray River suggests no connection with the Murray River (previously discussed).

The spatial extent of the North East CMA region model aligns with the CMA extent. The Murray River has been specified as the northern model boundary for the purposes of this exercise. In most instances more than 600m of native vegetation buffers the Murray River from agriculture land. For the purposes of this project, the Murray River was considered an adequate flow boundary feature for the scale and underlying assumptions of this project.

3.4 Model layers and parameterisation

The layered approach for model layers has been used (Figure 18). The layered approach uses a minimum thickness of 5 meters. In locations where a model layer is not present, a minimum thickness of 5 metres and aquifer attributes of the next active layer at the location is used. The thickness of the next active layer is 5 metres less than the total thickness (or more if more than one layer not present). Likewise, hydraulic conductivity and storage is assigned from the underlying active layer and the Vcont is set to 1 (e.g.

fully connected to underlying active layer). Figure 18 presents the layered approach for model layers graphically.

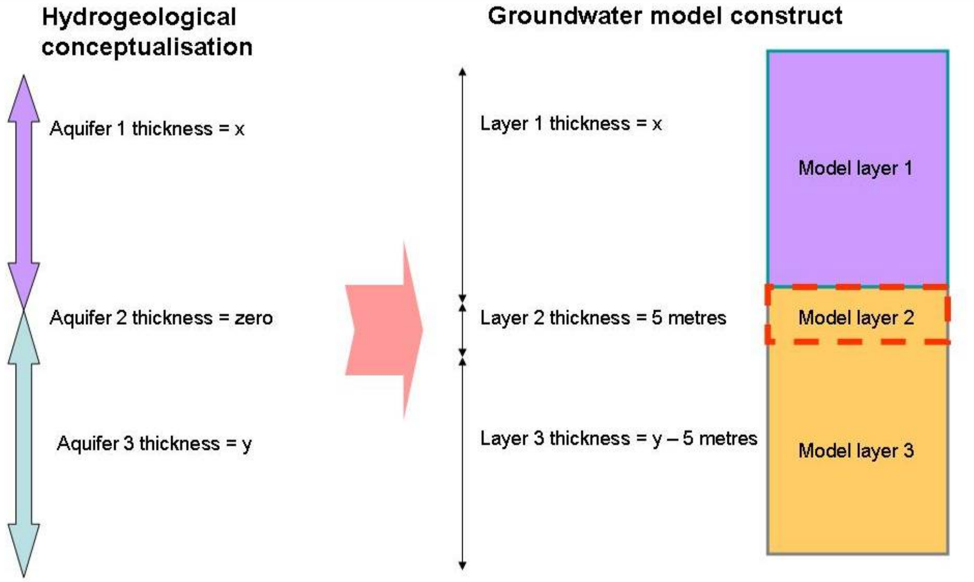


Figure 18 Layered model build method

3.4.1 Layer 1 (Coonambidgal Formation)

Model layer 1 represents the uppermost aquifer for the alluvial plains of the model domain and is unconfined throughout (Figure 19). No lateral flow boundary conditions were allocated to the model layer. Instead, as the aquifer is localised river stage heights were considered a reasonable representation of water movement through the aquifer.

3.4.2 Layer 2 (upper Shepparton Formation)

The extent of model layer 2 is attributed as confined/unconfined (Figure 20). Time varying groundwater level head dependent flow (GHBs) were specified on the northern boundary cells of the model.

3.4.3 Layer 3 (lower Shepparton Formation)

Model layer 3 is attributed as confined/unconfined (Figure 21). Time varying groundwater level defines head dependent flow (GHB) on boundary cells of the model.

3.4.4 Layer 4 (Calivil Formation)

Model layer 4 is attributed as confined/unconfined throughout (Figure 22). Time varying head dependent flow boundary conditions (GHB) were defined on the northern model extent based upon groundwater observation bore levels.

3.4.5 Layer 5 (Deeply weathered geology)

Model layer 7 is attributed as confined/unconfined throughout the model domain with no flow boundary conditions (Figure 23).

3.4.6 Layer 6 (Palaeozoic geology)

Model layer 6 is attributed as confined/unconfined with time varying head dependent flow boundaries based upon groundwater observation bore levels (GHB) (Figure 24).

3.4.7 Unconfined layer extents

Uppermost active model layers are presented in Figure 25.

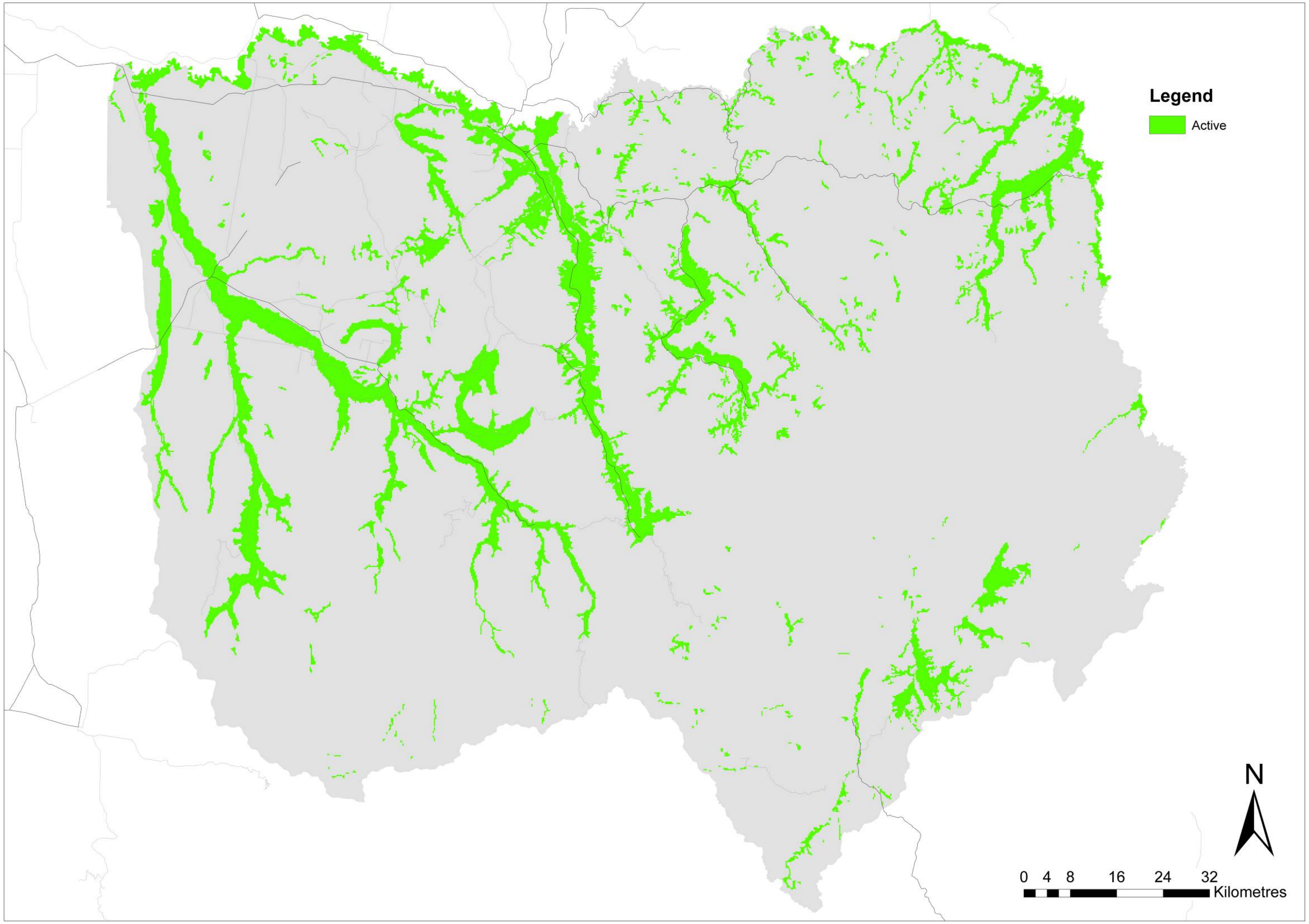


Figure 19 Layer 1 extent and boundary conditions

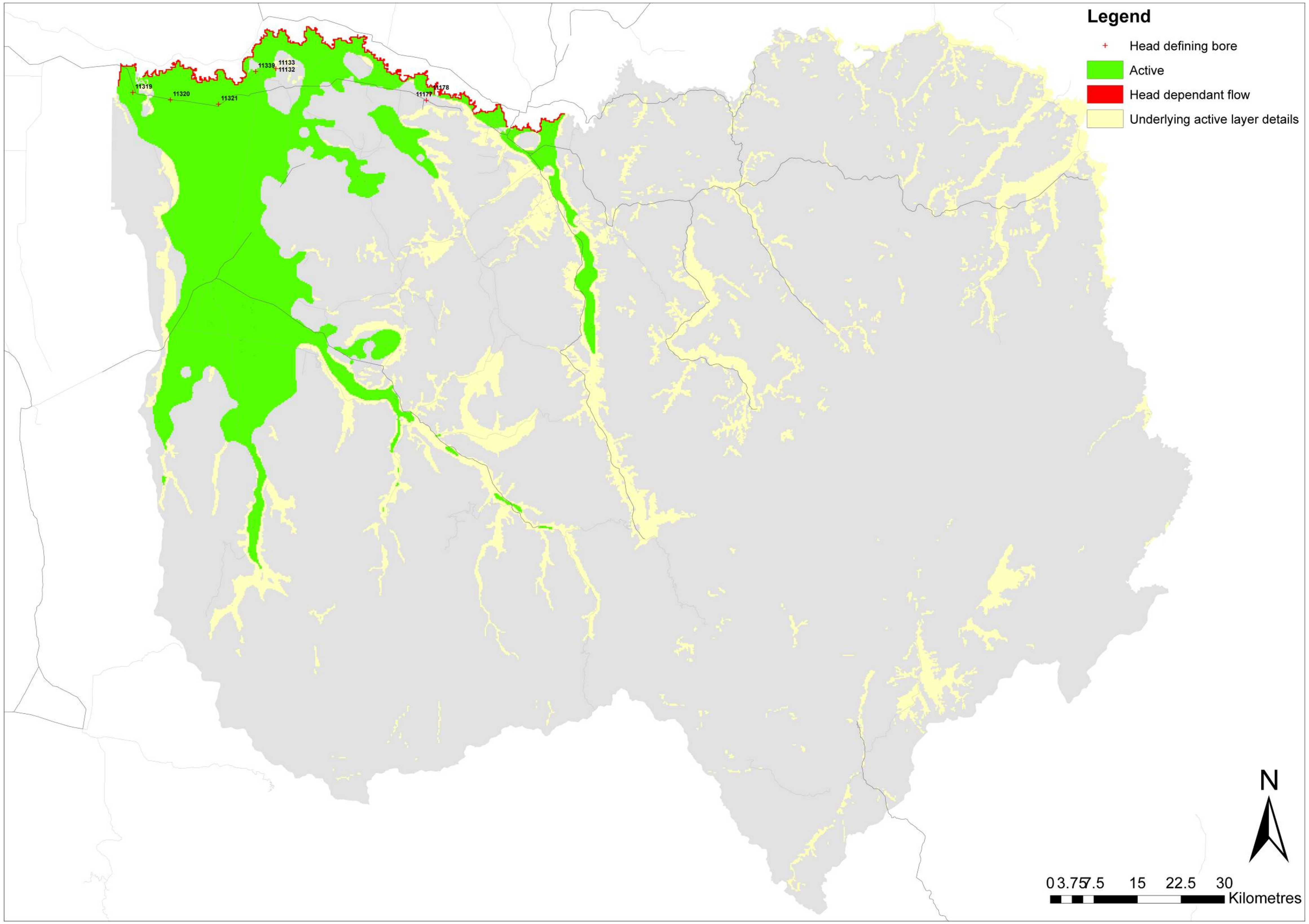


Figure 20 Layer 2 extent and boundary conditions

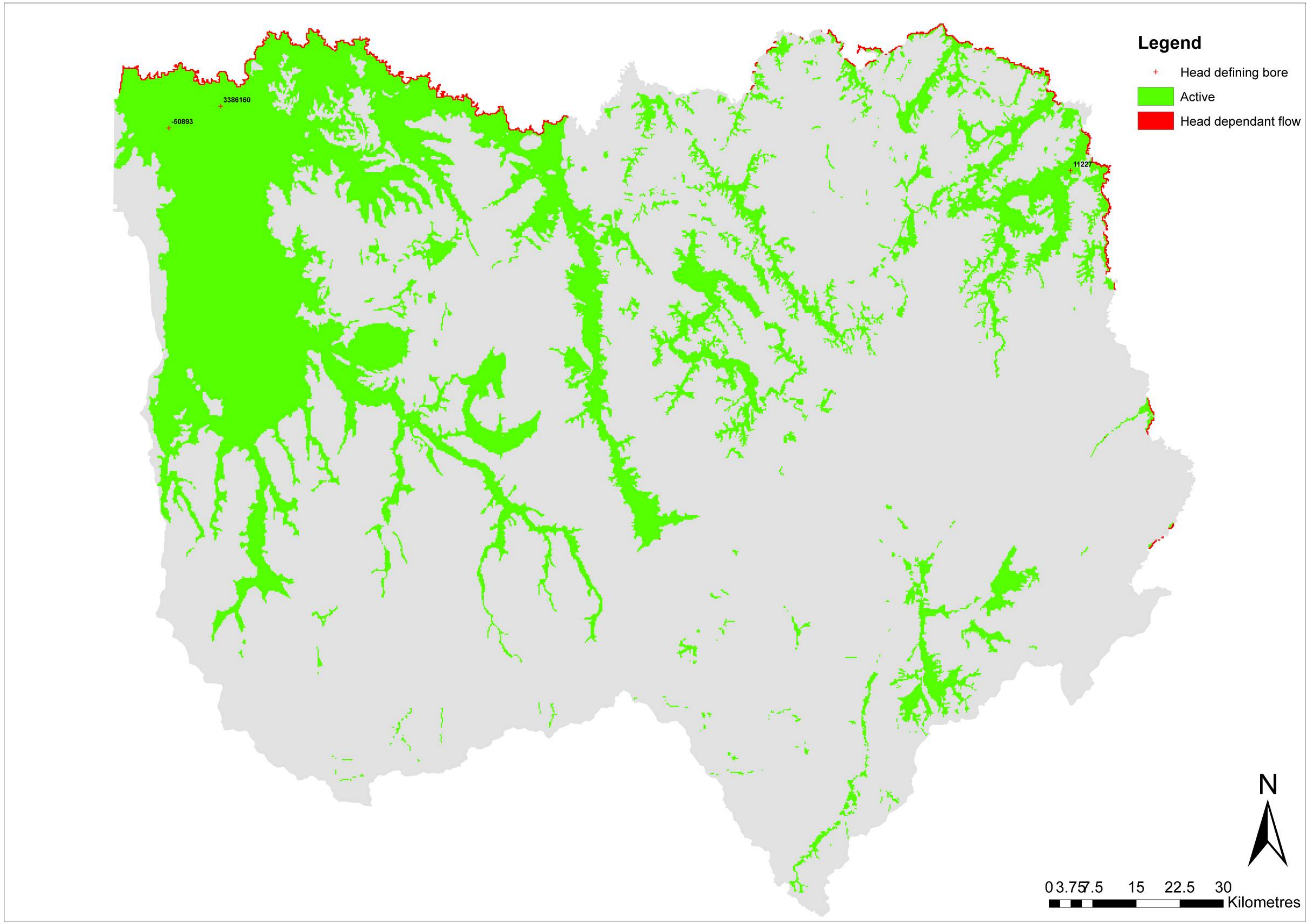


Figure 21 Layer 3 extent and boundary conditions

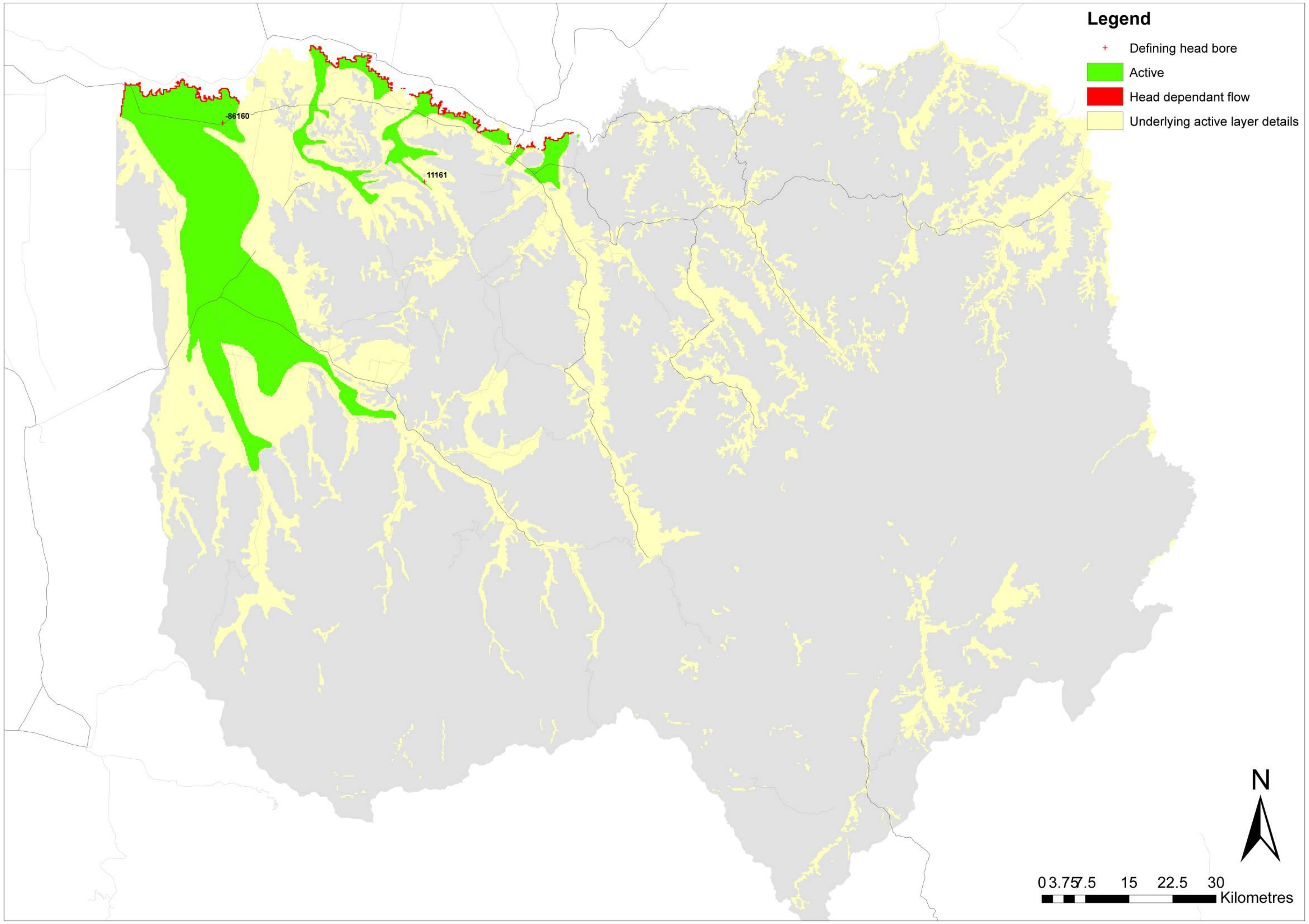


Figure 22 Layer 4 extent and boundary conditions

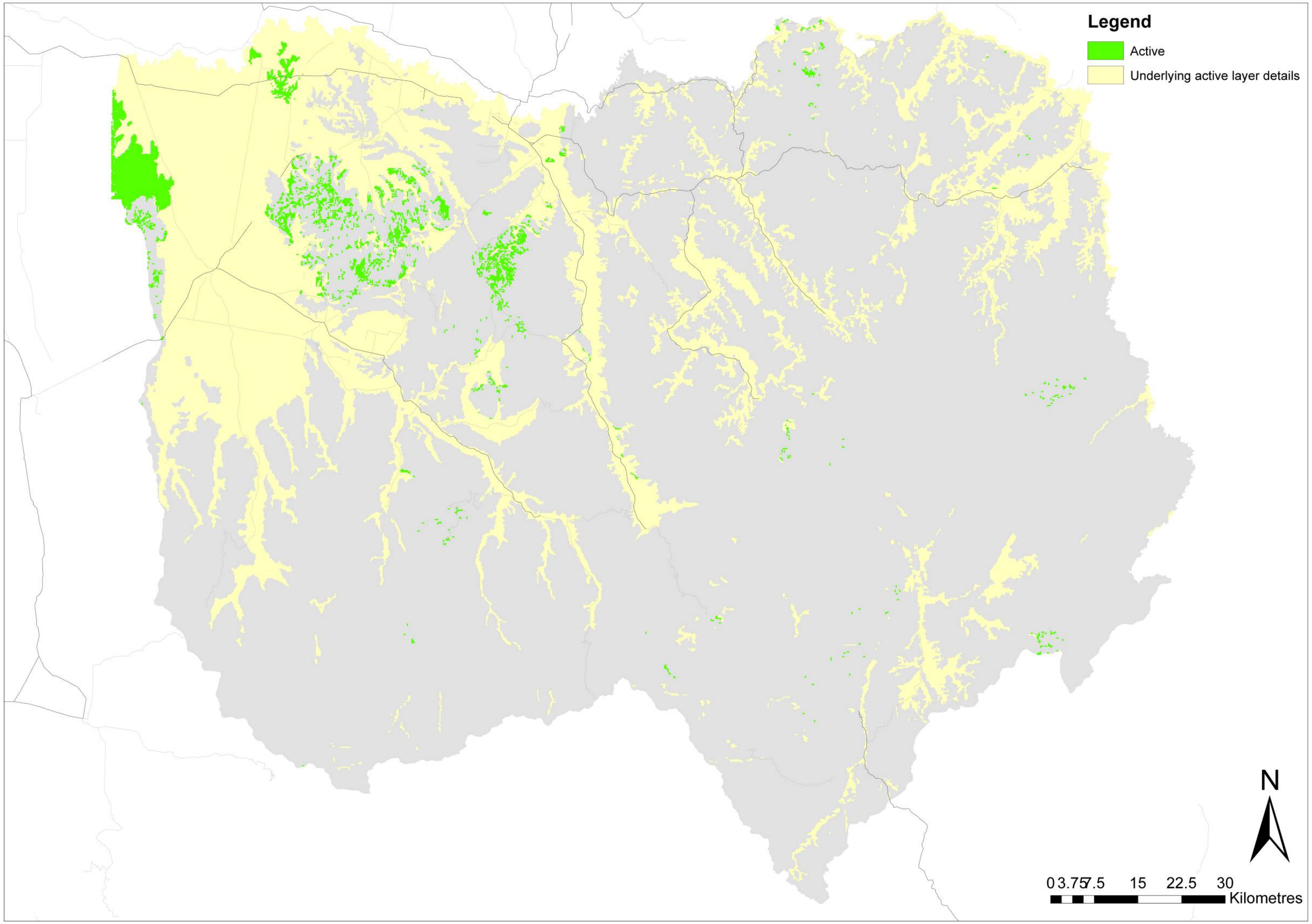


Figure 23 Layer 5 extent and no boundary conditions

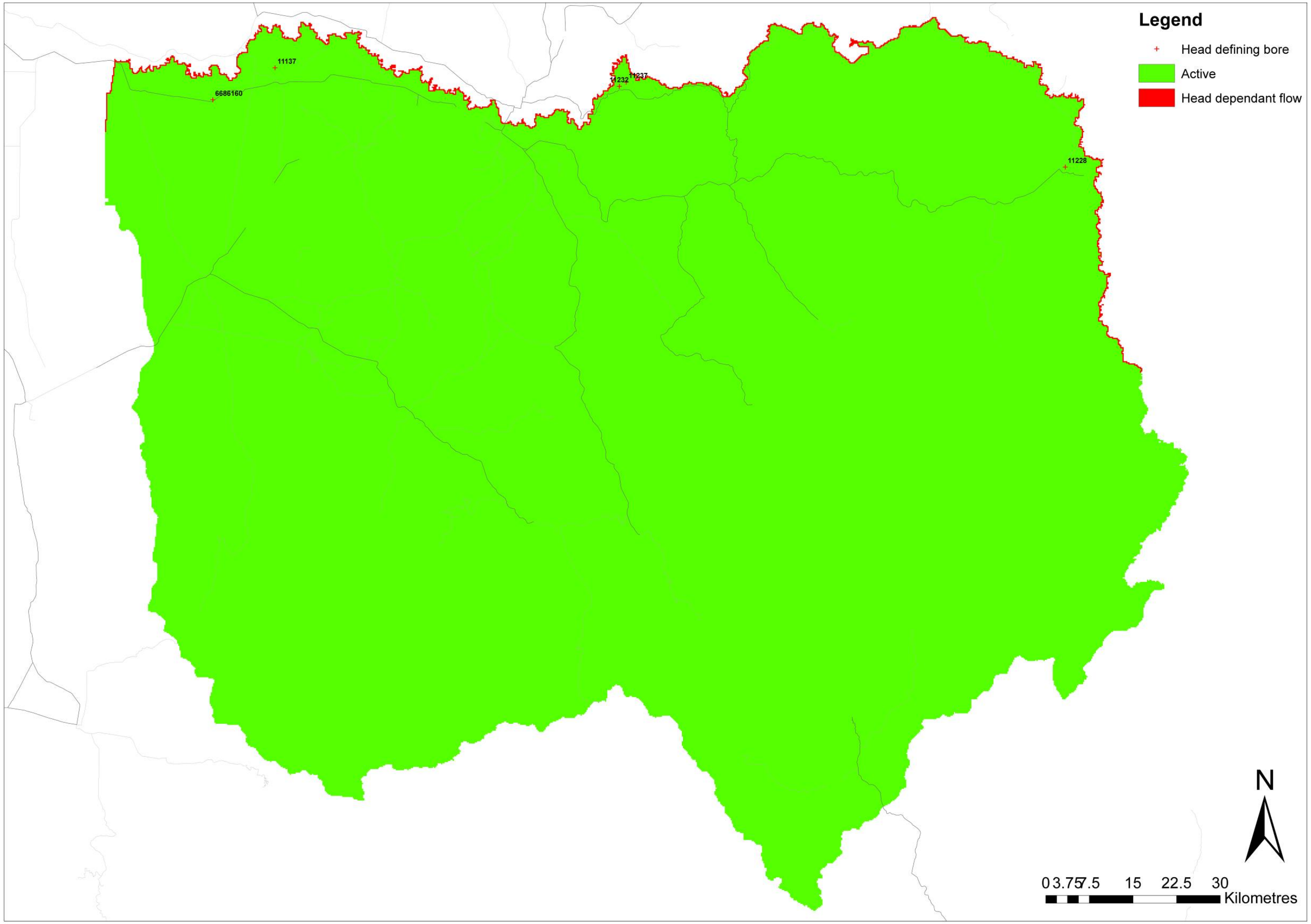


Figure 24 Layer 6 extent and boundary conditions

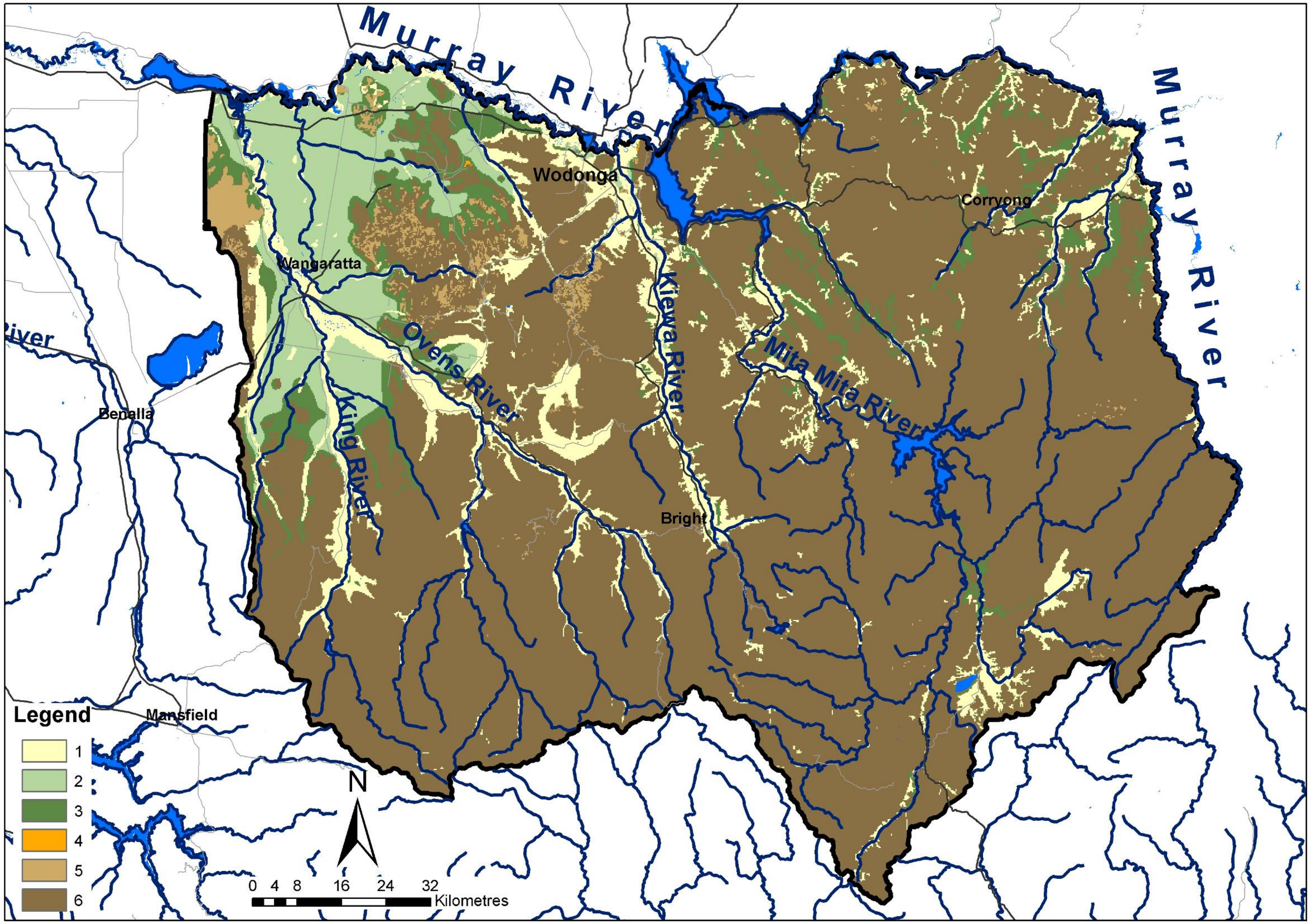


Figure 25 Uppermost active model layers

3.5 Model recharge and discharge features

The following section describes the input and output features of the groundwater model in the North East CMA region.

3.5.1 Groundwater abstraction

Described previously, the annual licensed volume of each groundwater pumping bore was supplied by Goulburn-Murray Water, where 60% of the licensed annual abstraction volume was extracted over between November and April (Figure 26).

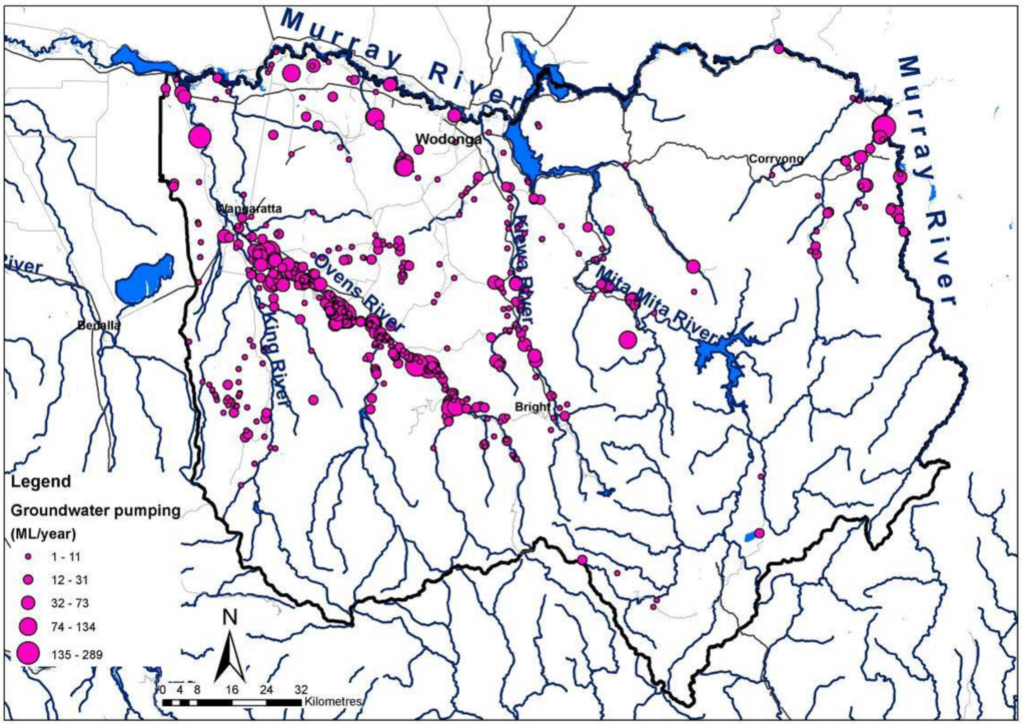


Figure 26 Groundwater abstraction locations and volumes

3.5.2 River features

Three hydrological settings were considered in accounting for surface water and groundwater interactions. These are (a) average river width (b) the depth of incision below the natural surface and (c) an estimate of the depth of water in the river. The classification was limited by the attribution assigned to the 1:25 000 hydrology network on the DSE geospatial database. Hydrology varies between gaining and losing streams. Table 6 summarises the generalised properties from each stream 'type' considered in the model.

Table 6 Groundwater-surface water dynamics settings

	Average river width (m)	Incised river bed depth below surface (m)	River stage (m) above river bed
Major waterway	20	7	0
Tributary	5	2	0

3.5.3 Drainage

Drainage was allocated over the entire model domain (e.g. every uppermost active cell). Drainage elevation was set at ground surface, with a uniform calibratable conductivity rate (presented in Appendix 3). This ensured any artesian water (e.g. above ground surface) was removed from the groundwater model and rerouted for baseflow accounting.

3.5.4 Surface water bodies

Water features such as lakes and reservoirs were not enforced in the groundwater model. That is, a shallow watertable was not enforced by setting fixed head conditions. Rather, it was considered (but not endorsed by DSE) recharge rates supplied by Ensym were sufficient to raise groundwater levels in the vicinity of water bodies.

3.5.5 DSE supplied recharge

Spatially and time varying simulated groundwater recharge was supplied between 1990 to 2005 by DSE. Spatially varying groundwater recharge was provided from the Ensym modelling and was set as a non-calibration parameter as required by DSE.

3.5.6 Evaporation

Spatially and time varying groundwater evapotranspiration data between 1990 to 2005 was used. Steady-state model groundwater evaporation depth and rates were applied to the transient model. Evaporation rate and depth were used as calibratable features (unlike in the steady state phase).

3.5.7 Irrigation

No irrigation was applied to the groundwater model. Irrigated land use was accounted for as recharge supplied by DSE.

3.6 Model time frames

This transient groundwater model was calibrated over a 10 year period between 1st January 1990 to 31st December 1999, with a 5 year validation period between 1st January 2000 to 31st December 2005.

3.6.1 Stress periods

A constant stress period of 30.4 days was applied to the groundwater model throughout the duration of the model. The stress period duration was based upon available calibration data (eg. most bores are monitored monthly, at best), computational power (eg. size of files were becoming excessively large) and project objectives (eg. DSE determined).

3.6.2 BAS summary

Table 7 summaries the information used in the transient Basic (BAS) package.

Table 7 Summary of Basic package

Size of first time-step	30.4
Number of time steps	3
Time step multiplier	1.2
Starting heads	Modified from steady state head file

3.6.3 Solver and tolerance

The SIP (Strongly Implicit Procedure) solver (Stone, 1968) was used as the MODFLOW solver. The SIP is an accepted algorithm for solving a sparse linear system of equations and was found to converge relatively fast.

A solver tolerance of 0.1 m was set, which was considered appropriate for the scale and underlying assumptions for this modelling exercise.

3.7 Assumptions and limitations

All numerical groundwater flow models have limitations. These limitations are usually associated with

- The extent of the hydrogeological understanding of the aquifer,
- Availability and accuracy of input data,
- Assumptions and simplifications used in developing the numerical model.

These limitations determine the spatial and temporal variation of uncertainties in the model, as calibration uncertainty generally decreases with increased availability of input data.

Specifically, the following assumptions have been made in developing the North East CMA region groundwater model:

- a strongly implicit procedure solver tolerance of 0.10 m adequately addresses the scale objectives of the project
- all aquifers and model layers are considered vertically uniform
- there is limited dual porosity (eg. equivalent porous medium flow system)
- groundwater concentration gradients have negligible impact on head pressures
- bores used in the model are representative of all modelled aquifers in the region
- bores used in the model have correct aquifers attributed
- the digital elevation model (DEM) has adequate vertical resolution to allow reasonable calibration of the model and represents the land surface topology over the entire domain.

These assumptions provide a foundation for the development of the model; while there is always some level of uncertainty the best *available* data has been used to limit associated errors.

It is likely that in some areas detailed hydrogeological processes have not been fully captured in the conceptualisation because further sub-catchment investigations would be required to achieve this end.

3.8 Model calibration targets

Model calibration was undertaken by automated and manual methods to ensure aquifer parameters and calibration targets remain within acceptable ranges. Specifically, the primary calibration targets were;

- Observed versus simulated groundwater level,
- Depth to watertable of the region, and
- Groundwater baseflow volume.

4 Steady-state model summary

The first stage of the Ecomarkets project (prior to this the second stage) was to develop and calibrate a steady state groundwater model of the North East (Hocking et al. 2010). The steady state model calibration was developed first to facilitate easier calibration because some parameters, such as aquifer storage and water level variations over time, do not need to be taken into consideration and secondly as a proof of concept.

Summary results for the steady state simulation are presented below and address all calibration targets as required for the steady state solution. The calibrated MODFLOW model for the region produced the following water balance (Figure 27). Steady-state model calibration was achieved by considering observed groundwater levels (Figure 28 & Table 8), groundwater outflow and river baseflow estimates for 2000, where 2000 was considered as an 'average' and 'representative' year for steady state simulation.

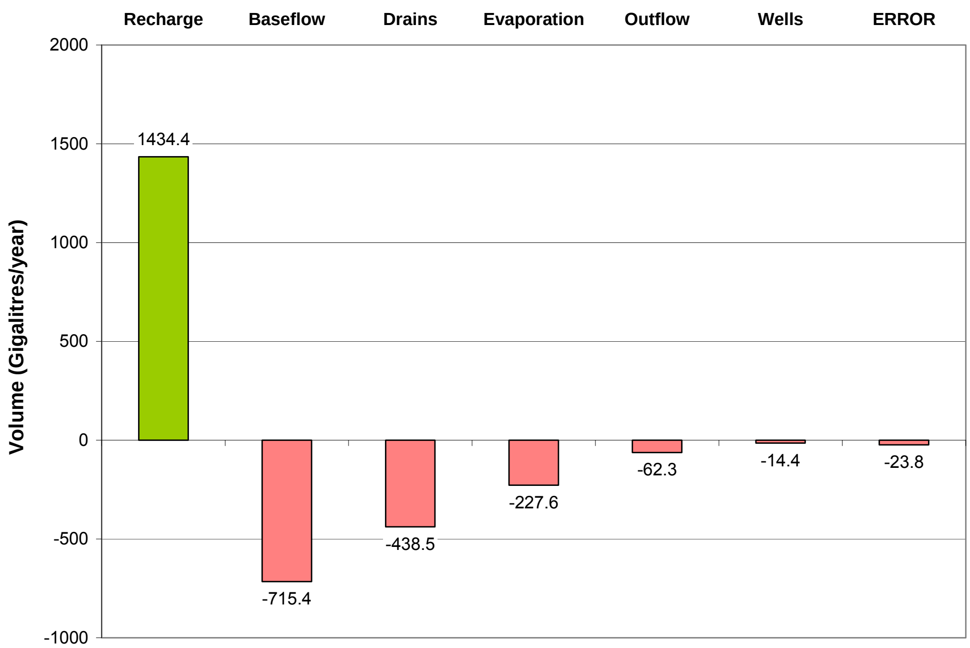


Figure 27 Calibration steady state water balance

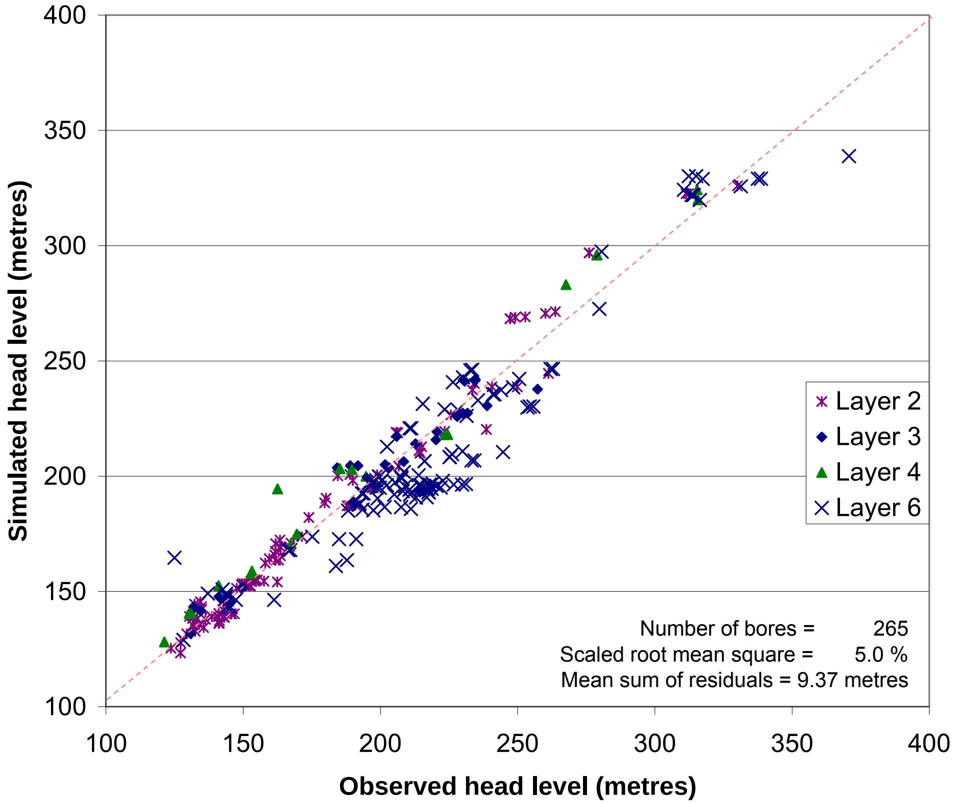


Figure 28 Simulated versus observed scatted plot

Table 8 Descriptive statistics of simulated versus observed

Statistic	Value
Number	265
Maximum residual	34.6m
Minimum residual	-39.7m
Average residual	1.5m
Median residual	-0.2m
Mean sum of residuals	9.37m
Scaled mean sum of residuals	3.76 %
Root mean square	12.47m
Scale root mean square (RMS)	5.00 %
Coefficient of determination (r^2)	0.91

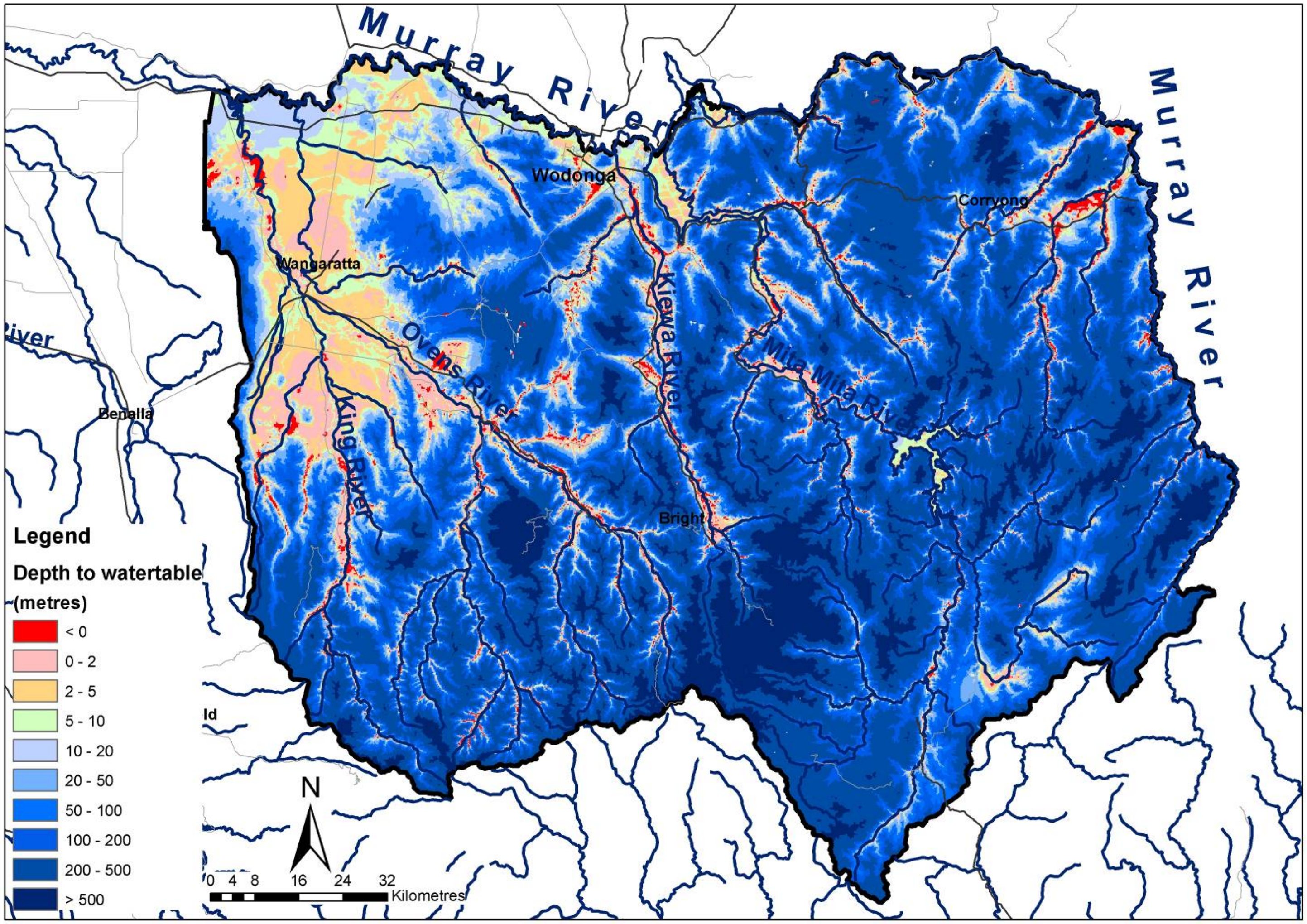


Figure 29 Steady state depth to watertable map

Steady state simulated depth to watertable (Figure 29) was considered to be a reasonable approximation of the depth to watertable.

5 Transient model solution and calibration

Following calibration of the steady-state model, the model was then calibrated to simulate transient conditions during the period 1990 to 1999. Transient model calibration was achieved by considering observed groundwater levels and depth to watertable (visual analysis), the results of which are discussed in the following sections. Model calibration was undertaken using automated and manual techniques. Individual calibrated model layer attributes are presented in Appendix 4.

5.1 Observed groundwater level

Comparison of simulated with observed groundwater level for each model layer was undertaken over time. To ensure the selection of bores wasn't bias, all available groundwater observation bores were considered in the statistical analysis.

The comparison of calibration with simulation data was undertaken for 1st January 2000. The first observation point after 1st January 2000 was selected, with the nearest simulation record, if no observation data was available less than two years after the comparison period no comparison measure was made.

Frequency distribution of observed versus simulated error between 1900 - 2005 (Figure 30) shows the highest density of data to sit near the zero value. This result suggests a normalised frequency distribution albeit slightly positively skewed during the calibration and validation period.

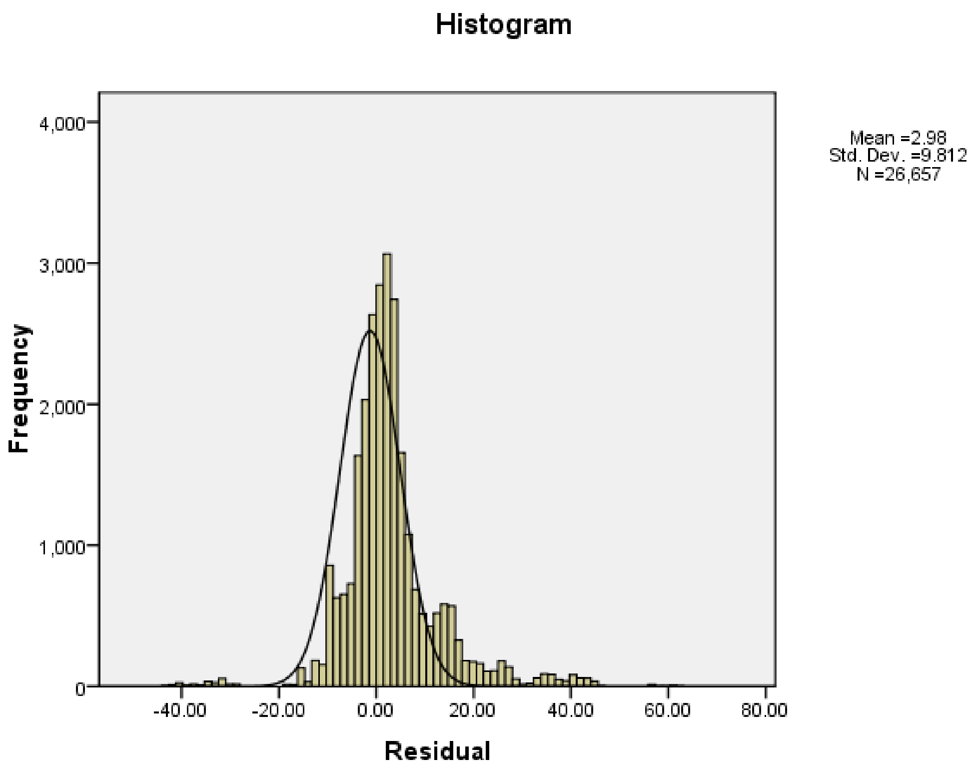


Figure 30 Frequency of observed minus simulated water level data between 1990 - 2005

One DSE project objective relates to simulating change in shallow watertable level, for this reason calibration plots relative to depth to watertable were presented. This information provides a good indication of the likely accuracy of the groundwater model to simulate depth to watertable.

A total of 442 groundwater observation bores were selected for calibration (all in catchment) for calibration (excluding the 18 GHB bores). However, 334 were used for statistical analysis as the remainder identified the monitored layer as being either inactive or dry at these locations, or had less than three data points over the analysis period.

Time-series calibration plots are presented in Appendix 8. Figure 31 presents the scaled RMS and mean absolute residual 1990 to 1999. Results show the scale RMS over time remains below 3% and mean absolute residual generally remains below 9m.

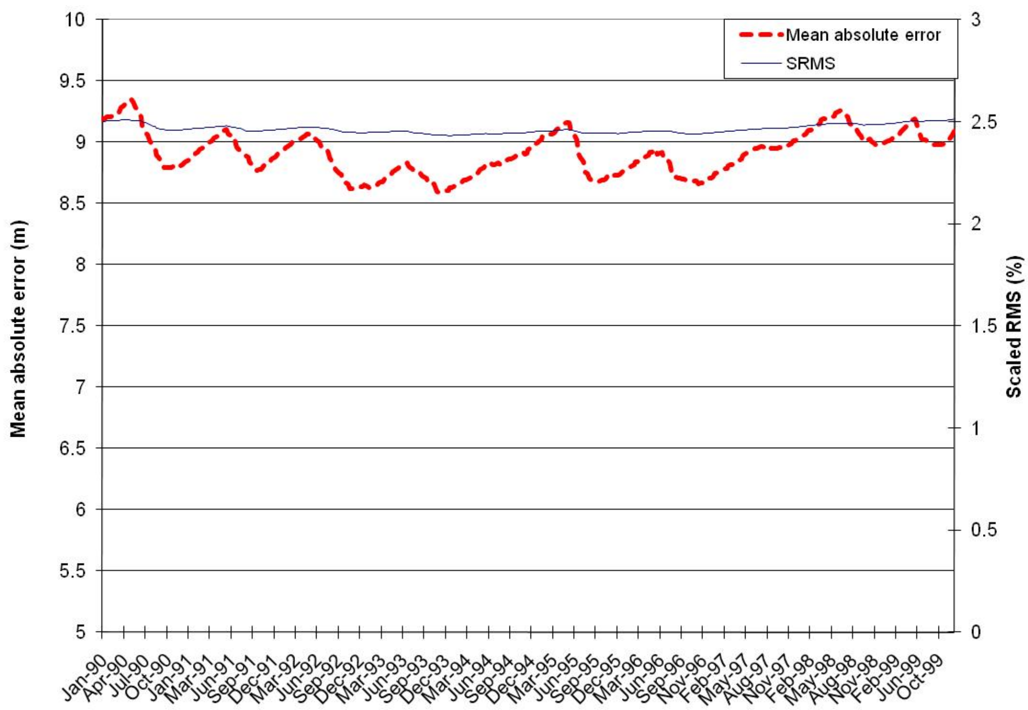


Figure 31 Calibrated scaled RMS and mean absolute error over time

5.2 Groundwater abstraction

Comparison of assigned versus simulated groundwater pumping volume was undertaken. Figure 32 presents the cumulative assigned versus simulated groundwater pumping volumes over the calibration period, results show over the 10 year calibration period there is a deficiency of 25 GL (≈2.5 GL/year). The volume deficiency is not ideal, and well optimisation would resolve this issue.

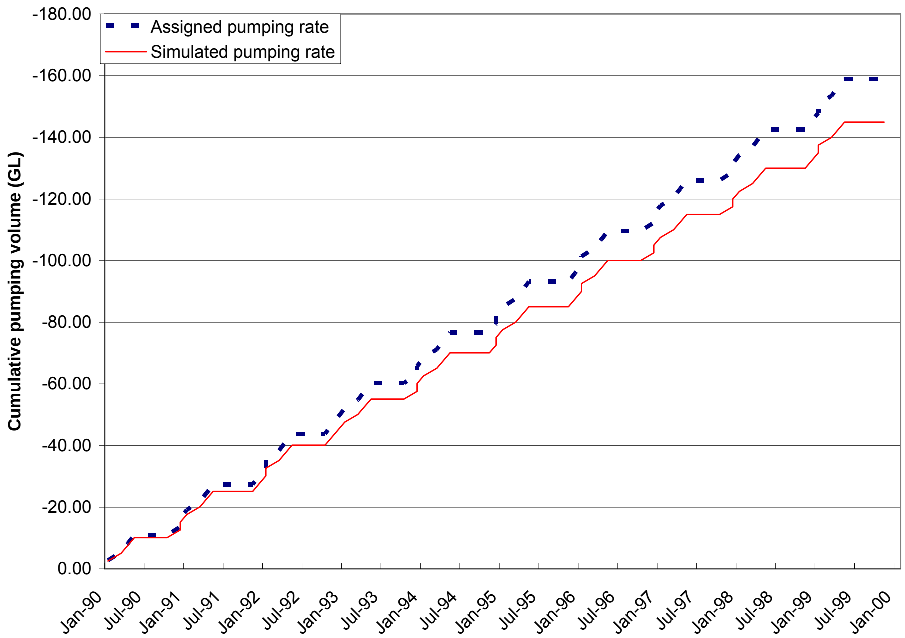


Figure 32 Cumulative observed versus simulated pumping volumes

5.3 Groundwater balance

Monthly time step water balance between 1990-1999 is presented below (Figure 33). Simulation data show oscillations in the waterbalance as a result of differing stress on the groundwater system.

In attempt to summarise the catchment groundwater balance Figure 34 presents the 1990 – 1999 mean annual groundwater balance. Results show groundwater recharge is the dominant source of water for the waterbalance, where a small source of water also comes from groundwater storage. The small change in storage reflects a slight overall rise in groundwater level from 1990 to 1999. This slight rise also matches cumulative residual rainfall trends over the same period. Overall, the 10 year water balance suggests the groundwater model is relatively stable.

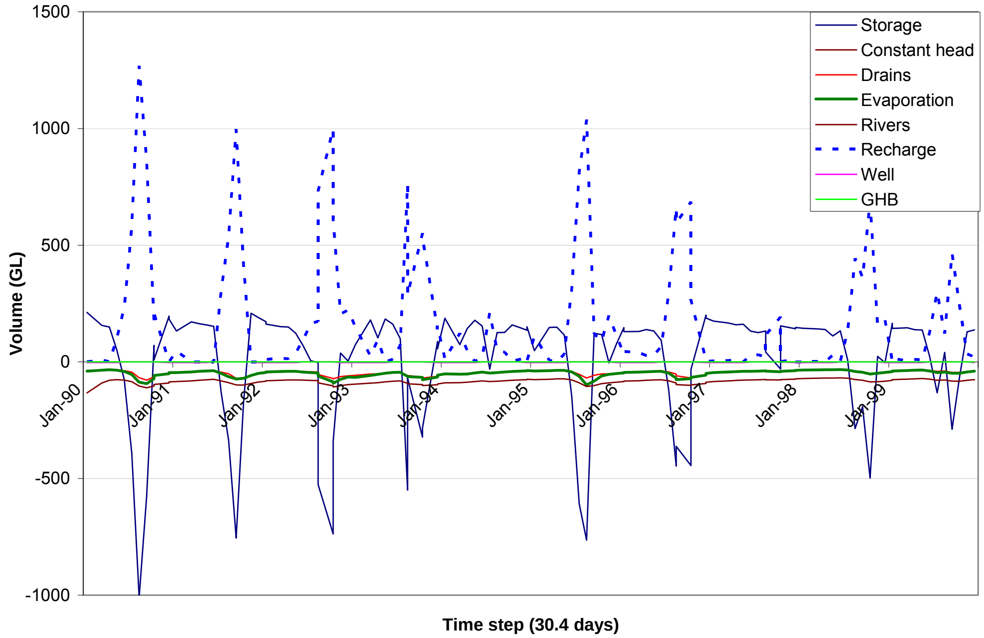


Figure 33 Simulated monthly 1990 – 1999 groundwater balance

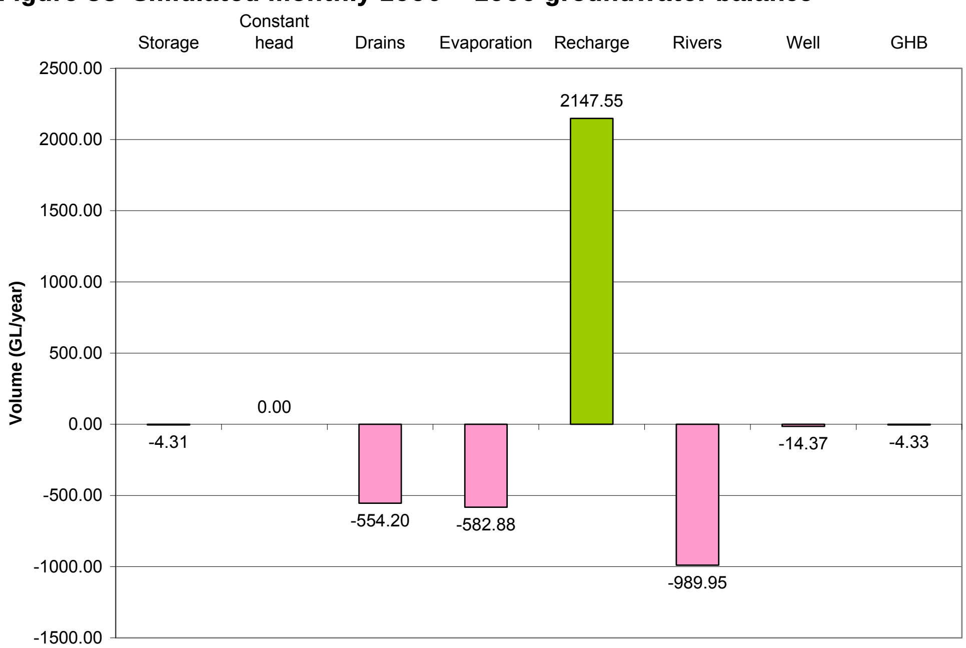


Figure 34 Simulated mean annual 1990-1999 groundwater balance

5.4 Water balance error versus shallow watertable area over time

Figure 35 presents the shallow watertable (e.g. < 2m) area on a monthly basis over the duration of the calibration period. Results show the shallow watertable area varies considerably over time which is closely related to variations groundwater recharge fluxes. Changes in water balance error over time generally oscillate by less than 0.5%, well within the 2% model target.

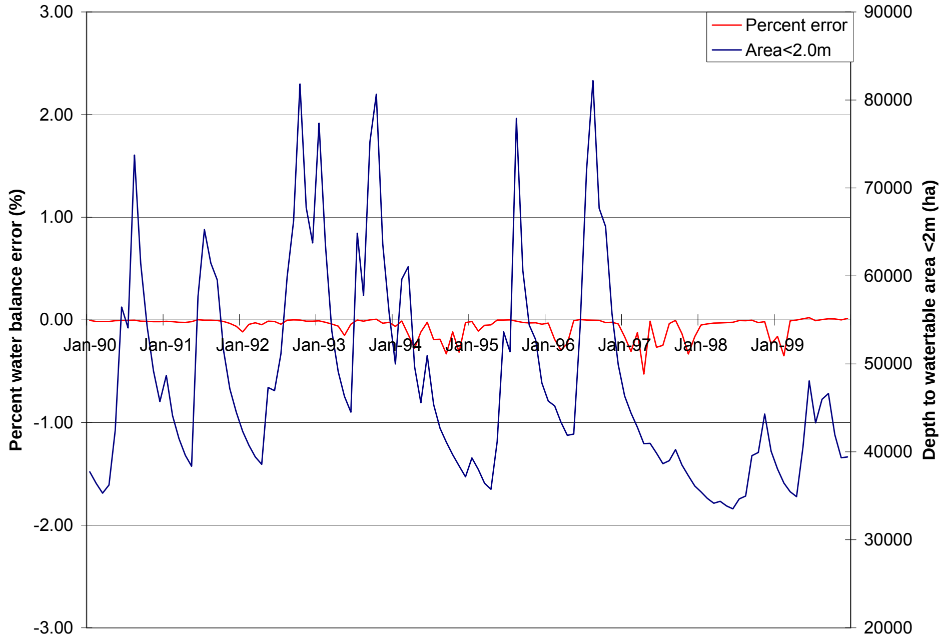


Figure 35 Calibration water balance error and shallow watertable area

5.6 Depth to watertable

Transient calibrated simulated depth to watertable for 2000 is presented below (Figure 36). The depth to watertable is generally shallow and follows the landscape topography in the lower parts of the catchment and is much deeper in the upper parts of the catchment. Overall, the simulated depth to watertable is believed to be a good reflection of the watertable.

5.7 Water level surface

Simulated 2000 water level surface (potentiometric surface) is presented in Figure 37. The gradient of the potentiometric surface is generally a subdued reflection of the landscape surface and generally follows surface water catchment boundaries. Direction of groundwater flow is north to north-west, which is consistent with regional hydrogeological understanding as previously mentioned. Appendix 5 presents individual water level elevations for each model layer.

5.8 Residual simulated versus observed 2000 water level data

Figure 38 presents simulated versus observed water level data for the period 2000 for the region, where individual model layer simulated versus observed data is presented in Appendix 6. Overall, residual data shows there is considerable variation in simulation error in both magnitude and spatial extent. The cause of the large variation in simulation versus observed water level is not clear from bore to bore, but is likely to be a combination of factors such as recharge estimation, elevation accuracy, aquifer properties, etc.

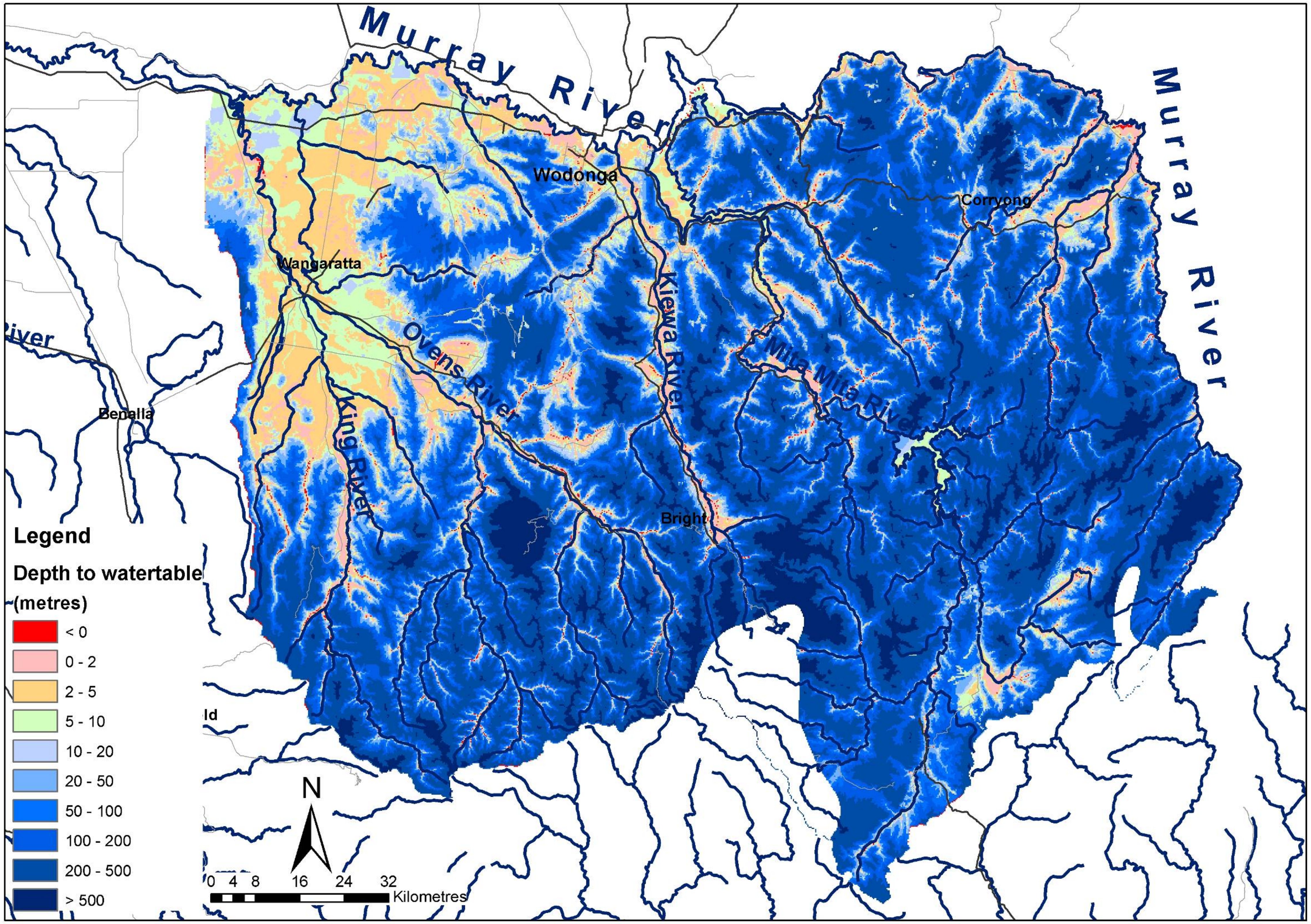


Figure 36 Simulated 2000 depth to watertable

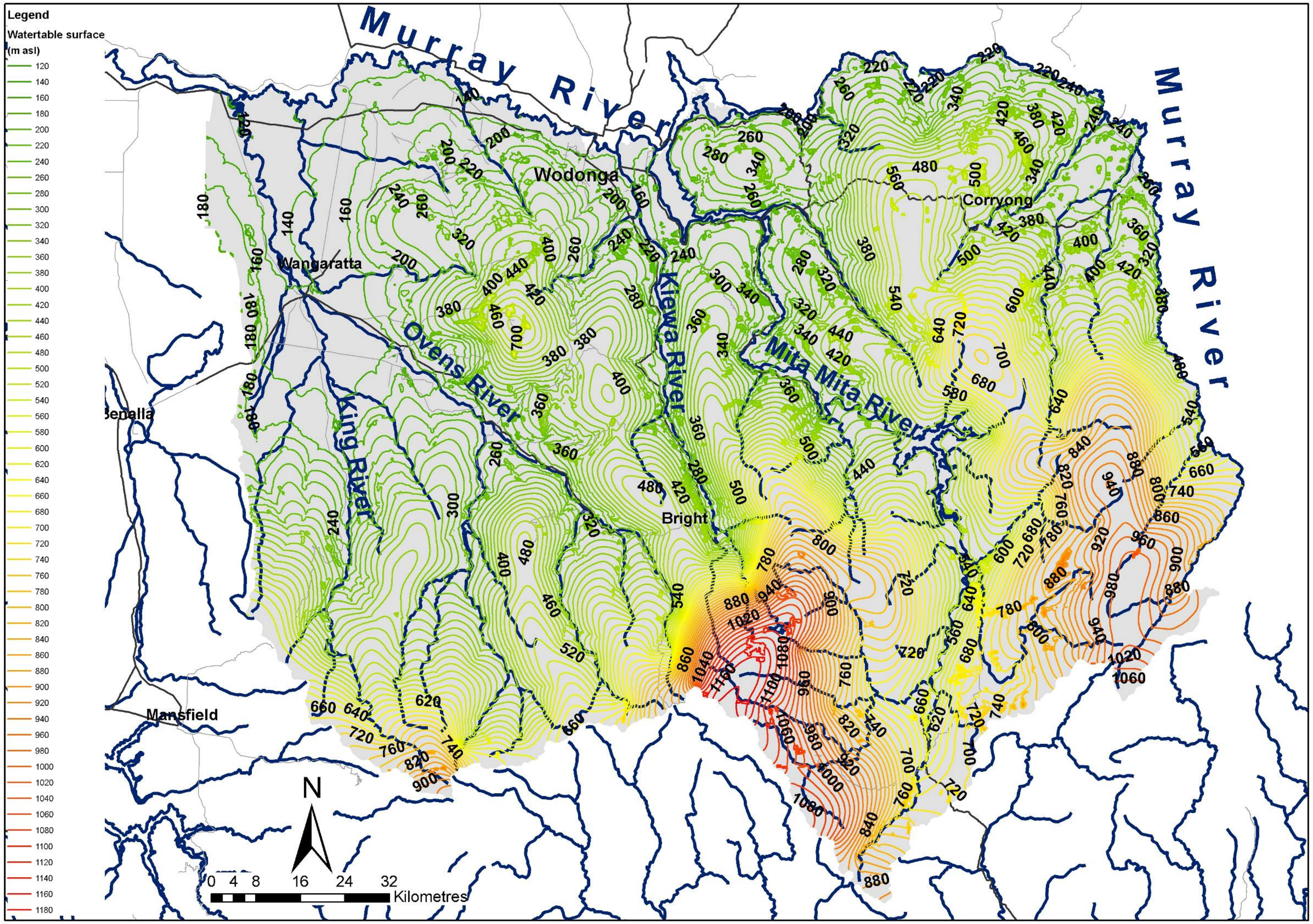


Figure 37 Simulated 2000 watertable surface

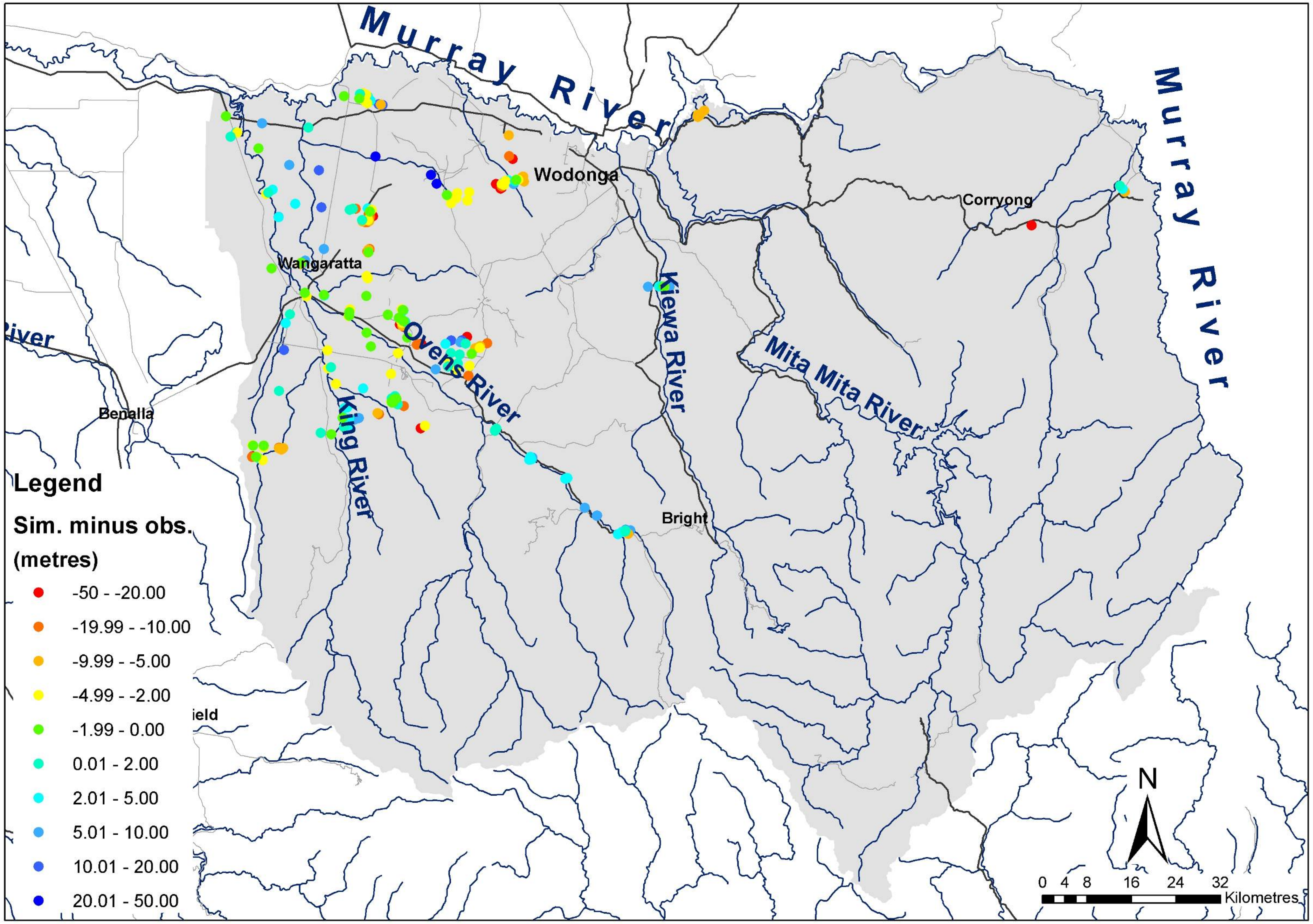


Figure 38 Simulated versus observed water level data

6 Model validation

Model validation process can be considered as an additional filter for independent model evaluation to assess the suitability of a model for its given purpose. Although there is a general agreement on the goal of model validation, no agreement exists on a uniform methodology for executing model validation (Duan et al., 2003).

For the purpose of this project, a five-year validation period (2000–2005) was selected to assess the projective capacity of the groundwater model. Scaled RMS of observed versus simulated groundwater levels was considered the most appropriate (and only consistent) dataset which could be used in this analysis. Also time-series groundwater balance information is presented to identify any underlying water balance trends.

6.1 Observed groundwater levels

Figure 39 shows the scaled RMS over the five-year validation period remains well below the calibration target of less than 10% (at 3%). The mean absolute error over the validation period appears to be slightly increasing with time, however generally remains around 9m.

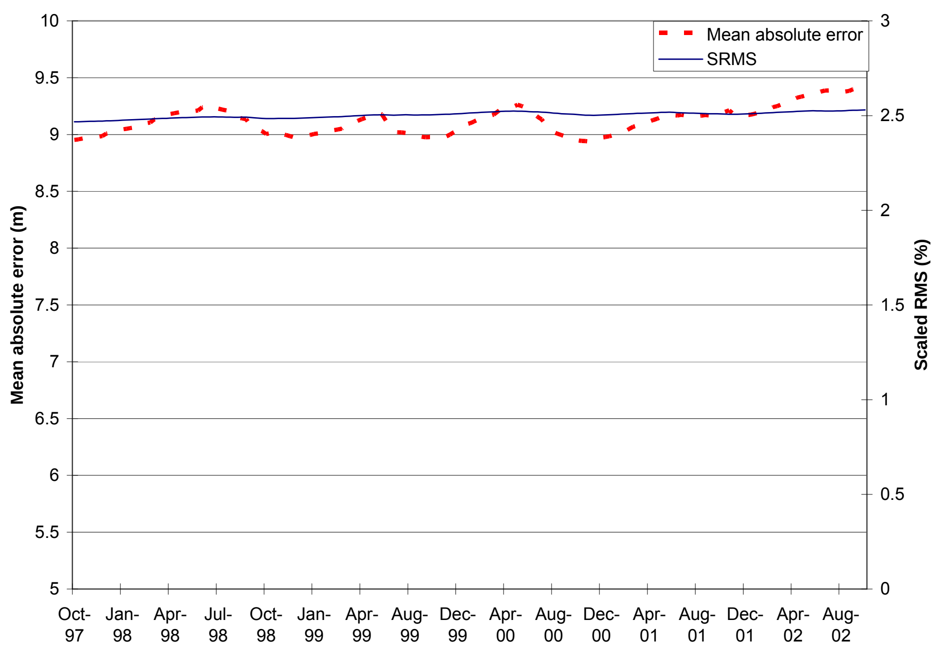


Figure 39 Scaled RMS and mean absolute error over the validation period

6.2 Groundwater balance

Figure 40 presents the simulated groundwater balance between 2000 and 2005. Data shows the water balance fluctuates comparable to that of the calibration period, with groundwater storage mirrors. Reduction in rainfall over the validation period has seen lower groundwater recharge rates and lower fluctuations in groundwater storage.

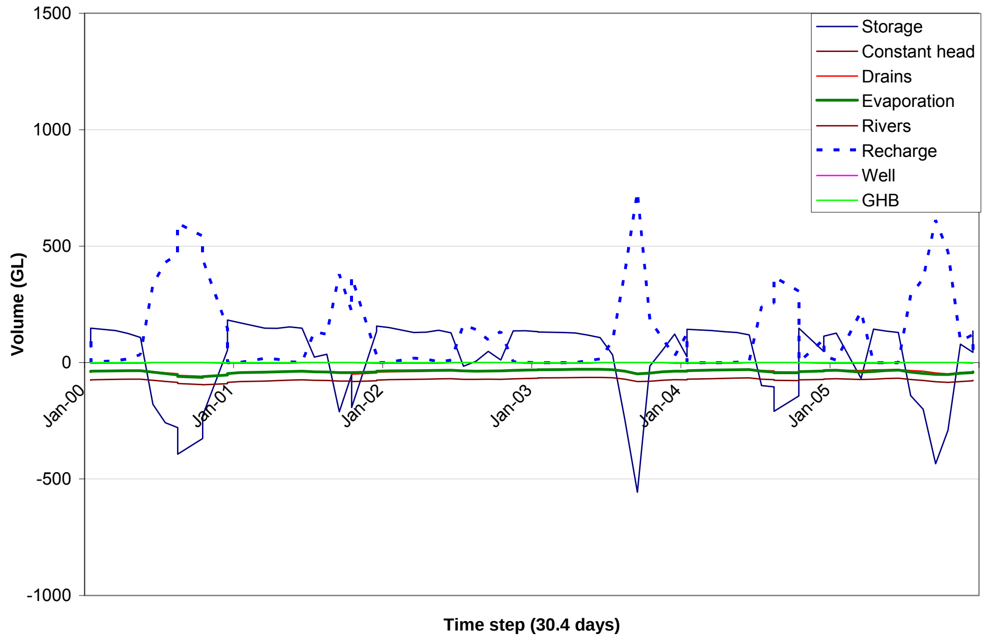


Figure 40 2000-2005 monthly water balance

The average annual groundwater balance over the validation period shows comparable relative proportions of the distribution of the water balance (Figure 41). The exception is groundwater storage where there is a net loss of groundwater storage in the validation period. The loss in groundwater storage is expected, as lower groundwater recharge rates over the validation period compared to the calibration period has caused a lowering of the watertable. The lowering of the watertable can also be seen in time-series groundwater level data presented in Appendix 8.

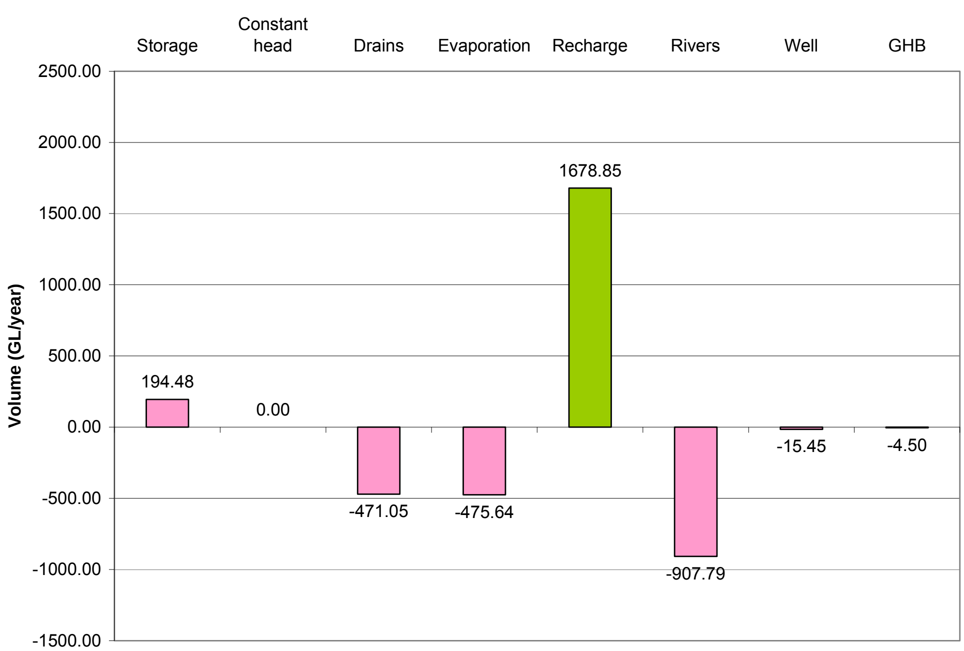


Figure 41 Mean annual validation groundwater balance

6.3 Mass balance error versus shallow watertable area over time

Analysis of water balance error percentage over time during validation (Figure 42) shows the error generally fluctuates around 0.25%. Shallow watertable area of the validation period decreases then increase, this variation is associated with a fluctuating rainfall trend and subsequent groundwater recharge.

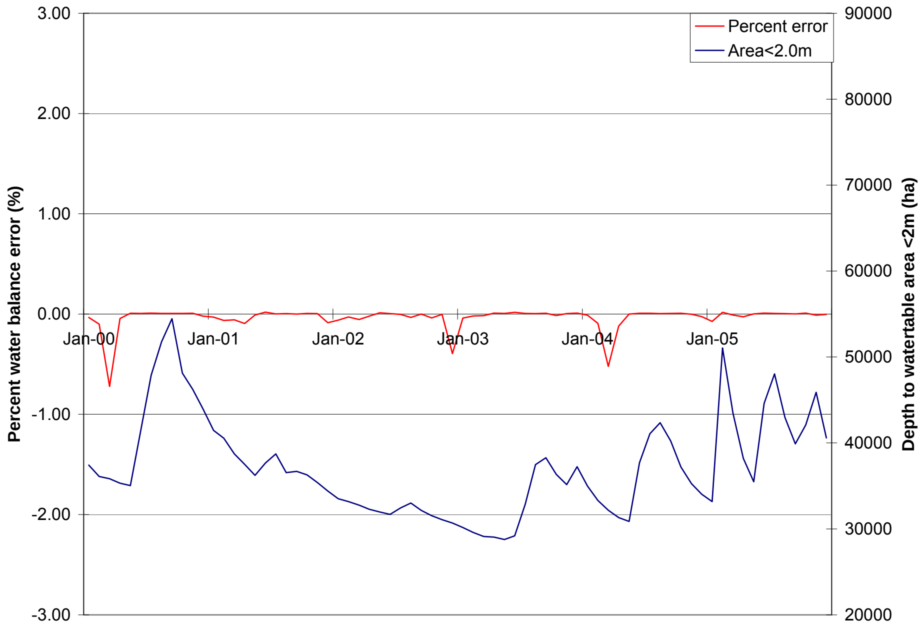


Figure 42 Validation mass balance and shallow depth to watertable area

7 Conversion of transient to steady state

The calibrated transient model was run in a steady state solution to provide an end-point comparison n for the transient simulation. Average groundwater recharge between 1990 – 2005 was used for this comparison, despite acknowledging temporal flux variations in groundwater recharge are likely to provide a different result.

7.1 Depth to watertable

Figure 43 presents transient North East CMA model in steady state depth to watertable. Results show the watertable is generally shallower than the 2000 transient watertable result. The depth to watertable surface seems a reasonable reflection of reality.

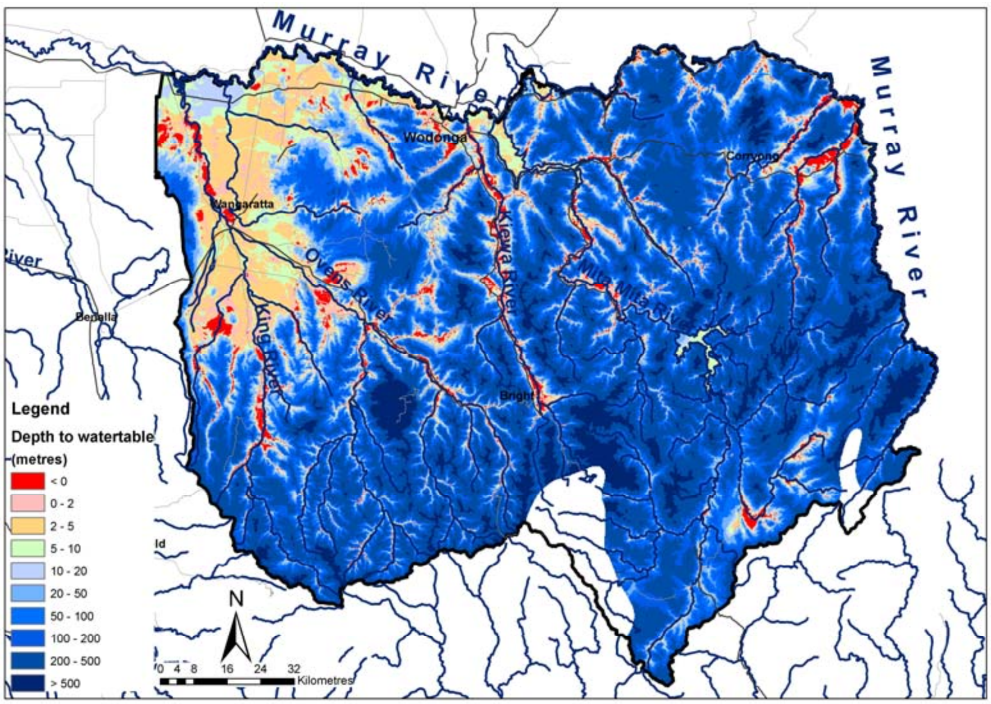


Figure 43 Simulated steady state depth to watertable

7.2 Model water balance

Analysis of the converted calibrated transient model in steady state water balance shows zero error (Figure 44). The small balance error and convergence tolerance of 0.1 metres suggests the converted steady state model may be used for scenario analysis in its' current form.

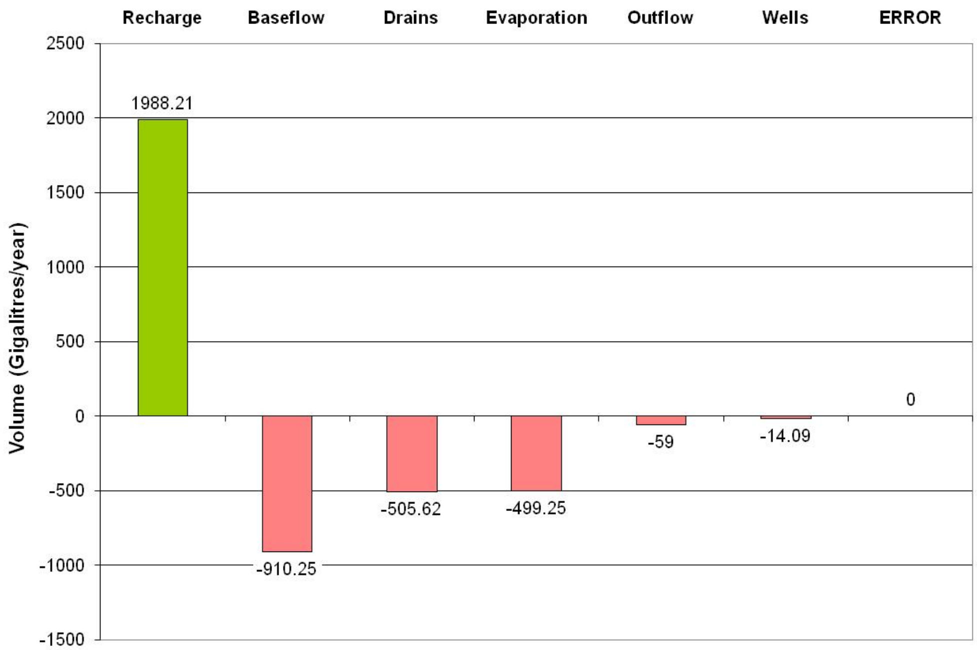


Figure 44 Converted transient steady state water balance

8 Model sensitivity

After calibration of the transient model, it then converted into steady state. Model parameters were analysed to assess the sensitivity of model results to respective input parameters, that is, hydraulic conductivity, Vcont, groundwater recharge rate, evapotranspiration rate and depth and river conductance. Sensitivity analysis is a method of quantifying uncertainty of the calibrated model related to uncertainty in the estimates of aquifer parameters (Anderson and Woessner, 1992). Determining the sensitivity of the model to specific parameters offers insights into the uniqueness of the calibrated model. Due to long time requirement to undertake transient sensitivity runs and short project time limitations, it was not possible to undertaken sensitivity analysis of specific yield and specific storage.

MDBC (2000) refer to four 'types' of parameter sensitivities. Type I and II are of no concern as the impacts of the predictions are insignificant. Type III is of concern for un-calibrated low complexity models. Type IV is of concern as model non-uniqueness in the model input may cause a range of valid calibrations, but the results may vary significantly on prediction. Each model parameter was considered for model sensitivity by applying a percentage difference from the calibrated parameter. In many instances model convergence failed during sensitivity analysis, these values were not plotted. A model is considered sensitive to an input parameter if relatively small changes in that parameter results in relatively large changes in simulated water level or the catchment water balance. That is, calibration is possible only over a narrow range of values and, as a result, model uncertainty is relatively low. A model is insensitive if relatively if relatively large changes of a parameter produces a relatively small change in water level or water balance. Insensitivity results in higher uncertainties because the model will calibrate over a range of input parameter values.

Detailed sensitivity results are presented in Appendix 7.

Table 9 summarises the sensitivity types of the North East CMA region model compared with the area of depth to watertable of less than two metres and change in groundwater base flow in the model domain.

Results show all attribute variations result in Type I sensitivity. Depth to watertable and groundwater base flow are most sensitive to recharge and evaporation rate, and, to a lesser extent, river conductance, hydraulic conductivity and Vcont.

The relatively low insensitivity of the model to hydraulic conductivity and Vcont in the confined model layers can be explained by the layers not having a direct impact on shallow watertable area or drainage conductivity. All model attributes converged with more than 50% variation, implying the model has capacity for attribute variance if required.

Table 9 Sensitivity types (described in MDBC, 2000)

		CHANGE IN sRMS CALIBRATION	
		Insignificant (e.g. < 50%)	Significant (e.g. > 50%)
CHANGE IN PREDICTION	Insignificant (e.g. < 50%)	HY (all layers) Vcont (1,2,3,4,5,6) River conductivity Evaporation rate Evaporation depth Groundwater recharge (base flow) Groundwater recharge (depth to watertable) TYPE I	TYPE II
	Significant (e.g. > 50%)	TYPE IV	TYPE III

HY = Hydraulic conductivity

Additionally, changes in model parameters were considered on the impact of scaled RMS (Appendix 7). Results show model parameters within a 100% range of the calibrated value do vary the scaled RMS by more than 50% in most instances. It was apparent groundwater recharge caused the greatest variation in scaled RMS. Results of this sensitivity analysis indicate groundwater recharge is the most sensitive on scaled RMS.

9 Model uncertainty and assumptions

A number of challenges have been faced when developing this groundwater model and many generalisations have been made in an attempt to best represent the groundwater conditions. The following section describes some of the generalisations, assumptions and areas of concern identified when developing the groundwater model.

9.1 Ensym evapotranspiration data

The provision of an Ensym-derived evapotranspiration module was assumed to represent physically reasonable estimates of groundwater evapotranspiration depth and rate. Upon further investigation, it was found the Ensym data prohibited developing a perceived reasonable depth to watertable layer (despite scale RMS and catchment water balance results being reasonable).

The range of evapotranspiration rates were heavily weighted under specific native vegetation species (e.g. skewed) causing model stability issues when attempting to uniformly adjust rates. It was decided the mean annual steady-state groundwater recharge layer would be used in the transient model. This assumed there is little temporal deference in evaporation rate from month to month, which is clearly not the case.

9.2 Groundwater base flow calibration

Calibration of groundwater base flow to calculated gauge flow data was not undertaken due to project time limitations and limited calibration data. Instead, calibrated steady-state base flow attributes (river and drainage modules) were used in the transient model. It is acknowledged the limited level of base flow calibration provides uncertainty and perhaps some error, but it is considered appropriate for the amount of calibration data available.

9.3 Groundwater abstraction

Groundwater pumping data in the model domain was found, in few instances, to require modification to correct for dry wells. In particular, model layers 3 and 4 required expansion of the groundwater pumping capture zone (e.g. area of extraction) to reduce the wells going dry. The issue of under extraction of groundwater rates confirm the issue of using near uniform aquifer parameters in attempting to simulate an aquifer and/or the aquifer maybe verging towards its’ sustainable extraction limit. To overcome this issue well pumping optimization may have assisted if project time permitted.

9.4 Areas of conceptual uncertainty

During the period of model calibration it was clear that there were locations where model simulations did not match circumstances which occurred in nature. There are a number of potential causes of this variability; one of which is the use of uniform values to represent entire model attributes. That is, the generalisation of a single value (such as conductivity) accurately representing an entire model layer is clearly with flaw. Regardless this generalisation was considered a reasonable initial assumption whereby zoning of differing values could be undertaken at a later time. However, the relatively short time between the delivery of Ensym groundwater recharge and required project completion (approximately nine weeks) prohibited zonal calibration. Despite having a

number of uniform model attributes, results suggest the use of uniform values is adequate within the calibration targets of this project.

Such areas which would benefit include:

- In locations of deeply incised valleys (i.e. Kiewa and Ovens Valleys) spatial variability in hydraulic conductivity has not been defined clearly. As a result many groundwater level and responses may not reflect nature.
- Basement hydraulic conductivity – variability in confined, unconfined and faulting locations. Applying spatial variability would enhance model calibration accuracy.

9.5 Groundwater recharge

Despite groundwater recharge being provided as a non-calibration feature there is likely to be some variability with groundwater recharge rates and timing. Some areas of low confidence include:

- the time delay between a rainfall events and groundwater recharge
- deep drainage partitioning (recharge – lateral flow relationship)
- area-specific land use factors which may impact on recharge rate
- overland flow contributing recharge in low points of the landscape
- accuracy of soil hydraulic data, and

9.6 Elevation variation

Mentioned previously, there is likely an inherent error in the landscape elevation. Scatter plot data of surveyed versus DEM point data suggests an average elevation error of 3.84m. While there is little which can be done with the inherent error, the information should be kept in mind when reviewing individual simulated versus observed data and overall calibration statistics. The current cell size and inherent elevation error of the model is considered reasonable within the specifications and underlying assumptions of this project.

9.7 Depth to watertable

There is no definitive information set which defines the current depth to watertable of the North East CMA region. For the purpose of this project, it was considered on-ground knowledge of the depth to watertable in the region was an adequate means to determine if the simulated depth to watertable was "reasonable". With this qualitative assessment there is no measure of determining the true accuracy of the simulated depth to watertable in the region.

9.8 Temporal water balance

With any temporal simulation of groundwater levels it is difficult to history match underlying groundwater trends. Underlying trends have attempted to be matched; however, it is more than likely that these trends will differ from simulated groundwater trending. This difference, in some locations, may impact on changes in the catchment water balance both temporally and spatially.

9.9 Groundwater extraction rates

During model construction it became apparent there was little information available regarding the relevant pumping aquifer. To overcome tis problem, pumping aquifers were assumed based upon the most productive aquifer at those locations.

During the model calibration phase a number of groundwater pumping bores went "dry" (e.g. became inactive). That is, the pumping bores were unable to extract the allocated volume from the aquifer, resulting in lower overall volumes of groundwater pumping in the catchment groundwater balance. Despite the modification of a number pumping bores to allow the allocated volume to be extracted (e.g. expanding the pumping area) a number of groundwater pumping bores run dry during the simulation. Ideally, well optimisation would have been undertaken as part of this project, however large computational time requirements and a short project timeline prohibited this to be undertaken.

10 Conclusions

This report describes a hydrogeological model assembled for the entire North East CMA region. The size of the model and the complexity of the processes simulated reaffirm many of the challenges faced in assembling large hydrogeological simulations in both steady and transient states.

The application of MODFLOW allowed for the simulation of regional hydrogeological flow processes. Whilst it is likely there are some areas where the simulated depth to watertable does not correlate well with known values, every effort has been made within the scope of this project to make the model reflect reality. The absolute accuracy of the depth to watertable map is difficult to quantify, particularly with an underlying elevation error with a mean sum of residuals of 3.74 m existing within the catchment. Despite this 'residual' elevation variation, a scaled RMS of less than 10% was able to be achieved throughout the duration of the model calibration and validation period.

It has become apparent that despite reaching all required calibration targets there is considerable scope for improving the accuracy of this groundwater model in specific locations. Most of these enhancements centre on the ability to incorporate spatially varying data (such as vertical and lateral hydraulic conductivity, full extent base flow calibration, temporal groundwater pumping rates, etc.) into the existing groundwater. These enhancements are anticipated to provide better spatial and temporal calibration.

Limited data analysis of model validation data suggests overall the North East CMA region groundwater model has adequate predictive capacity to simulate groundwater levels beyond the 1990–1999 calibration period of the model.

10.1 Model fit for purpose

The purpose of the North East CMA region groundwater model is to assess the impacts of land use change on the water balance, and in particular the influence on depth to watertable and base flow volume. In previous chapters a number of assumptions and generalisations have been discussed in an attempt to contextualise the scale and limitations of the groundwater model.

The model developer considers the application of the North East CMA region groundwater model has the capacity to predict changes to the water balance; however there are a number of potential limitations which should be kept in mind:

- Analysis of transient converted steady state solution suggests the model has capacity for long-term prediction of the transient model (e.g. > 15 years), however underlying groundwater trends may impact model prediction capacity beyond this period.
- Only relative water balance changes should be considered, not absolute changes. That is, due to scale, complexity, availability of calibration data and time limitations model calibration is not at sufficient detail to warrant absolute values.
- Likewise, the application of the North East steady-state groundwater model may be used for assessment of impacts of land use change as calibrated recharge rates appear to be a reasonable recharge approximation and therefore may redistribute the groundwater balance proportionately.

11 Recommendations

Whilst the development of a useful regional surface water/groundwater model was possible for the North East the capacity to simulate the water balance was limited in some areas by a general lack of information and knowledge. The following recommendations propose actions that would improve the results of the simulation and the usefulness of the modelling framework.

The specific recommendations are as follows:

- Better simulation of catchment groundwater recharge in the region is required to better simulate the actual groundwater balance. This would also allow for better calibration statistics.
- There is a need to improve the knowledge of groundwater abstraction across the region. This should extend to a better appreciation of the location of pumped wells, the volumes removed, and the nature of the aquifers.
- Further area specific hydrogeological investigations should be undertaken to improve the knowledge of groundwater processes in areas where there is a poor correlation between simulated and observed depth to watertable. Specifically, the construction of groundwater monitoring bores in the highlands of the North East region.
- Groundwater level monitoring should continue in the region to support the development of temporal catchment simulations.
- In its' current form, this catchment water balance should be applied in further considering relative land management and groundwater allocations in the North East CMA region.
- Time series groundwater data retained within the Victorian groundwater database be inspected and filtered for spurious data.
- Further review and calibration of groundwater recharge and run-off estimates determined by Ensym should be undertaken to ensure the full catchment water balance is considered.
- Undertaking well optimisation would enable simulated groundwater pumping volumes to closer match observed groundwater pumping rates.
- Refinement of this groundwater model in areas of significant error. This would provide other potential applications of the model, such as groundwater availability modelling.
- The differing conceptualisation of the modelling team with the review team in the steady state modelling should be further investigated in attempt to resolve the question of groundwater flow pathways in the region.

References

Anderson, M. and Woessner, W. (1992) Applied groundwater modelling: Simulation of flow and advective transport. Academic press, Inc., San Diega, 381 p.

Arnold, J.G. and P.M. Allen. 1999. Automated methods for estimating baseflow and ground water recharge from streamflow records. Journal of the American Water Resources Association 35(2): 411-424.

Beverly, C. (2007). Technical Manual - Models of the Catchment Analysis Tool. Department of Sustainability and Environment, Victoria.

Douglas, J. and Ferguson, J. (eds) (1988) The Geology of Victoria. Geological Society of Australia, Victorian Division, Melbourne, 663p

DPI (2006). Progress report for groundwater modelling approach in the Ovens catchment – conceptual model. Department of Primary Industries, Primary Industries Victoria, Victorian Government

DPI (2003) Victoria Geoscientific data CD. Department of Primary Industries, April 2003.

DSE (2007) Models of the Catchment Analysis Tool (CAT1D version 22) – Technical manual. Department of Sustainability and Environment, Victoria. ISBN 978-1-74208-046-8.

Duan, Q., H.V. Gupta, S. Sorooshian, A.N. Rousseau, and R. Turcotte (Eds.). 2003. Calibration of watershed models, Water Sci. Appl. Ser., vol 6, AGU, Washington, D.C.

Ha, J. (2010 in prep.). A Programmer's Guide for BioSym – the Biophysical Modelling Toolbox of EnSym. Victoria Department of Sustainability and Environment

Heislers, D., (1993) Groundwater in the Central Victorian Highlands, Report no. 87, Department of Conservation and Natural Resources, Water Division, Melbourne

Hocking et al. (2010) North East CMA groundwater model - interim steady-state model development report. Report prepared for DSE, Ecomarkets branch. Unpublished report.

MDBC (2000) Murray Darling Basin groundwater modelling guidelines. Prepared by Aquaterra. October 2000, 125p.

Lawrence, C. (1975) Geology, hydrodynamics and hydrogeochemistry of the southern Murray Basin. Geological Survey of Victoria, memoir 30, Volume 1 - Report, Volume 2 - maps.

Roderick, M. and Farquhar, G. (2004) Changes in Australian pan evaporation from 1972 to 2002. Int. J. Climatol. 24: 1077 – 1090 (2004).

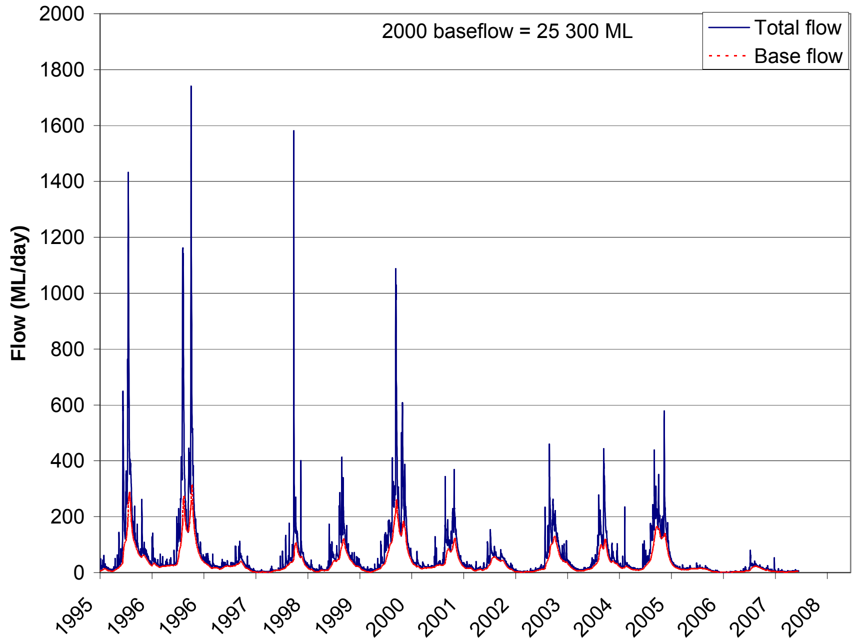
Shugg, A. (2005) Hydrogeology of the Upper Ovens in Victoria, DRAFT report revising GSV unpublished reports.

Stone, H. L. (1968). "Iterative Solution of Implicit Approximations of Multidimensional Partial Differential Equations". *SIAM Journal of Numerical Analysis* **5**: 530 – 538

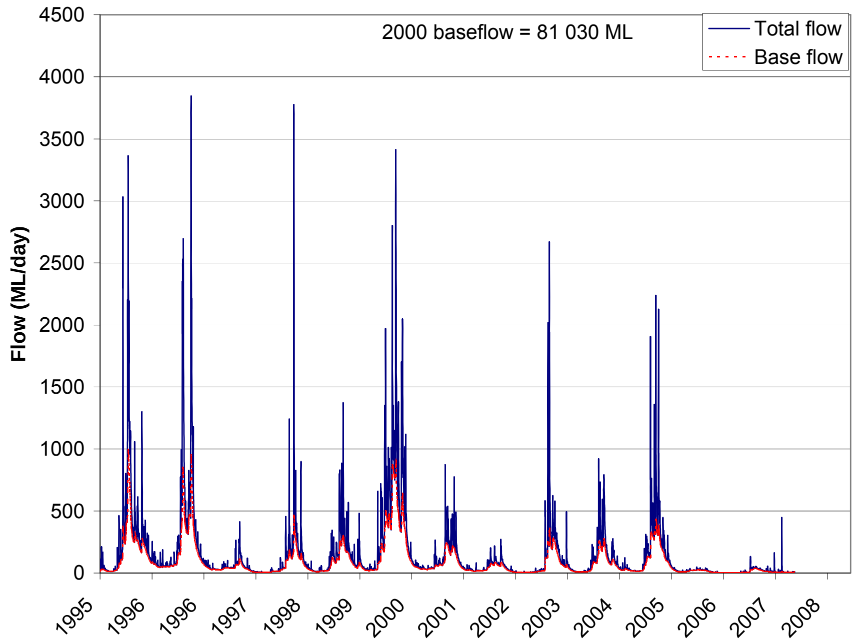
SKM (2007) Upper Ovens conceptual hydrogeological model. Report written for Goulburn Murray Water, unpublished report.

Appendix 1 – Automated baseflow calculations for selected sub-catchments

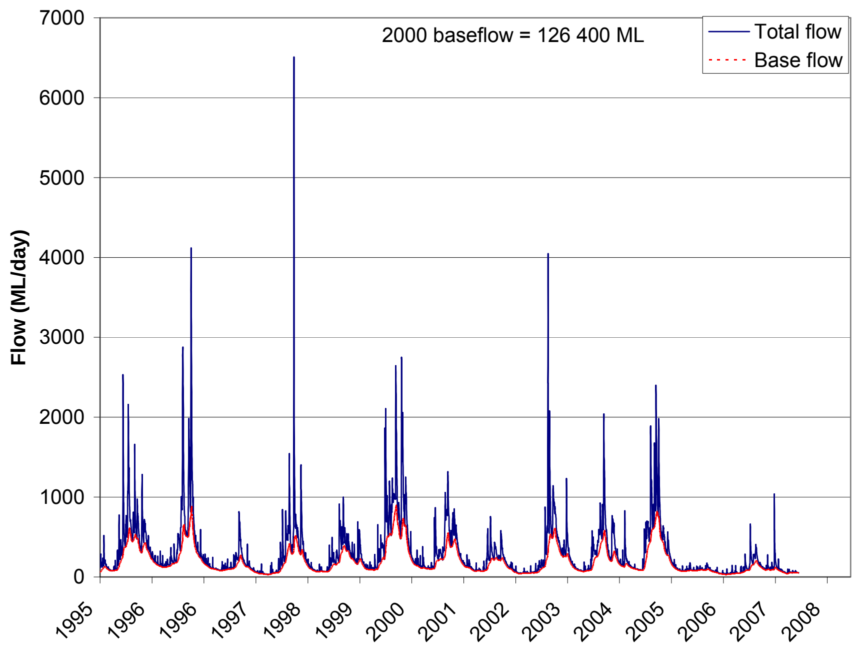
402206



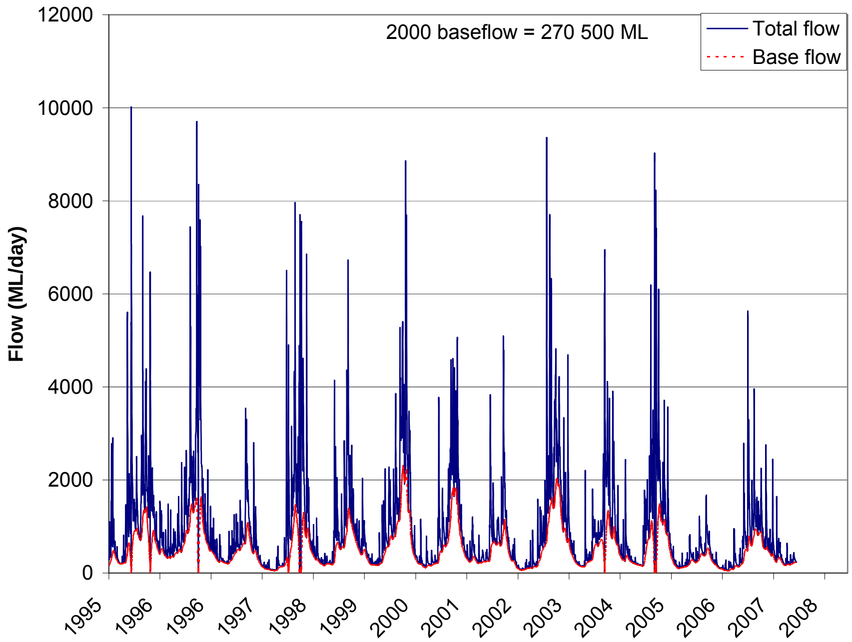
401220



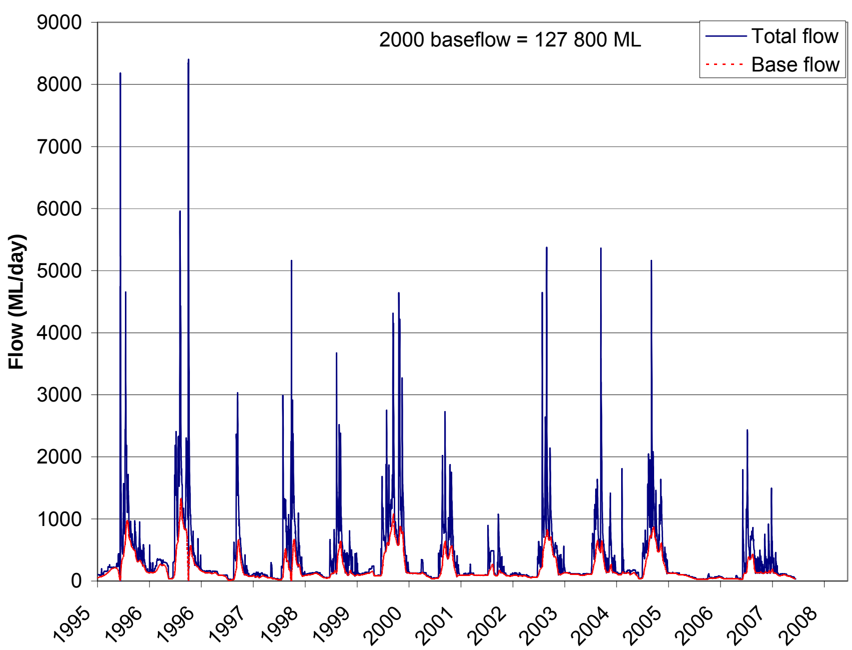
401212



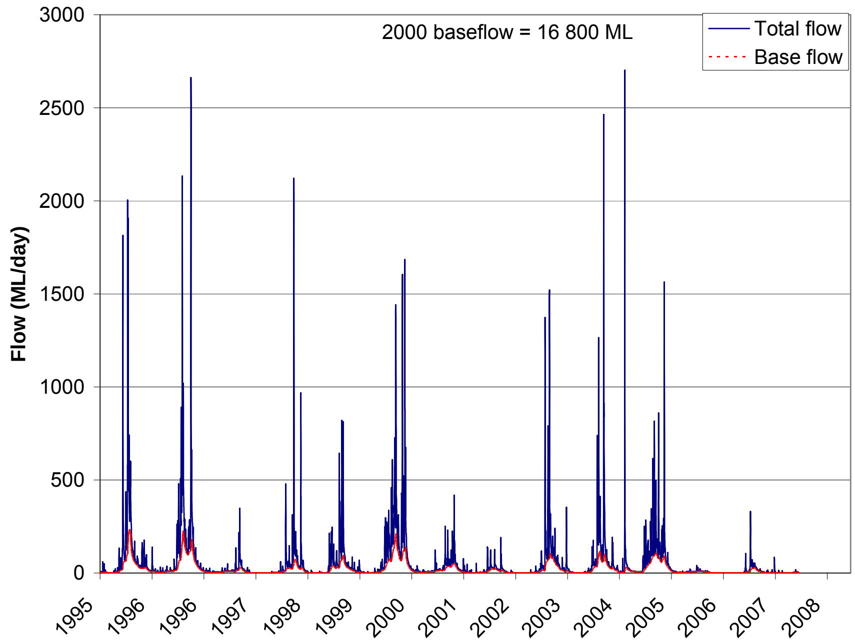
401203



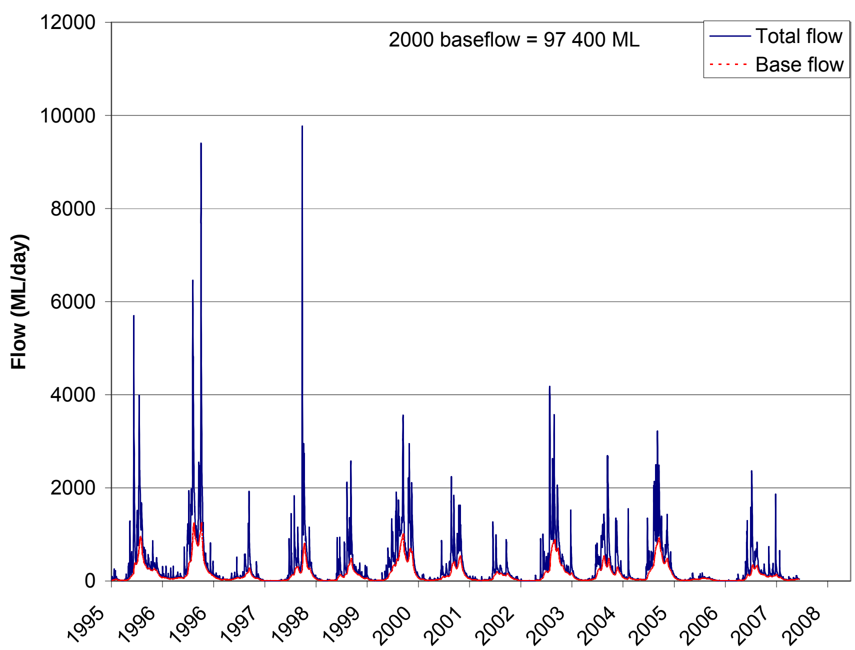
403228



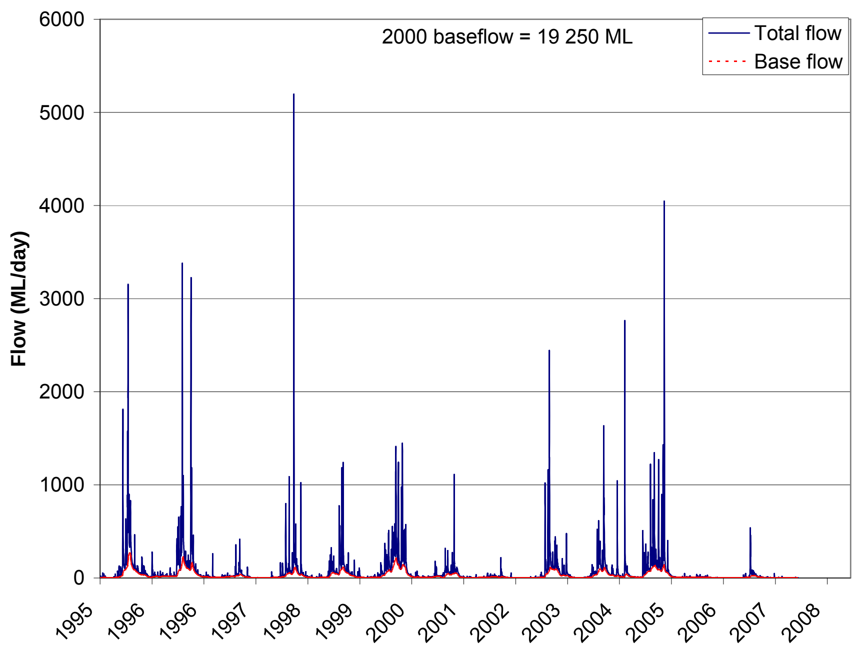
403224



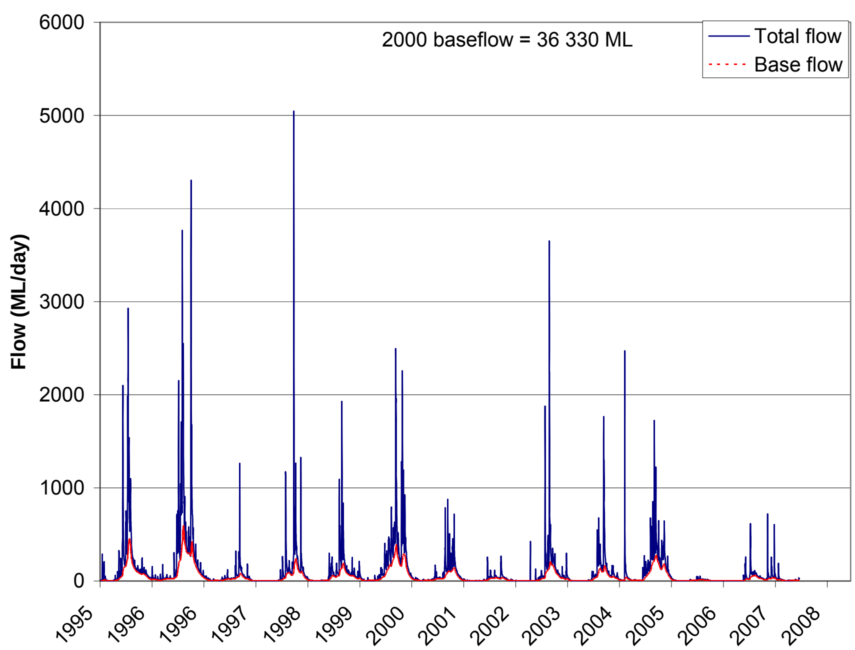
403222



403221



403213



Appendix 2 – Model layer development

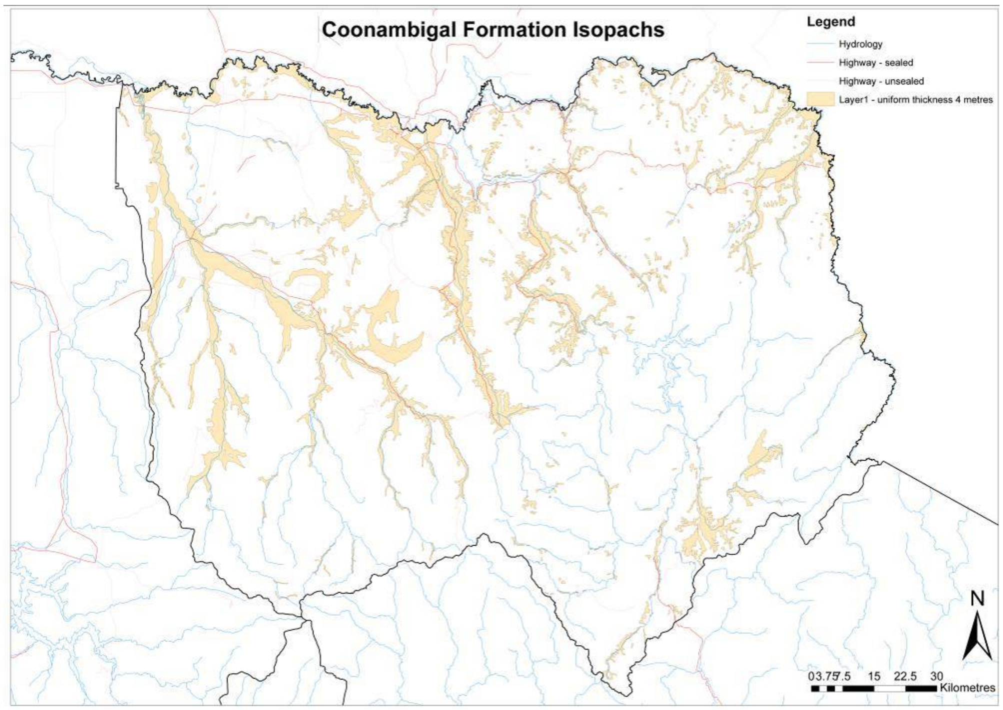
This section describes the data used in the assembly of each model layer.

Model layer 1 (Coonambidgal Formation)

Described previously, model layer 1 is primarily composed of the Coonambidgal Formation. The extent of layer 1 was defined by 1:250 000 geology mapping (DPI, 2003) of the Coonambidgal Formation.

Isopachs

Layer 1 was considered by assuming a uniform thickness of 4m.



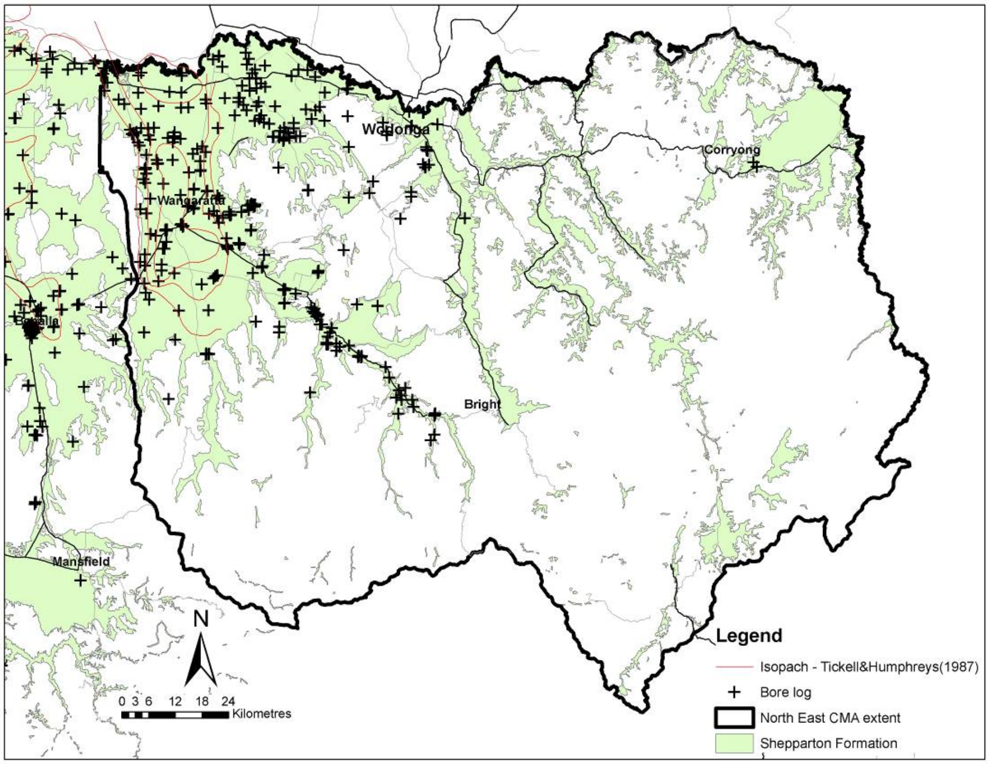
Hydraulic conductivity

Uniform hydraulic conductivity of 0.8 m/day was assigned in layer 1 prior to calibration.

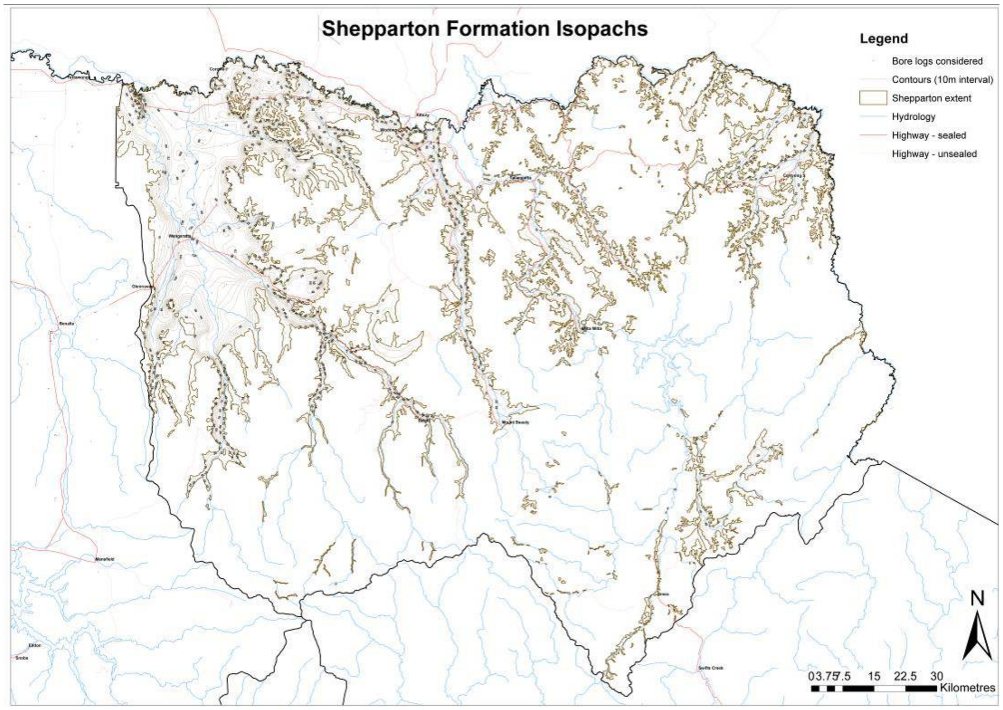
Shepparton Formation

The Shepparton Formation has been sub-divided into two parts based upon lithological variations identified in the lower Ovens Valley predominantly at a depth between 35m to 50m. Isopach of the entire Shepparton Formation is presented below.

The Shepparton Formation was considered by contouring the thickness of published and bore log interpretation (sources below). Raster contouring using Topogrid® was applied, where point and boundary enforcement was applied.



Source	Data type
DSE state-wide database	Interpreted stratigraphy
PIRVic salinity database	Interpreted stratigraphy
Eureka database	Bore logs
Tickell & Humphrys (1987)	Isopach contours & bore logs
Lawence (1975)	Bore logs
DPI (2006)	Cross sections
SKM (2007)	Cross sections
Shugg (2005)	Bore logs

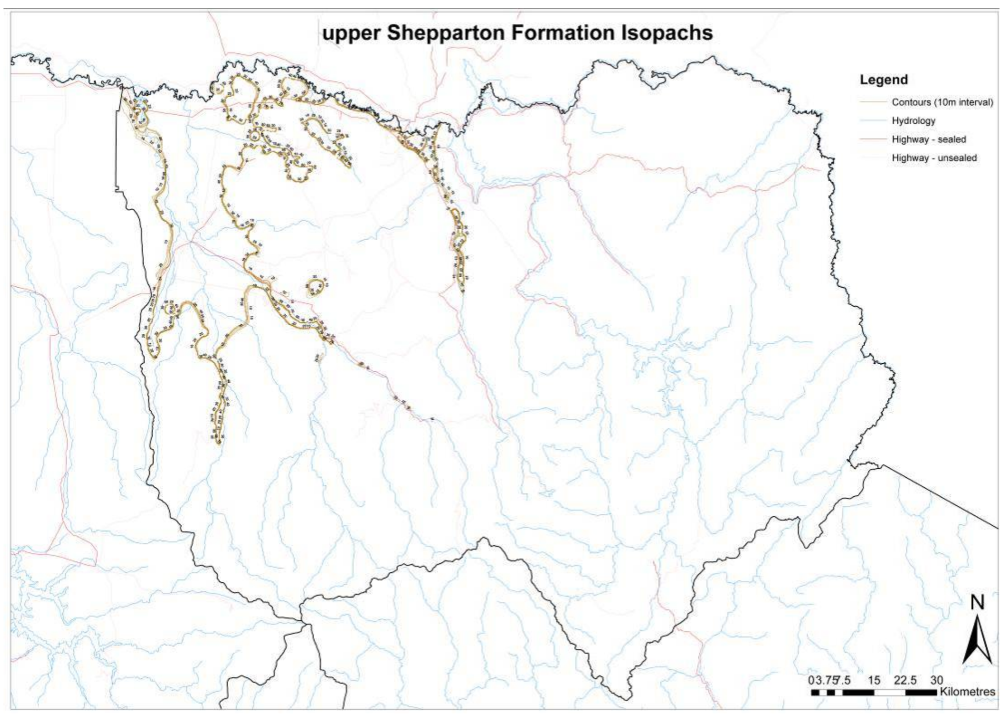


Model layer 2 (upper Shepparton Formation)

The extent of layer 2 was defined where the Shepparton Formation thickness is greater than 35m and absent in the upper Ovens Valley.

Isopachs

Layer 2 thickness is presented below.



Hydraulic conductivity

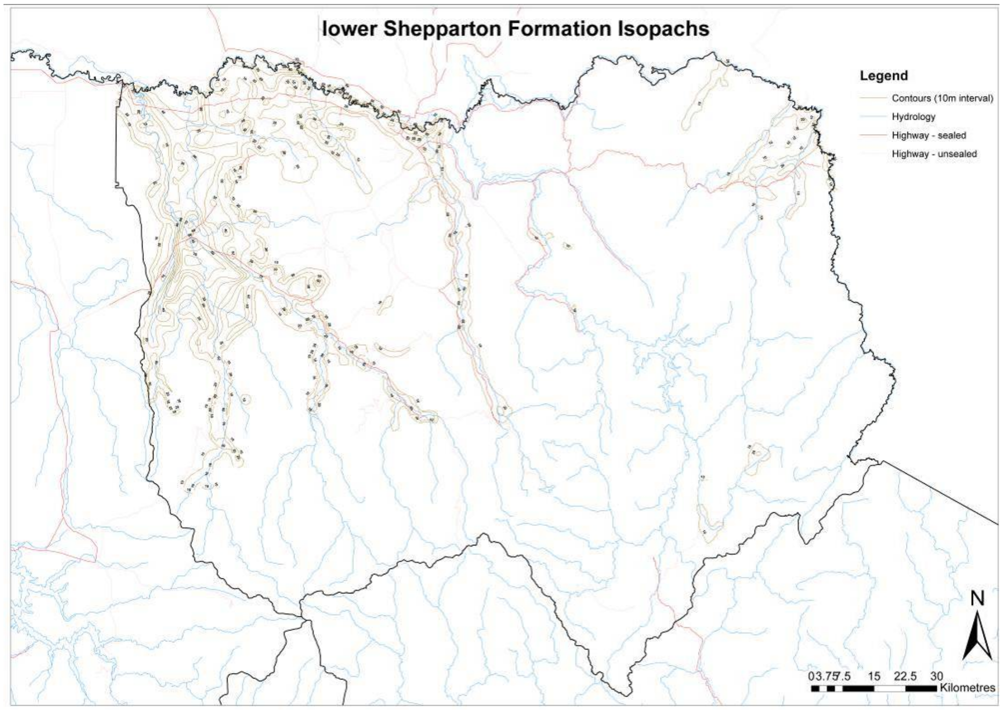
Uniform hydraulic conductivity of 2 m/day was assigned in layer 2 prior to calibration.

Model layer 3 (lower Shepparton Formation)

The extent of layer 3 was defined as the entire extent of the Shepparton Formation minus the thickness of the upper Shepparton Formation thickness (model layer 2).

Isopachs

Layer 3 thickness is presented below.



Hydraulic conductivity

Uniform hydraulic conductivity of 7 m/day was assigned in layer 3 prior to calibration.

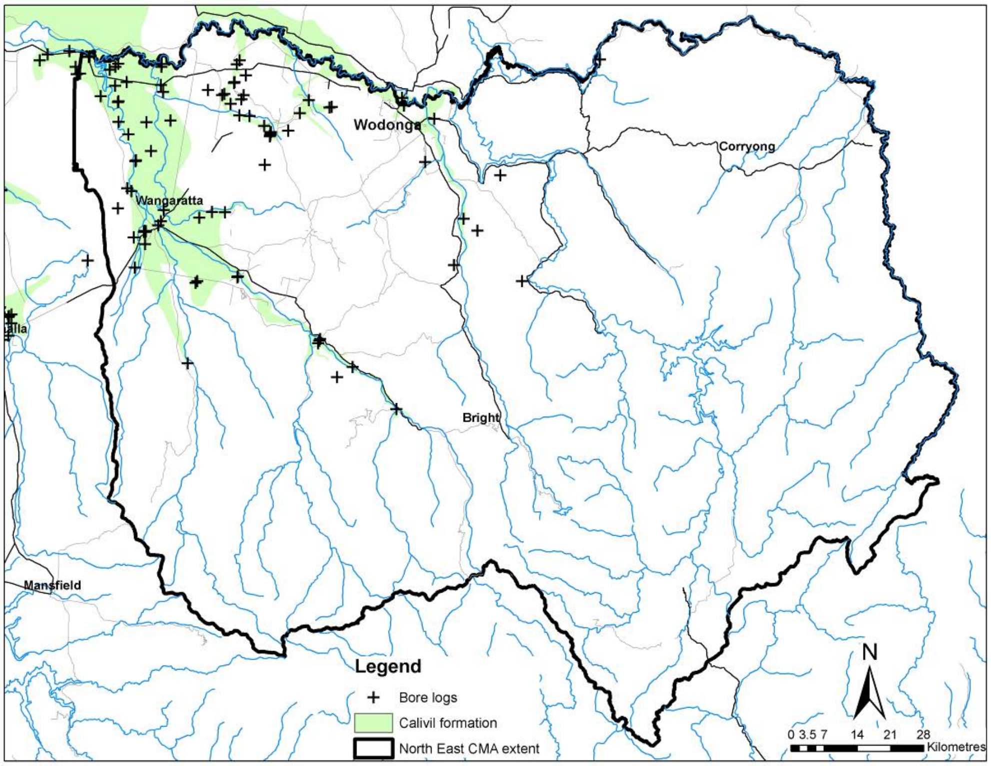
Model layer 4 (Calivil Formation)

Previously described, model layer 4 is composed of Calivil Formation.

The primary extent of layer 4 was defined by 1:250 000 hydrogeology mapping (MDBA, 2009), comments by Dr Phil Macumber and bore log interpretation.

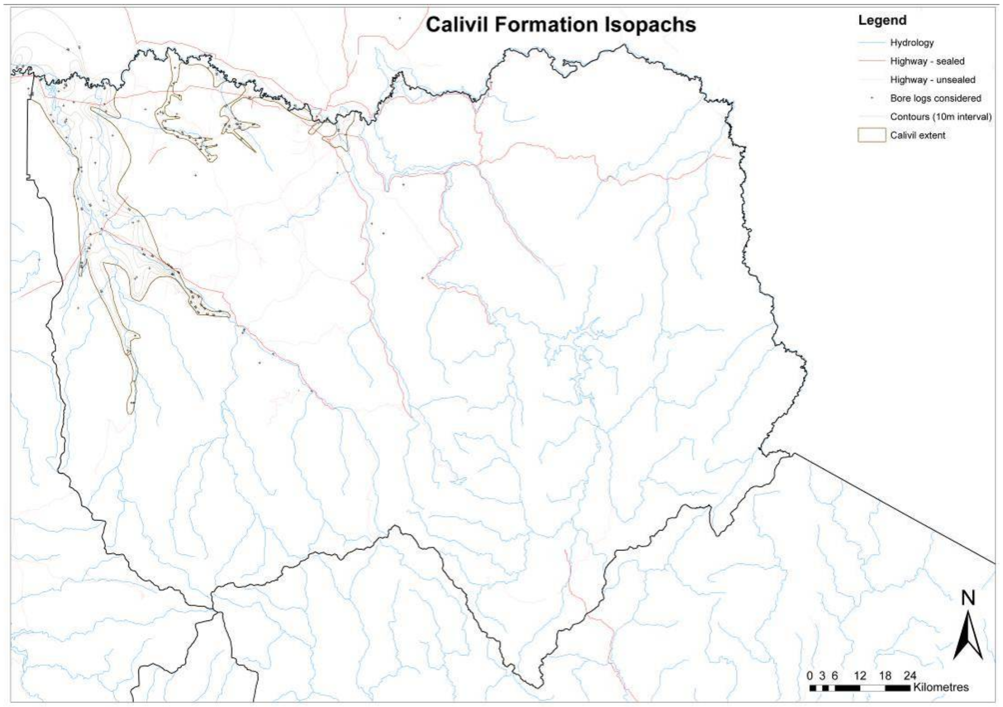
Raster contouring using Topogrid® was applied, using point and boundary enforcement.

Source	Data type
DSE state-wide database	Interpreted stratigraphy
PIRVic salinity database	Interpreted stratigraphy
Eureka database	Bore logs
Tickell & Humphrys (1987)	Isopach contours & bore logs
Lawence (1975)	Bore logs
DPI (2006)	Cross sections
SKM (2007)	Cross sections
Shugg (2005)	Bore logs



Isopachs

Layer 4 thickness is presented below.



Hydraulic conductivity

Uniform hydraulic conductivity of 20 m/day was assigned in layer 4 prior to calibration.

Model layer 5 (deeply weathered geology)

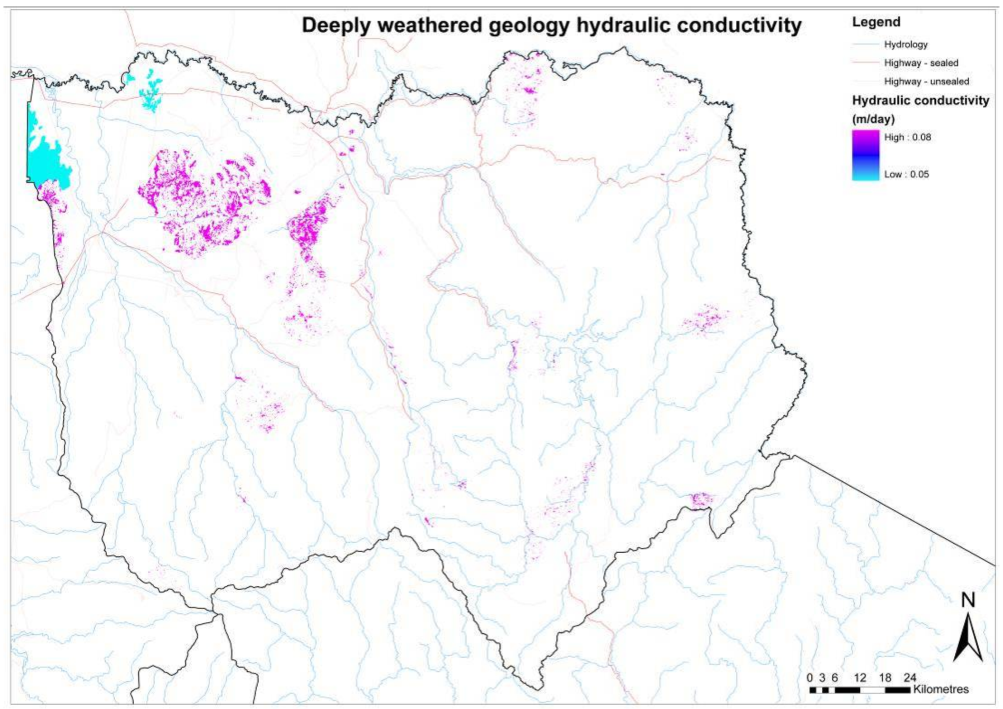
Described previously, model layer 5 is composed of deeply weathered geology. The primary extent of layer 5 was defined by 1:250 000 GFS mapping.

Isopachs

The thickness of layer 5 was determined based upon geology. For Palaeozoic sediments effective thickness was assumed at 20m, and for Devonian granite assumed at 40m. A smoothing algorithm was then applied to ensure a smooth transition on and off the aquifer.

Hydraulic conductivity

Variable hydraulic conductivity was assigned in layer 5 depending on geology, that is, Devonian granite effective thickness was set at 0.8 m/day and Palaeozoic meta-sediments at 0.5 m/day.



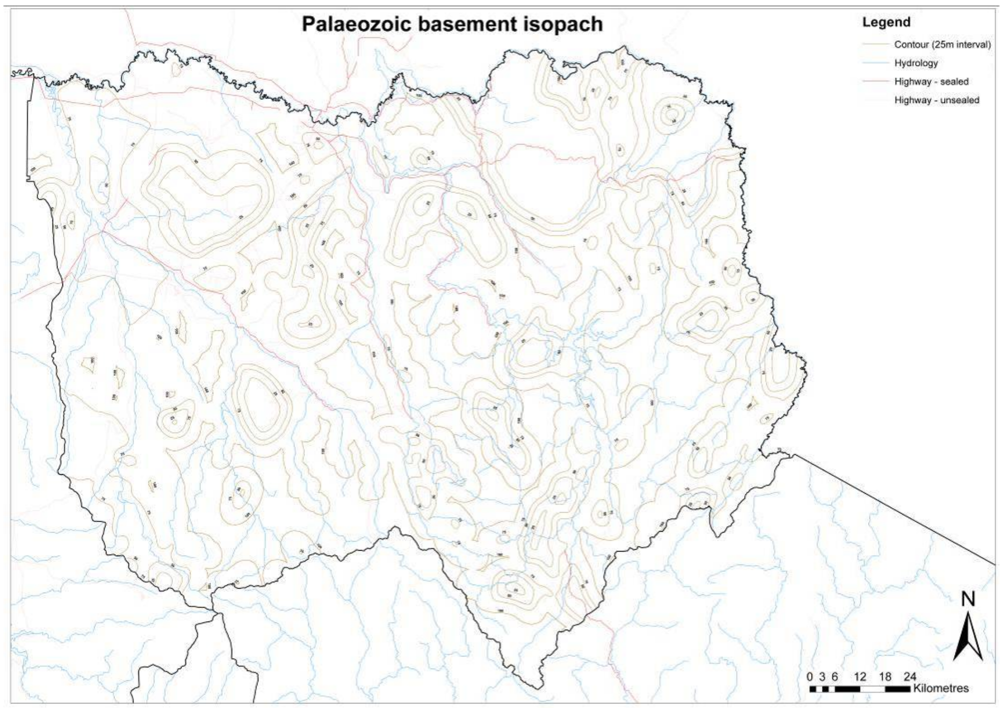
Model layer 6 (Palaeozoic basement)

Described previously, model layer 6 is composed of Palaeozoic basement. The extent of layer 6 was set as the entire model domain as confined/unconfined.

Isopachs

The basement behaves as an aquifer where fractures in the rock are sufficiently open to allow for groundwater transmission. Overburden pressures are believed to moderate/reduce the effective hydraulic conductivity.

The effective thickness of layer 6 when confined was based upon overlying sediment thickness. That is, when unconfined it was assumed the aquifer thickness was 100m and when overlying sediment thickness was greater than 250m aquifer thickness was 10m.



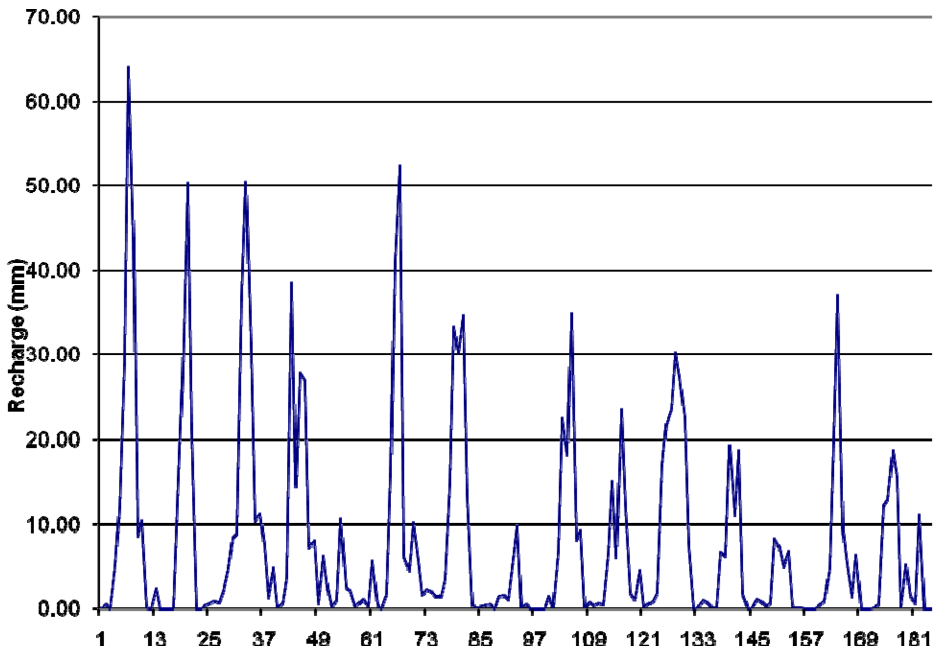
Hydraulic conductivity

Uniform hydraulic conductivity of 0.5 m/day was assigned in layer 6 prior to calibration.

Appendix 3 Calibrated aquifer parameters

Groundwater recharge

Spatially and time varying recharge was applied to the groundwater model as a non-calibratable feature.



Time step	ML	mm	days
1	416.15	0.02	30.4
2	7980.71	0.40	30.4
3	226.85	0.01	30.4
4	99354.57	5.01	30.4
5	233469.63	11.76	30.4
6	576625.37	29.05	30.4
7	71271558.95	64.06	30.4
8	860376.90	43.35	30.4
9	170754.41	8.60	30.4
10	206593.78	10.41	30.4
11	594.15	0.03	30.4
12	60.64	0.00	30.4
13	46861.55	2.36	30.4
14	86.71	0.00	30.4
15	313.11	0.02	30.4
16	311.46	0.02	30.4
17	42.27	0.00	30.4
18	306175.89	15.43	30.4
19	542361.29	27.33	30.4
20	201000277.62	50.40	30.4
21	416831.96	21.00	30.4

22	56.83	0.00	30.4
23	255.87	0.01	30.4
24	7451.17	0.38	30.4
25	10385.45	0.52	30.4
26	16084.96	0.81	30.4
27	13148.37	0.66	30.4
28	38846.30	1.96	30.4
29	95172.29	4.79	30.4
30	164545.36	8.29	30.4
31	173939.12	8.76	30.4
32	733441.21	36.95	30.4
33	331000513.50	50.41	30.4
34	615376.56	31.00	30.4
35	205715.10	10.36	30.4
36	223178.55	11.24	30.4
37	149195.50	7.52	30.4
38	25448.90	1.28	30.4
39	94151.56	4.74	30.4
40	870.06	0.04	30.4
41	11676.75	0.59	30.4
42	71639.83	3.61	30.4
43	763801.60	38.48	30.4
44	287145.42	14.47	30.4
45	553508.25	27.89	30.4
46	532425.12	26.82	30.4
47	140615.86	7.08	30.4
48	157619.22	7.94	30.4
49	10292.12	0.52	30.4
50	123844.77	6.24	30.4
51	48119.13	2.42	30.4
52	2015.23	0.10	30.4
53	18612.56	0.94	30.4
54	211208.52	10.64	30.4
55	49493.94	2.49	30.4
56	42298.99	2.13	30.4
57	3388.35	0.17	30.4
58	10367.39	0.52	30.4
59	20555.27	1.04	30.4
60	3563.70	0.18	30.4
61	110372.71	5.56	30.4
62	6460.72	0.33	30.4
63	19.50	0.00	30.4
64	32903.54	1.66	30.4
65	314587.65	15.85	30.4
66	814867.10	41.05	30.4
67	671040216.07	52.41	30.4
68	120723.61	6.08	30.4
69	88682.48	4.47	30.4
70	199976.42	10.08	30.4
71	112649.74	5.68	30.4

72	32635.12	1.64	30.4
73	45052.23	2.27	30.4
74	39914.54	2.01	30.4
75	27254.61	1.37	30.4
76	28821.06	1.45	30.4
77	65602.55	3.31	30.4
78	292046.54	14.71	30.4
79	661098.51	33.31	30.4
80	596683.65	30.06	30.4
81	687767.45	34.65	30.4
82	264233.62	13.31	30.4
83	6577.11	0.33	30.4
84	2113.76	0.11	30.4
85	4337.80	0.22	30.4
86	5625.96	0.28	30.4
87	8875.68	0.45	30.4
88	21.57	0.00	30.4
89	27793.01	1.40	30.4
90	30978.64	1.56	30.4
91	20195.68	1.02	30.4
92	115168.84	5.80	30.4
93	193662.04	9.76	30.4
94	1055.86	0.05	30.4
95	9897.38	0.50	30.4
96	58.01	0.00	30.4
97	84.95	0.00	30.4
98	359.77	0.02	30.4
99	2.63	0.00	30.4
100	28151.15	1.42	30.4
101	1420.03	0.07	30.4
102	131983.84	6.65	30.4
103	445253.25	22.43	30.4
104	361246.84	18.20	30.4
105	691922.38	34.86	30.4
106	161179.49	8.12	30.4
107	182160.34	9.18	30.4
108	932.99	0.05	30.4
109	14542.02	0.73	30.4
110	5423.53	0.27	30.4
111	10588.87	0.53	30.4
112	8772.00	0.44	30.4
113	127362.91	6.42	30.4
114	299069.28	15.07	30.4
115	121320.52	6.11	30.4
116	466200.48	23.49	30.4
117	240517.14	12.12	30.4
118	34879.82	1.76	30.4
119	20157.03	1.02	30.4
120	90208.95	4.54	30.4
121	2475.31	0.12	30.4

122	7993.05	0.40	30.4
123	15405.31	0.78	30.4
124	34822.73	1.75	30.4
125	336485.12	16.95	30.4
126	431016.23	21.72	30.4
127	465967.54	23.48	30.4
128	599639.67	30.21	30.4
129	544225.19	27.42	30.4
130	446059.89	22.47	30.4
131	148914.25	7.50	30.4
132	333.12	0.02	30.4
133	1045.23	0.05	30.4
134	18232.73	0.92	30.4
135	14248.72	0.72	30.4
136	2936.76	0.15	30.4
137	1343.58	0.07	30.4
138	133251.10	6.71	30.4
139	121596.66	6.13	30.4
140	380602.11	19.18	30.4
141	220707.39	11.12	30.4
142	369338.57	18.61	30.4
143	32618.96	1.64	30.4
144	294.11	0.01	30.4
145	1075.93	0.05	30.4
146	19528.17	0.98	30.4
147	14835.63	0.75	30.4
148	3745.79	0.19	30.4
149	10305.39	0.52	30.4
150	162557.34	8.19	30.4
151	142497.73	7.18	30.4
152	97677.33	4.92	30.4
153	134090.68	6.76	30.4
154	3644.89	0.18	30.4
155	1071.89	0.05	30.4
156	480.45	0.02	30.4
157	120.53	0.01	30.4
158	102.21	0.01	30.4
159	54.65	0.00	30.4
160	7614.19	0.38	30.4
161	16047.67	0.81	30.4
162	94863.66	4.78	30.4
163	392605.01	19.78	30.4
164	734972.48	37.03	30.4
165	184111.69	9.28	30.4
166	104731.04	5.28	30.4
167	28139.60	1.42	30.4
168	125711.41	6.33	30.4
169	183.17	0.01	30.4
170	121.43	0.01	30.4
171	5.35	0.00	30.4

172	1685.20	0.08	30.4
173	7732.90	0.39	30.4
174	241914.11	12.19	30.4
175	256143.75	12.90	30.4
176	368984.96	18.59	30.4
177	306989.36	15.47	30.4
178	1841.42	0.09	30.4
179	100250.44	5.05	30.4
180	28584.20	1.44	30.4
181	10799.77	0.54	30.4
182	219422.42	11.05	30.4
183	293.07	0.01	30.4
184	201.48	0.01	30.4
185	11.33	0.00	30.4
186	290623.76	14.64	30.4
187	361415.53	18.21	30.4
188	613908.56	30.93	30.4
189	477215.45	24.04	30.4
190	91915.82	4.63	30.4
191	120621.15	6.08	30.4
192	19858.72	1.00	30.4
TOTAL	**1301954775.67**	**1609.93**	

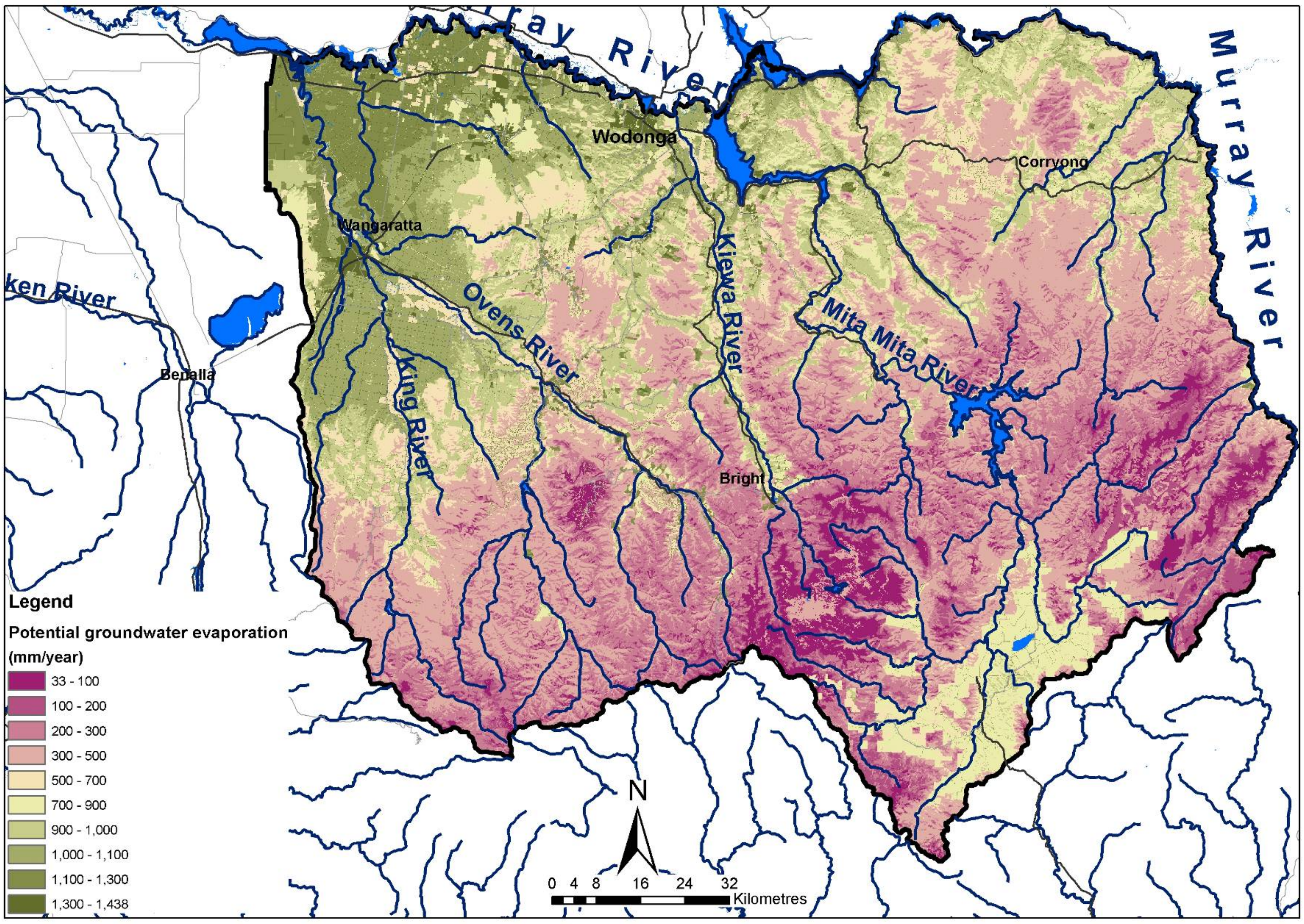
Drainage conductivity

Uniform at 40 000 m^2/day

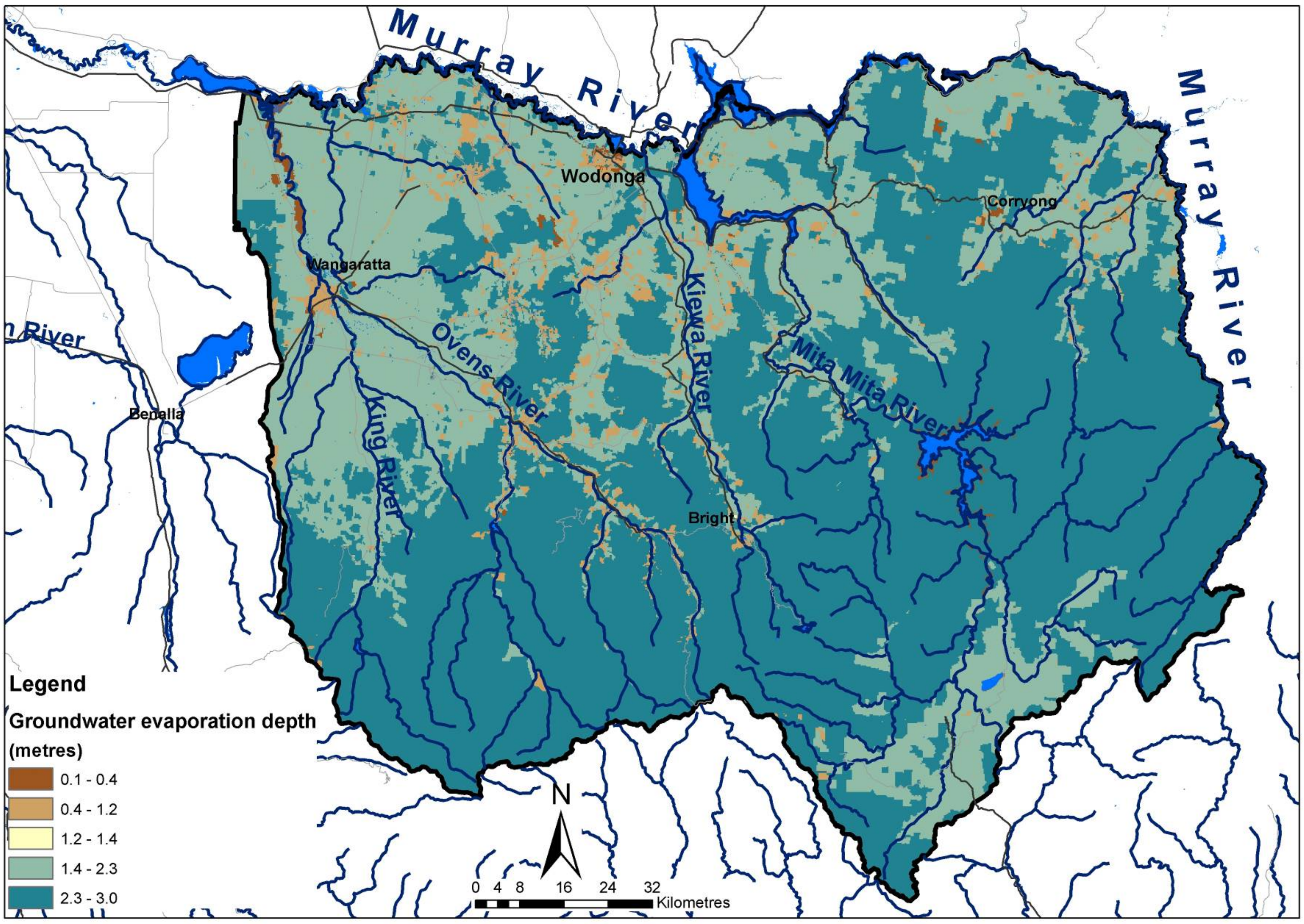
Drainage depth

Set at DEM surface

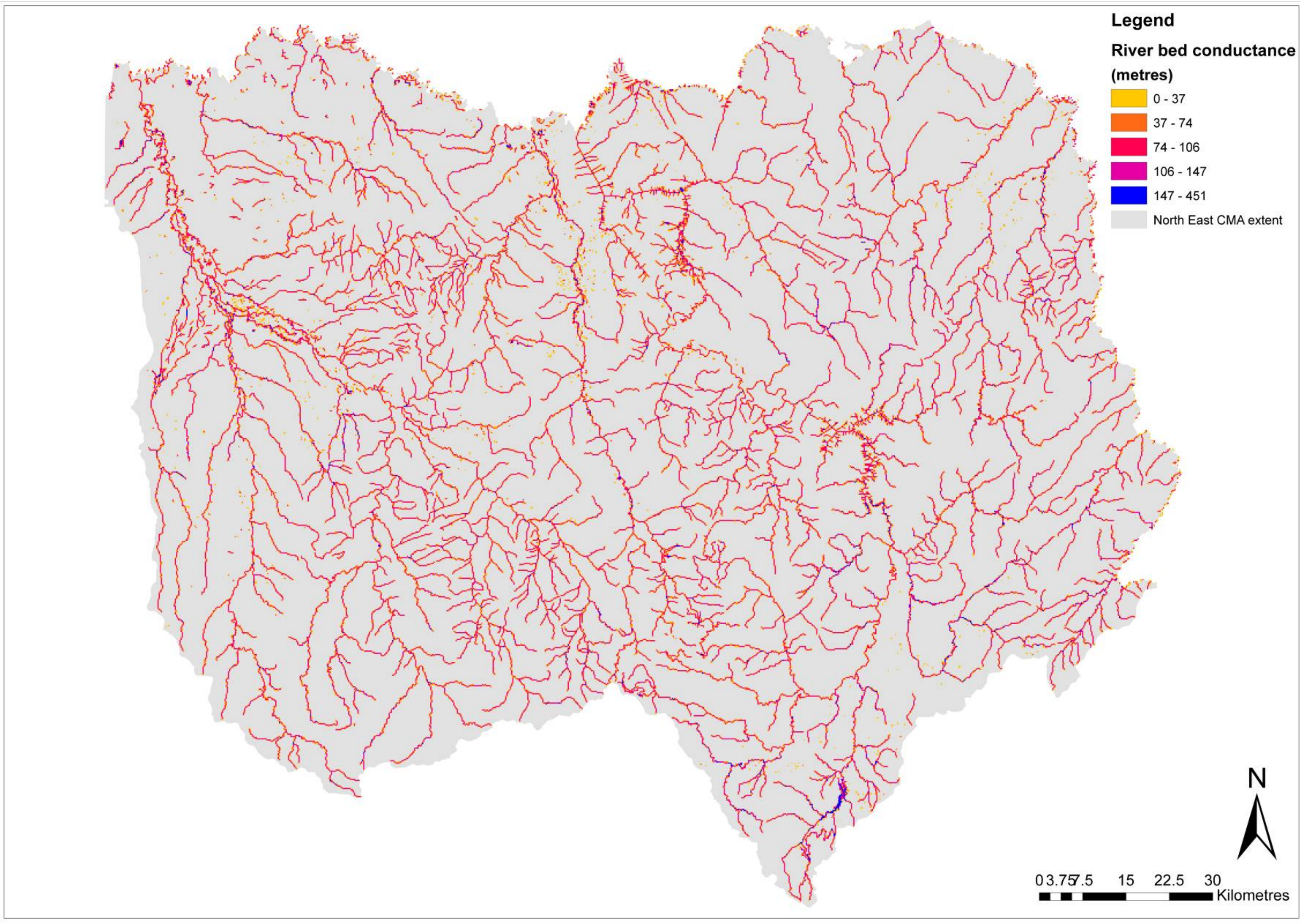
Evaporation rate



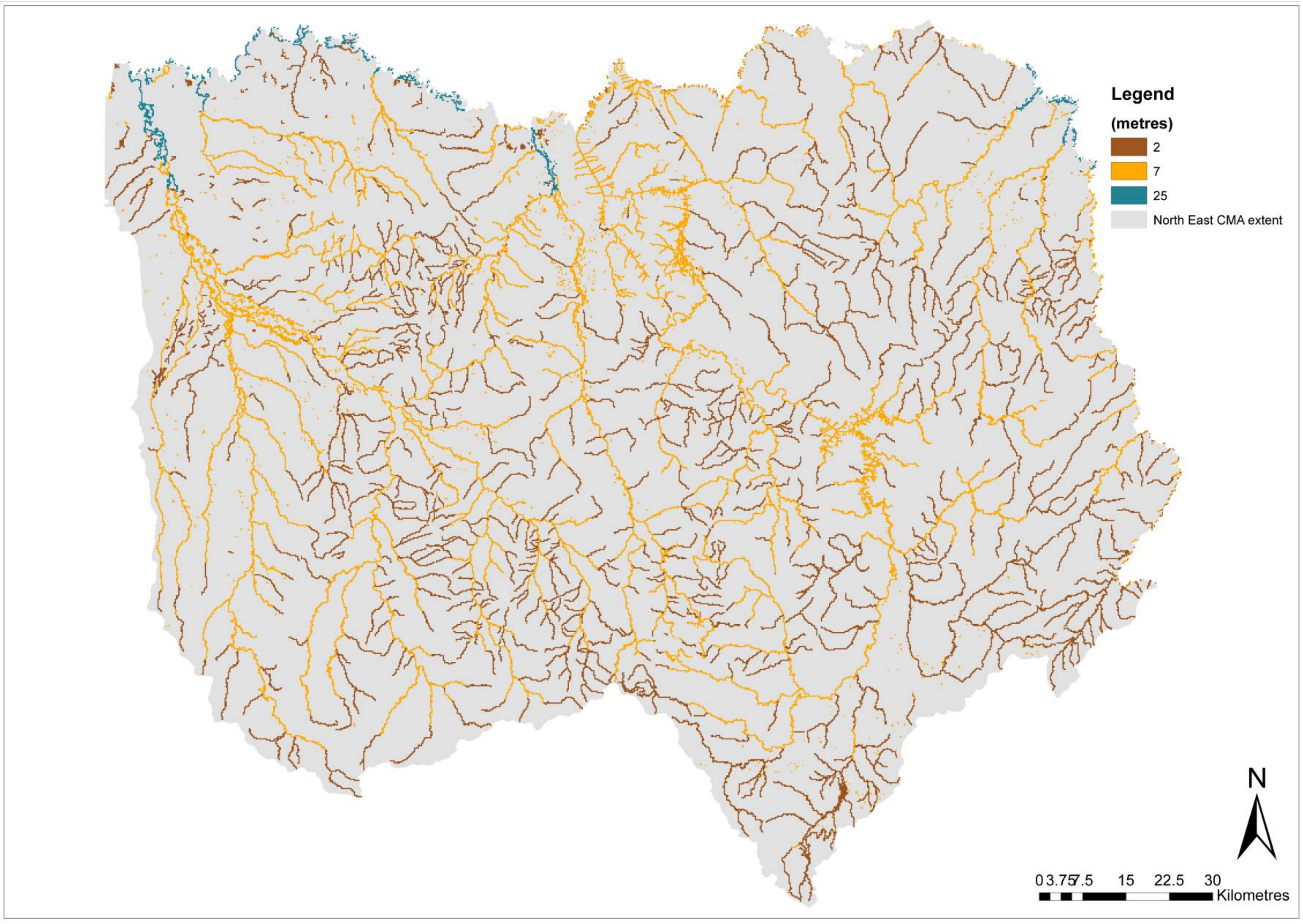
Evaporation depth



River conductivity



River incision depth



Groundwater abstraction

Provided annual groundwater pumping rates were further subdivided into seasonal monthly rates. Irrigation seasonality was assumed to occur between November – April each year. Groundwater pumping rates were held as a non-calibratable attribute.

Time step	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
1	0	0	-0.95	-1.51	0	-0.28
2	0	0	-0.95	-1.51	0	-0.28
3	0	0	-0.95	-1.51	0	-0.28
4	0	0	-0.95	-1.51	0	-0.28
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	-0.95	-1.51	0	-0.28
12	0	0	-0.95	-1.51	0	-0.28
13	0	0	-0.95	-1.51	0	-0.28
14	0	0	-0.95	-1.51	0	-0.28
15	0	0	-0.95	-1.51	0	-0.28
16	0	0	-0.95	-1.51	0	-0.28
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	-0.95	-1.51	0	-0.28
24	0	0	-0.95	-1.51	0	-0.28
25	0	0	-0.95	-1.51	0	-0.28
26	0	0	-0.95	-1.51	0	-0.28
27	0	0	-0.95	-1.51	0	-0.28
28	0	0	-0.95	-1.51	0	-0.28
29	0	0	0	0	0	0
30	0	0	0	0	0	0
31	0	0	0	0	0	0
32	0	0	0	0	0	0
33	0	0	0	0	0	0
34	0	0	0	0	0	0
35	0	0	-0.95	-1.51	0	-0.28
36	0	0	-0.95	-1.51	0	-0.28
37	0	0	-0.95	-1.51	0	-0.28
38	0	0	-0.95	-1.51	0	-0.28
39	0	0	-0.95	-1.51	0	-0.28
40	0	0	-0.95	-1.51	0	-0.28
41	0	0	0	0	0	0
42	0	0	0	0	0	0
43	0	0	0	0	0	0
44	0	0	0	0	0	0
45	0	0	0	0	0	0

46	0	0	0	0	0	0
47	0	0	-0.95	-1.51	0	-0.28
48	0	0	-0.95	-1.51	0	-0.28
49	0	0	-0.95	-1.51	0	-0.28
50	0	0	-0.95	-1.51	0	-0.28
51	0	0	-0.95	-1.51	0	-0.28
52	0	0	-0.95	-1.51	0	-0.28
53	0	0	0	0	0	0
54	0	0	0	0	0	0
55	0	0	0	0	0	0
56	0	0	0	0	0	0
57	0	0	0	0	0	0
58	0	0	0	0	0	0
59	0	0	-0.95	-1.51	0	-0.28
60	0	0	-0.95	-1.51	0	-0.28
61	0	0	-0.95	-1.51	0	-0.28
62	0	0	-0.95	-1.51	0	-0.28
63	0	0	-0.95	-1.51	0	-0.28
64	0	0	-0.95	-1.51	0	-0.28
65	0	0	0	0	0	0
66	0	0	0	0	0	0
67	0	0	0	0	0	0
68	0	0	0	0	0	0
69	0	0	0	0	0	0
70	0	0	0	0	0	0
71	0	0	-0.95	-1.51	0	-0.28
72	0	0	-0.95	-1.51	0	-0.28
73	0	0	-0.95	-1.51	0	-0.28
74	0	0	-0.95	-1.51	0	-0.28
75	0	0	-0.95	-1.51	0	-0.28
76	0	0	-0.95	-1.51	0	-0.28
77	0	0	0	0	0	0
78	0	0	0	0	0	0
79	0	0	0	0	0	0
80	0	0	0	0	0	0
81	0	0	0	0	0	0
82	0	0	0	0	0	0
83	0	0	-0.95	-1.51	0	-0.28
84	0	0	-0.95	-1.51	0	-0.28
85	0	0	-0.95	-1.51	0	-0.28
86	0	0	-0.95	-1.51	0	-0.28
87	0	0	-0.95	-1.51	0	-0.28
88	0	0	-0.95	-1.51	0	-0.28
89	0	0	0	0	0	0
90	0	0	0	0	0	0
91	0	0	0	0	0	0
92	0	0	0	0	0	0
93	0	0	0	0	0	0
94	0	0	0	0	0	0
95	0	0	-0.95	-1.51	0	-0.28

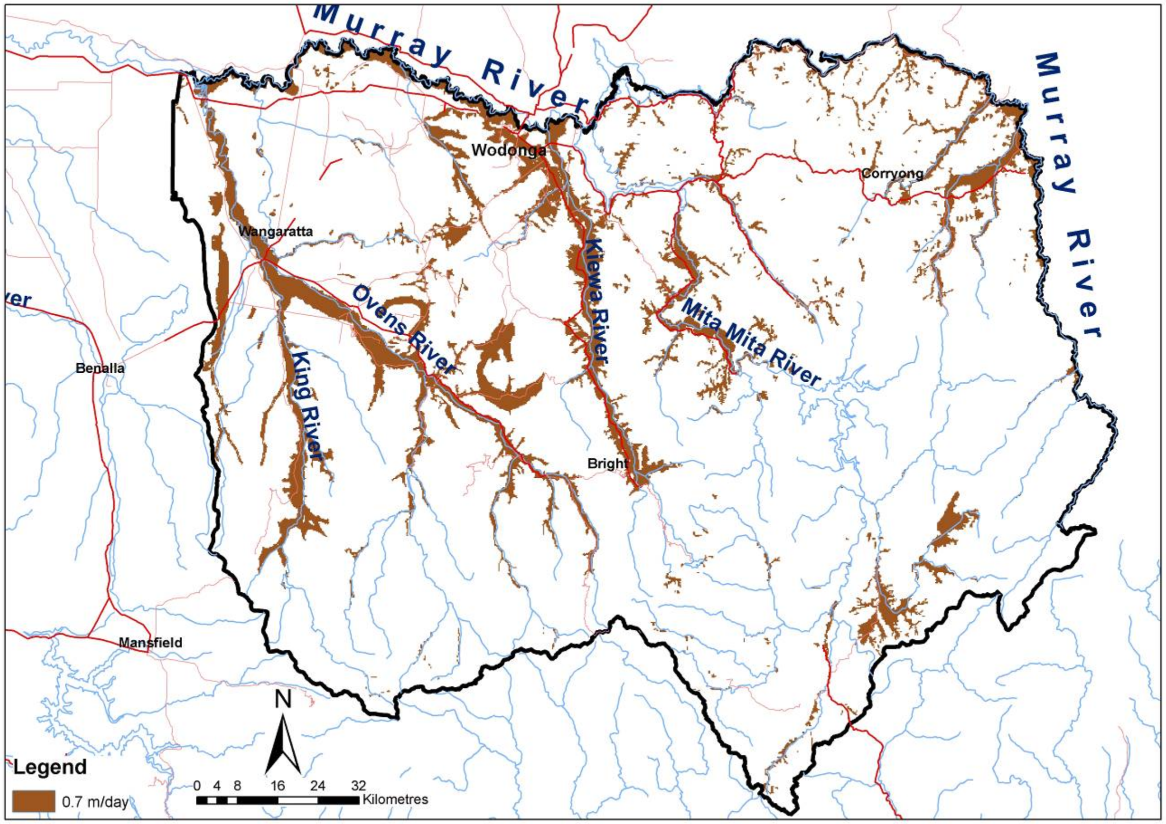
96	0	0	-0.95	-1.51	0	-0.28
97	0	0	-0.95	-1.51	0	-0.28
98	0	0	-0.95	-1.51	0	-0.28
99	0	0	-0.95	-1.51	0	-0.28
100	0	0	-0.95	-1.51	0	-0.28
101	0	0	0	0	0	0
102	0	0	0	0	0	0
103	0	0	0	0	0	0
104	0	0	0	0	0	0
105	0	0	0	0	0	0
106	0	0	0	0	0	0
107	0	0	-0.95	-1.51	0	-0.28
108	0	0	-0.95	-1.51	0	-0.28
109	0	0	-0.95	-1.51	0	-0.28
110	0	0	-0.95	-1.51	0	-0.28
111	0	0	-0.95	-1.51	0	-0.28
112	0	0	-0.95	-1.51	0	-0.28
113	0	0	0	0	0	0
114	0	0	0	0	0	0
115	0	0	0	0	0	0
116	0	0	0	0	0	0
117	0	0	0	0	0	0
118	0	0	0	0	0	0
119	0	0	-0.95	-1.51	0	-0.28
120	0	0	-0.95	-1.51	0	-0.28
121	0	0	-0.95	-1.51	0	-0.28
122	0	0	-0.95	-1.51	0	-0.28
123	0	0	-0.95	-1.51	0	-0.28
124	0	0	-0.95	-1.51	0	-0.28
125	0	0	0	0	0	0
126	0	0	0	0	0	0
127	0	0	0	0	0	0
128	0	0	0	0	0	0
129	0	0	0	0	0	0
130	0	0	0	0	0	0
131	0	0	-0.95	-1.51	0	-0.28
132	0	0	-0.95	-1.51	0	-0.28
133	0	0	-0.95	-1.51	0	-0.28
134	0	0	-0.95	-1.51	0	-0.28
135	0	0	-0.95	-1.51	0	-0.28
136	0	0	-0.95	-1.51	0	-0.28
137	0	0	0	0	0	0
138	0	0	0	0	0	0
139	0	0	0	0	0	0
140	0	0	0	0	0	0
141	0	0	0	0	0	0
142	0	0	0	0	0	0
143	0	0	-0.95	-1.51	0	-0.28
144	0	0	-0.95	-1.51	0	-0.28
145	0	0	-0.95	-1.51	0	-0.28

146	0	0	-0.95	-1.51	0	-0.28
147	0	0	-0.95	-1.51	0	-0.28
148	0	0	-0.95	-1.51	0	-0.28
149	0	0	0	0	0	0
150	0	0	0	0	0	0
151	0	0	0	0	0	0
152	0	0	0	0	0	0
153	0	0	0	0	0	0
154	0	0	0	0	0	0
155	0	0	-0.95	-1.51	0	-0.28
156	0	0	-0.95	-1.51	0	-0.28
157	0	0	-0.95	-1.51	0	-0.28
158	0	0	-0.95	-1.51	0	-0.28
159	0	0	-0.95	-1.51	0	-0.28
160	0	0	-0.95	-1.51	0	-0.28
161	0	0	0	0	0	0
162	0	0	0	0	0	0
163	0	0	0	0	0	0
164	0	0	0	0	0	0
165	0	0	0	0	0	0
166	0	0	0	0	0	0
167	0	0	-0.95	-1.51	0	-0.28
168	0	0	-0.95	-1.51	0	-0.28
169	0	0	-0.95	-1.51	0	-0.28
170	0	0	-0.95	-1.51	0	-0.28
171	0	0	-0.95	-1.51	0	-0.28
172	0	0	-0.95	-1.51	0	-0.28
173	0	0	0	0	0	0
174	0	0	0	0	0	0
175	0	0	0	0	0	0
176	0	0	0	0	0	0
177	0	0	0	0	0	0
178	0	0	0	0	0	0
179	0	0	-0.95	-1.51	0	-0.28
180	0	0	-0.95	-1.51	0	-0.28
181	0	0	-0.95	-1.51	0	-0.28
182	0	0	-0.95	-1.51	0	-0.28
183	0	0	-0.95	-1.51	0	-0.28
184	0	0	-0.95	-1.51	0	-0.28
185	0	0	0	0	0	0
186	0	0	0	0	0	0
187	0	0	0	0	0	0
188	0	0	0	0	0	0
189	0	0	0	0	0	0
190	0	0	0	0	0	0
191	0	0	-0.95	-1.51	0	-0.28
192	0	0	-0.95	-1.51	0	-0.28
TOTAL	**0**	**0**	**-91.2**	**-144.96**	**0**	**-26.88**

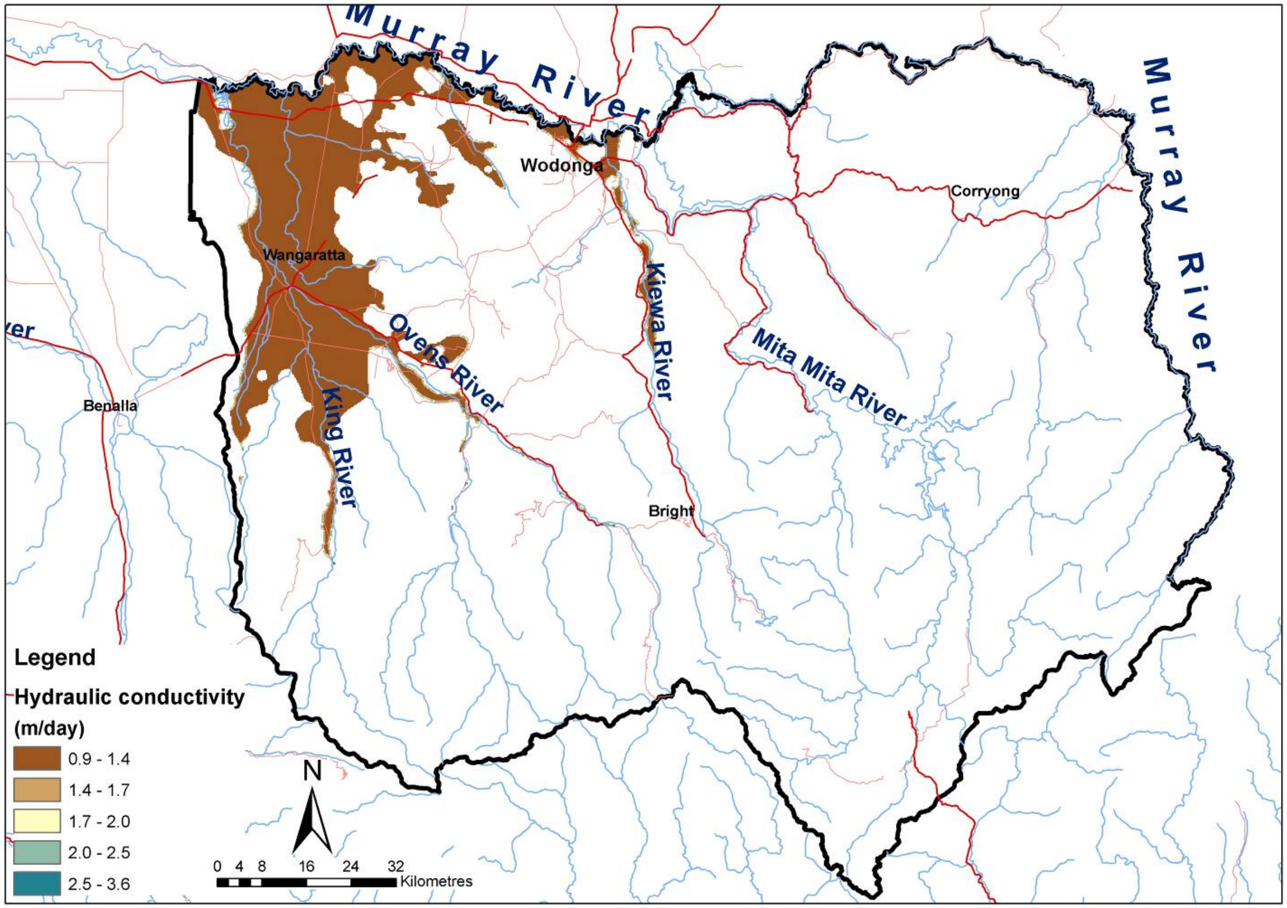
Appendix 4 Calibrated aquifer parameters

Hydraulic conductivity (m/day)

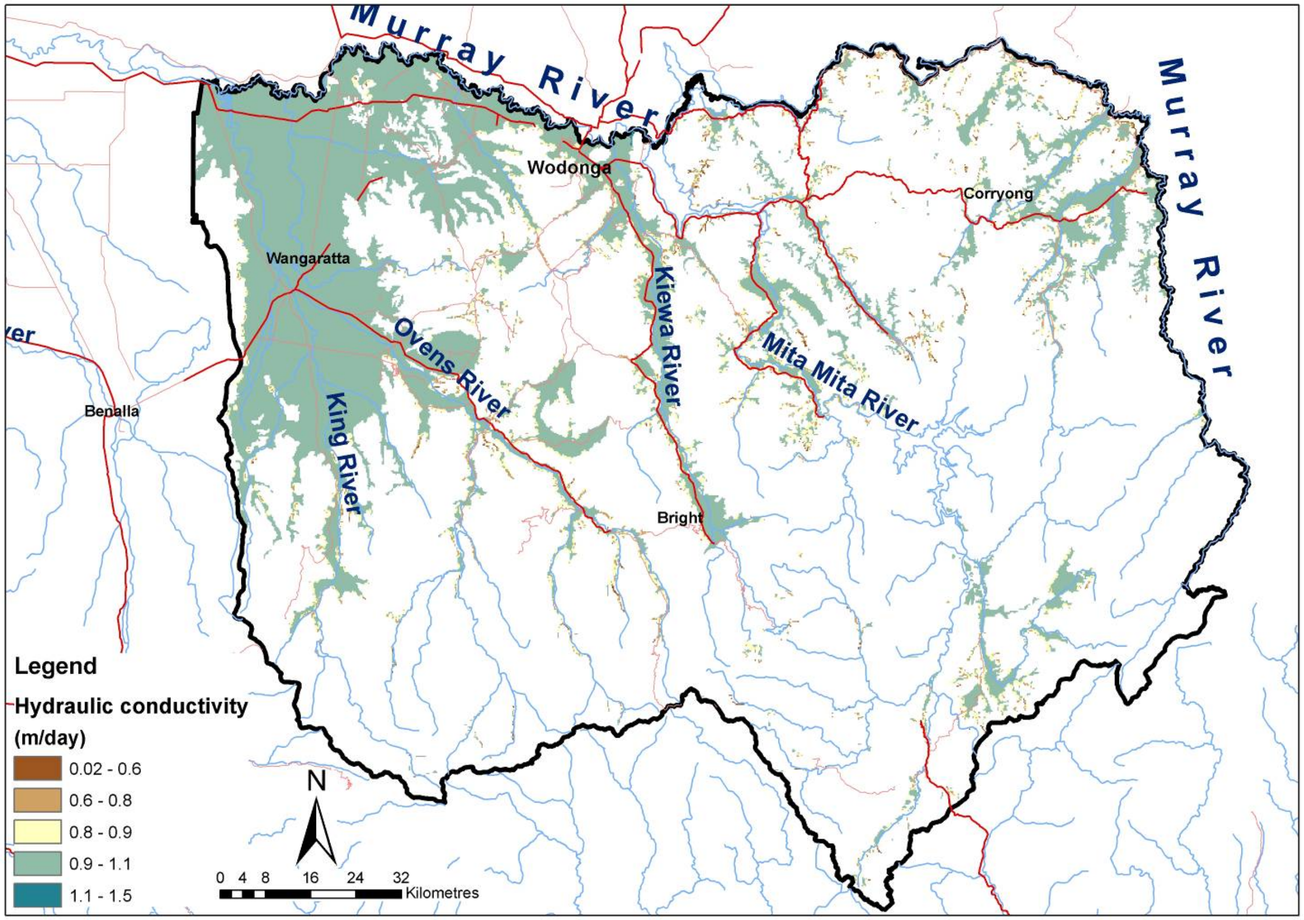
Layer 1 (Coonambidgal Formation)



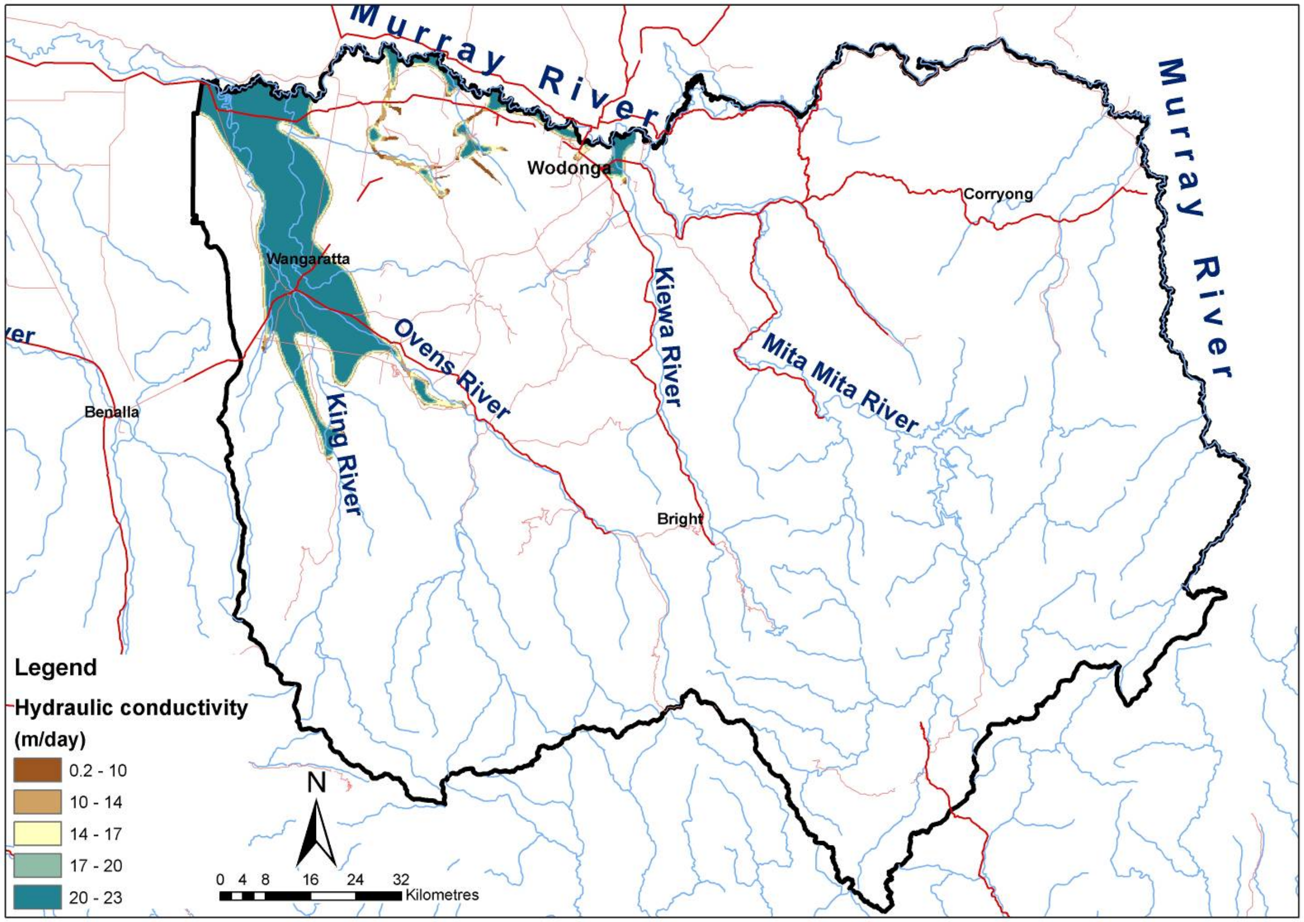
Layer 2 (upper Shepparton Formation)



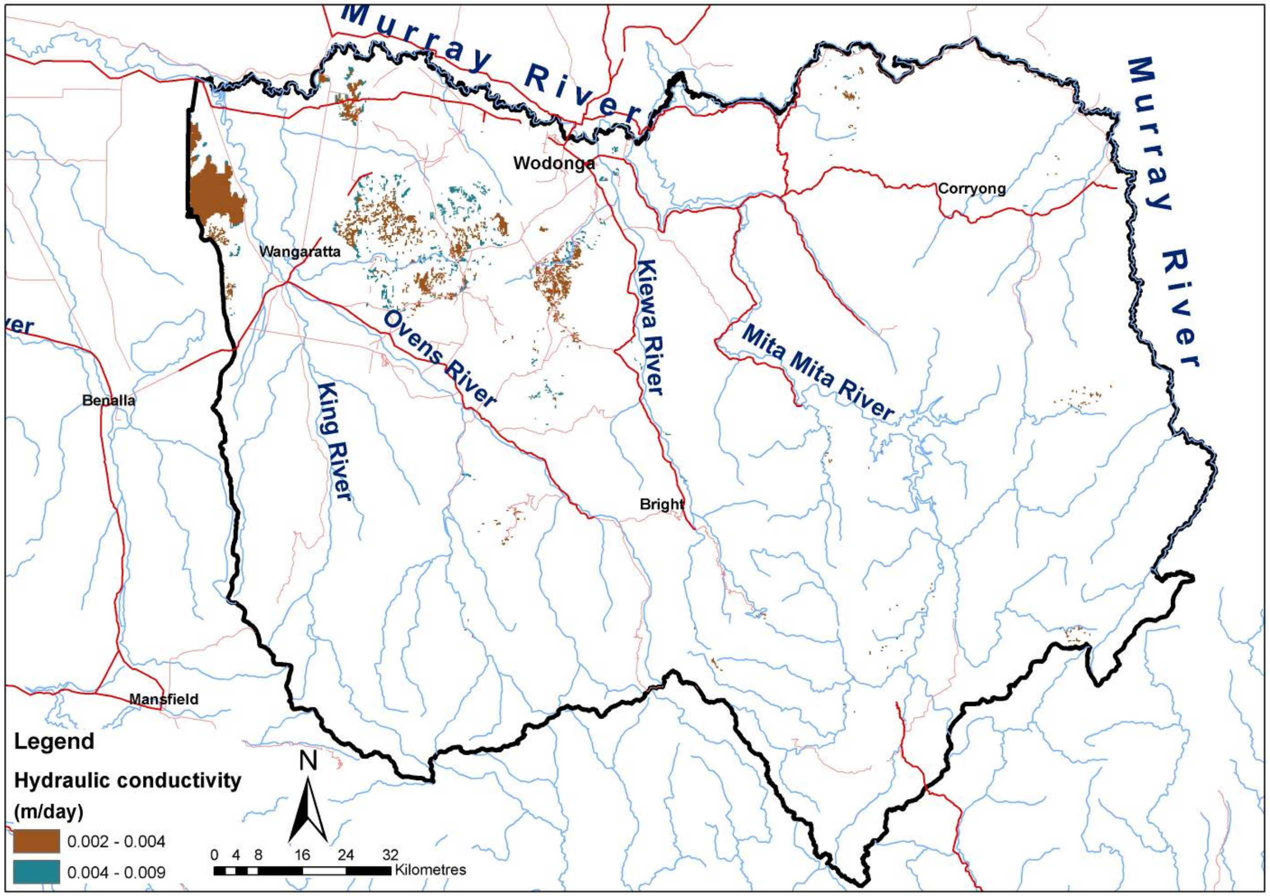
Layer 3 (lower Shepparton Formation)



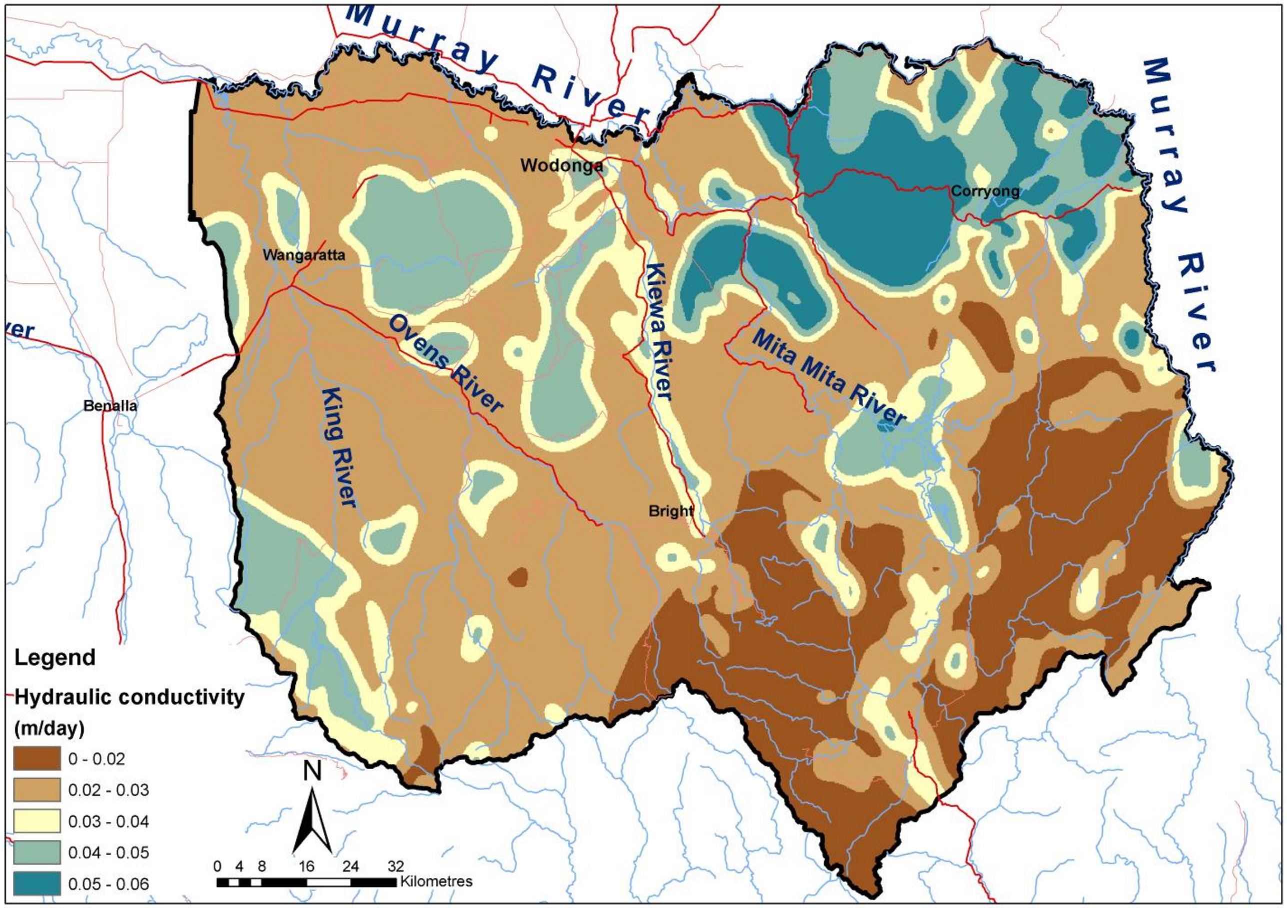
__Layer 4 (Calivil Formation)__



Layer 5 (Deeply weathered Palaeozoic meta sediments)

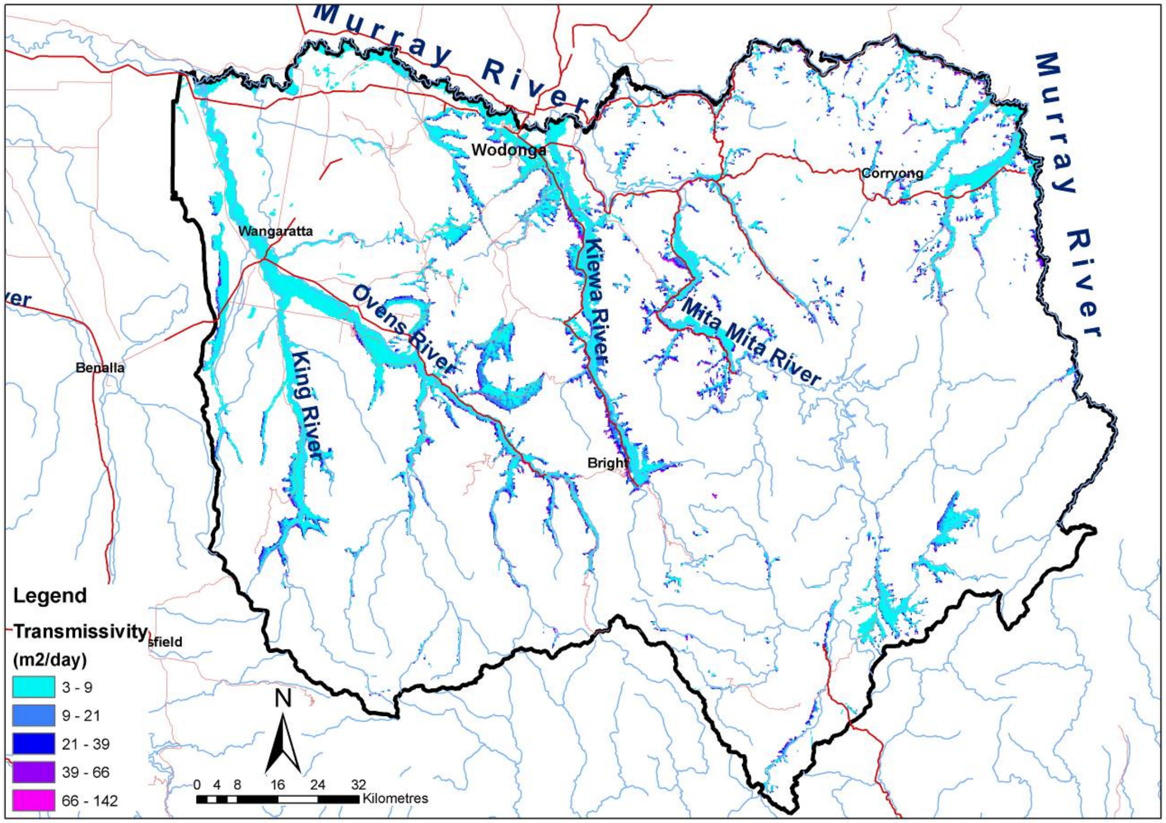


Layer 6 (Palaeozoic meta sediments)

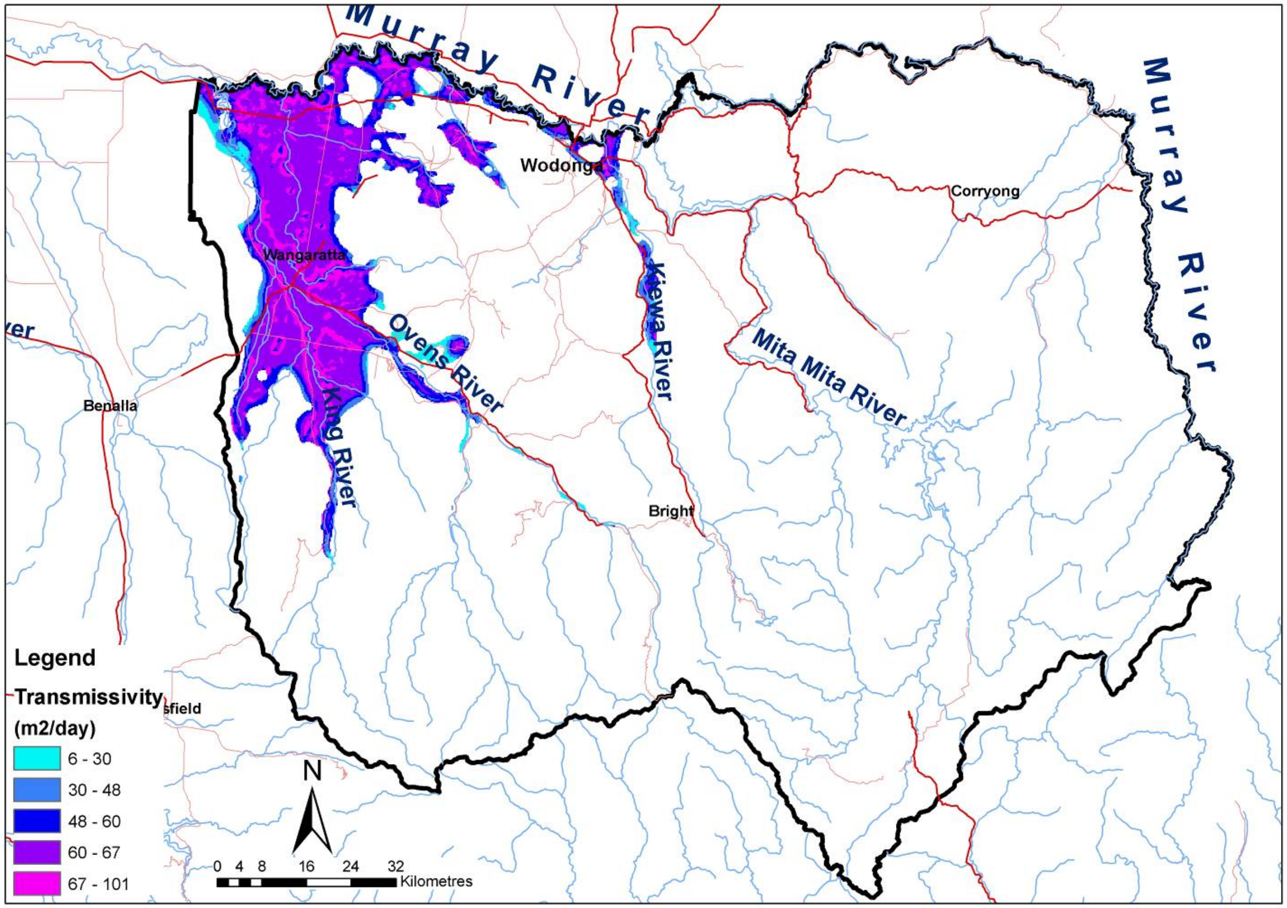


Transmissivity (m2/day)

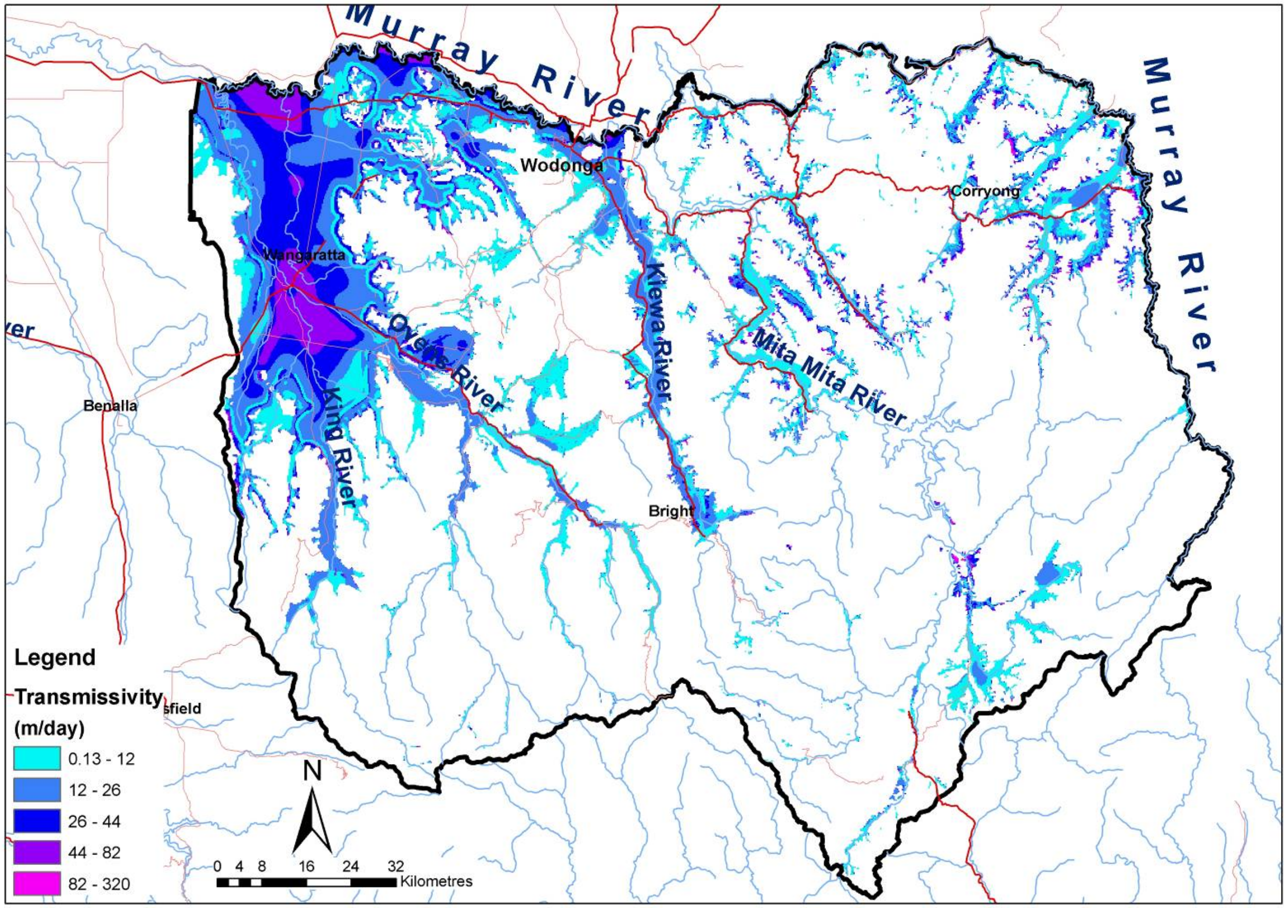
Layer 1 (Coonambidgal Formation)



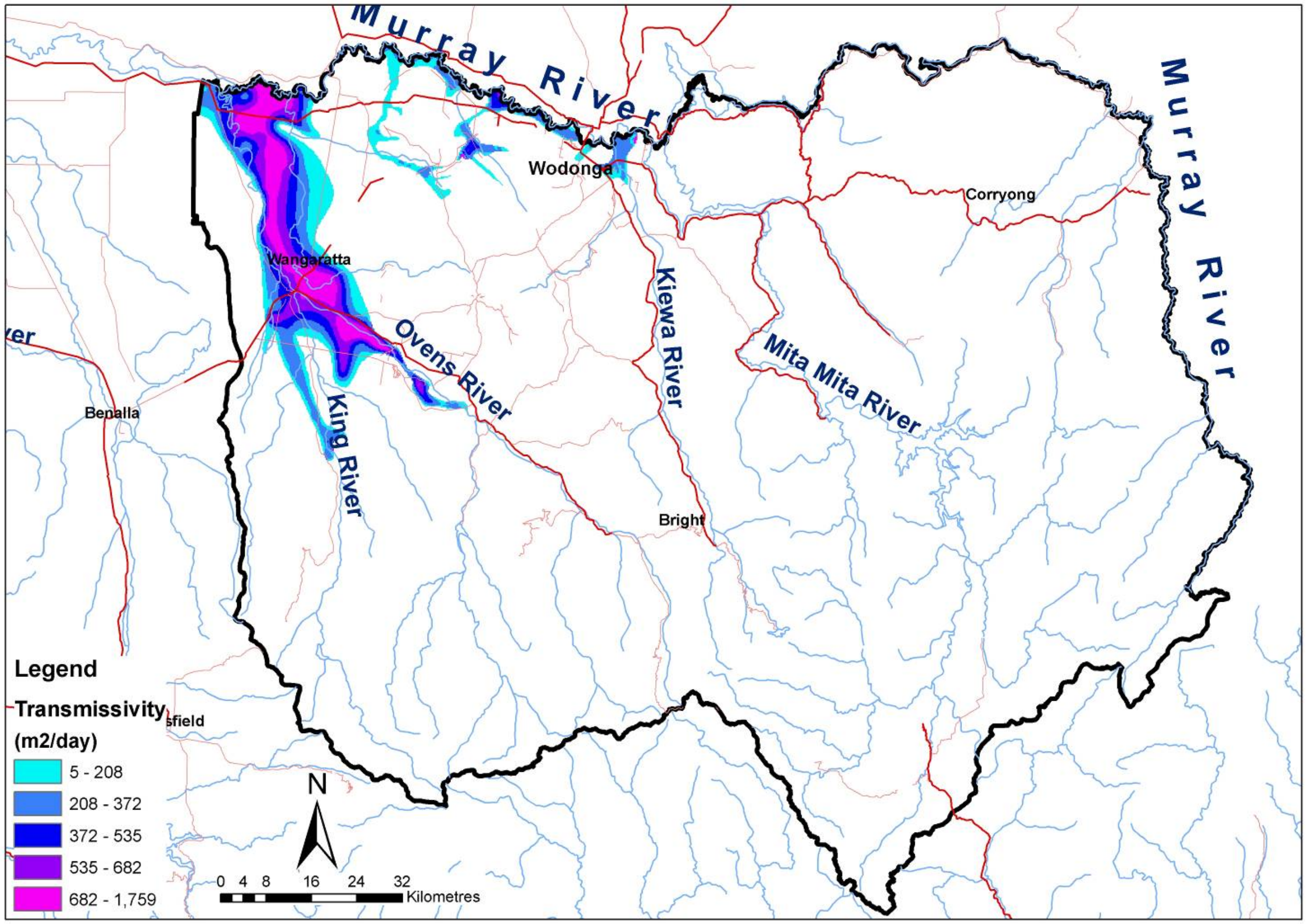
Layer 2 (upper Shepparton Formation)



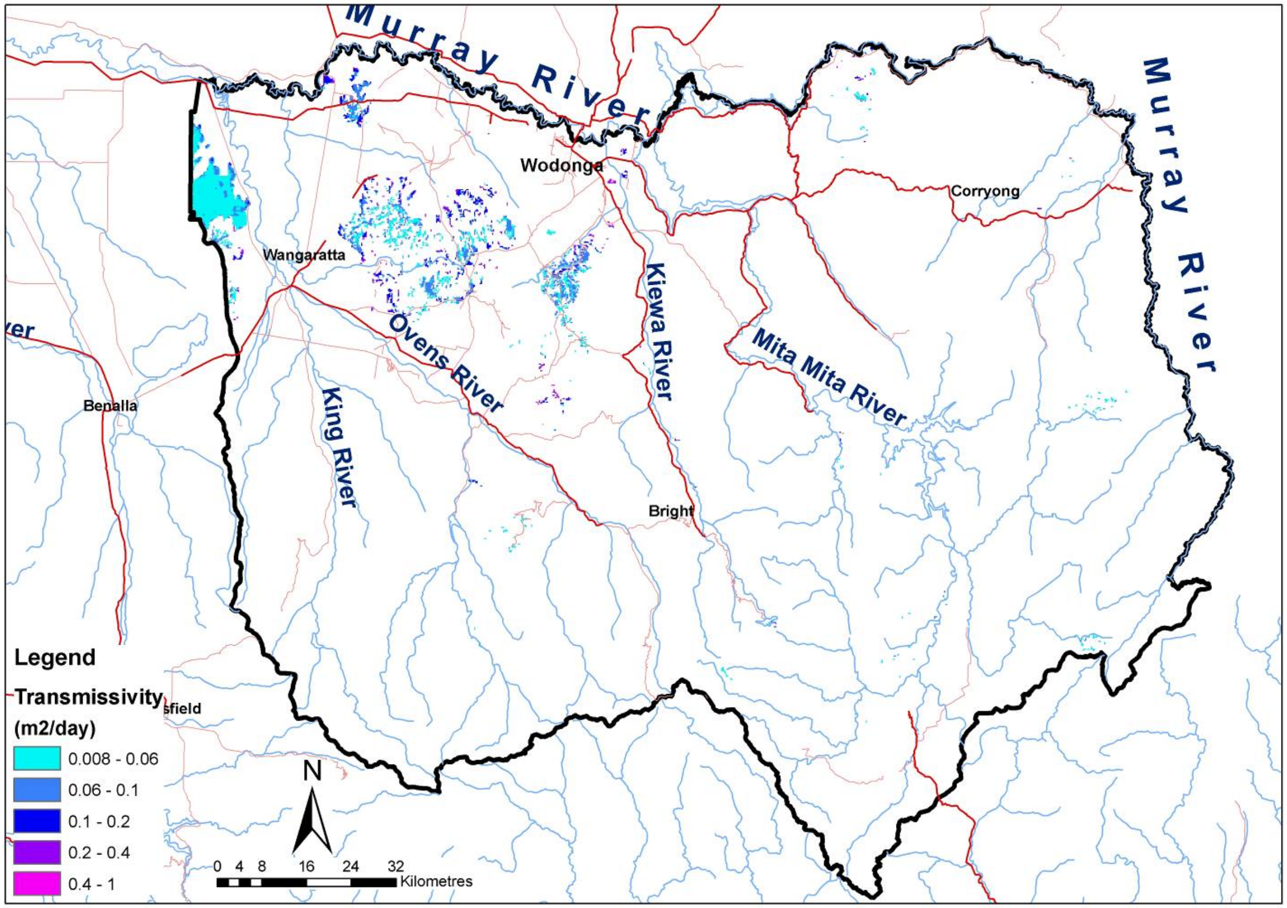
Layer 3 (lower Shepparton Formation)



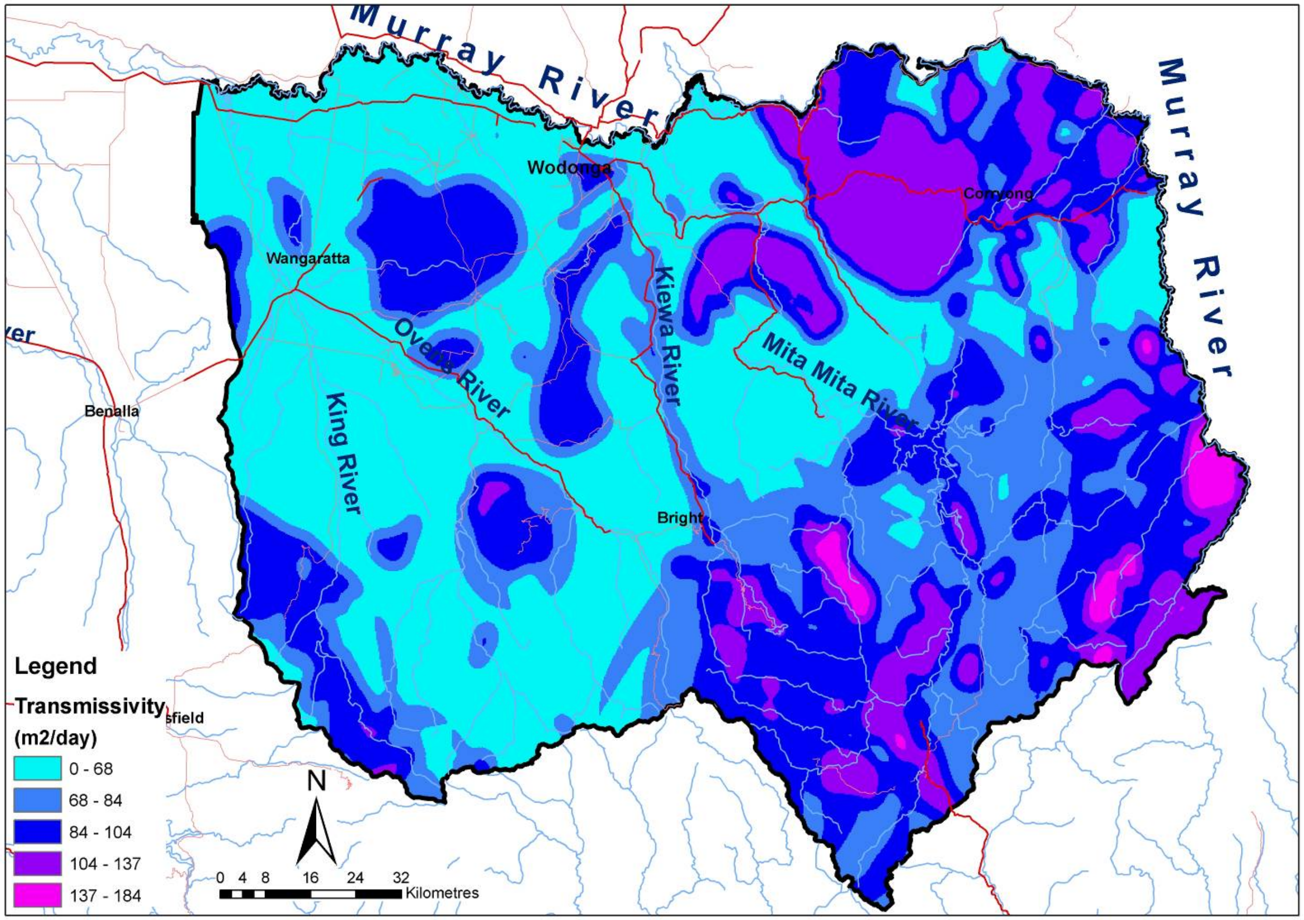
Layer 4 (Calivil Formation)



Layer 5 (Deeply weathered Palaeozoic meta sediments)



Layer 6 (Palaeozoic meta sediments)



Vcont

Vcont (1/day) Layer 1 (Coonambidgal Formation)

Uniform value of 6.3×10^{-4} 1/day

Vcont (1/day) Layer 2 (upper Shepparton Formation)

Uniform value of 1.8×10^{-4} 1/day

Vcont (1/day) Layer 3(lower Shepparton Formation)

Uniform value of 3.9×10^{-4} 1/day

Vcont (1/day) Layer 4 (Calivil Formation)

Uniform value of 4.2×10^{-4} 1/day

Vcont (1/day) Layer 5 (deeply weathered Palaeozoic basement)

Uniform value of $2.\ 5 \times 10^{-4}$ 1/day

Specific yield

Specific yield (unit less) Layer 1 (Coonambidgal Formation)

Uniform value of 0.10

Specific yield (unit less) Layer 2 (upper Shepparton Formation)

Uniform value of 0.04

Specific yield (unit less) Layer 3 (lower Shepparton Formation)

Uniform value of 0.12

Specific yield (unit less) Layer 4 (Calivil Formation)

Uniform value of 0.20

Specific yield (unit less) Layer 5 (deeply weathered geology)

Uniform value of 0.001

Specific yield (unit less) Layer 6 (Palaeozoic basement)

Uniform value of 0.02

Confined storage

Confined storage (unit less) Layer 2 (upper Shepparton Formation)

Uniform value of 7.7×10^{-6}

Confined storage (unit less) Layer 3 (lower Shepparton Formation)

Uniform value of 1.5×10^{-4}

Confined storage (unit less) Layer 4 (Calivil Formation)

Uniform value of 2.6×10^{-4}

Confined storage (unit less) Layer 5 (deeply weathered basement)

Uniform value of 1.0×10^{-5}

Confined storage (unit less) Layer 6 (Palaeozoic basement)

Uniform value of 0.9×10^{-6}

Appendix 5 Water level contour maps

Model layer 1

Model layer 2

Model layer 3

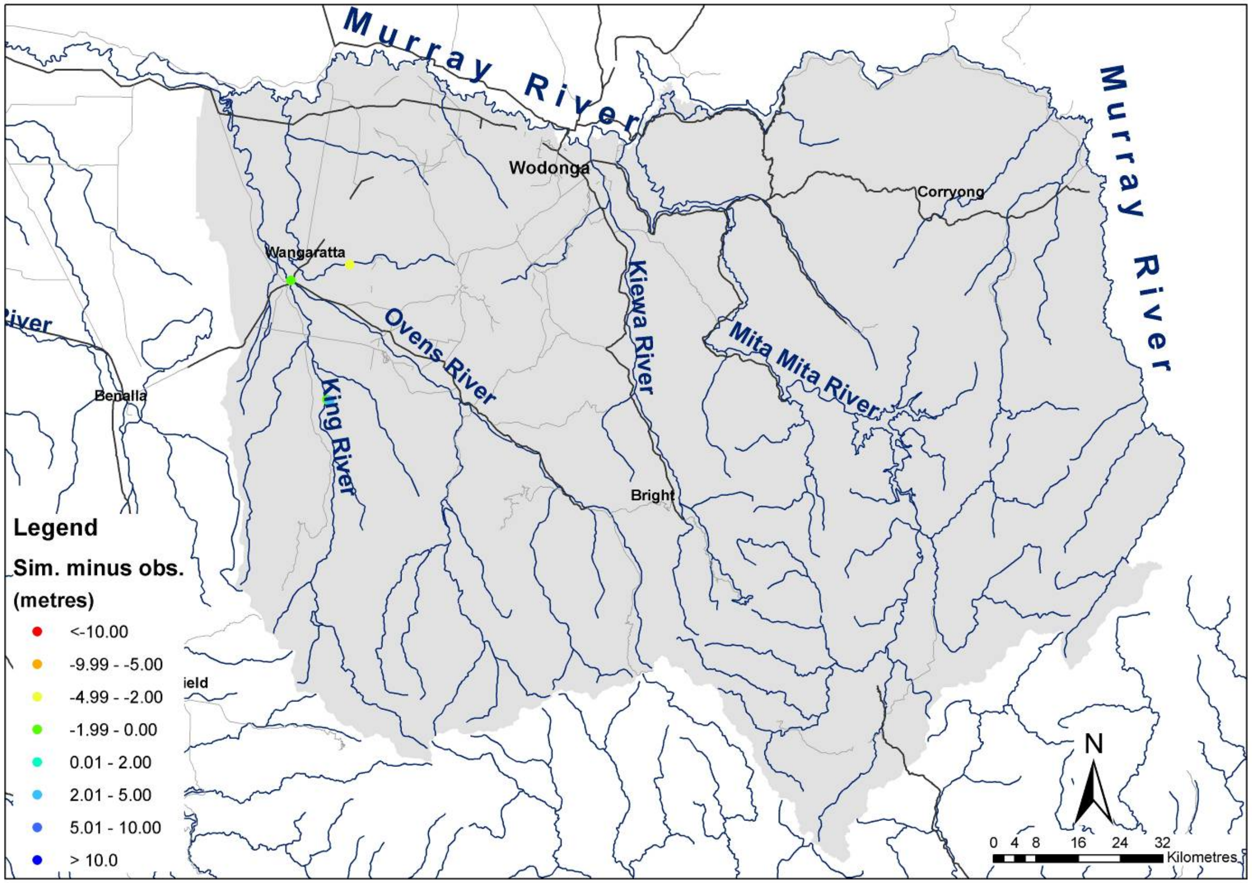
Model layer 4

Model layer 5

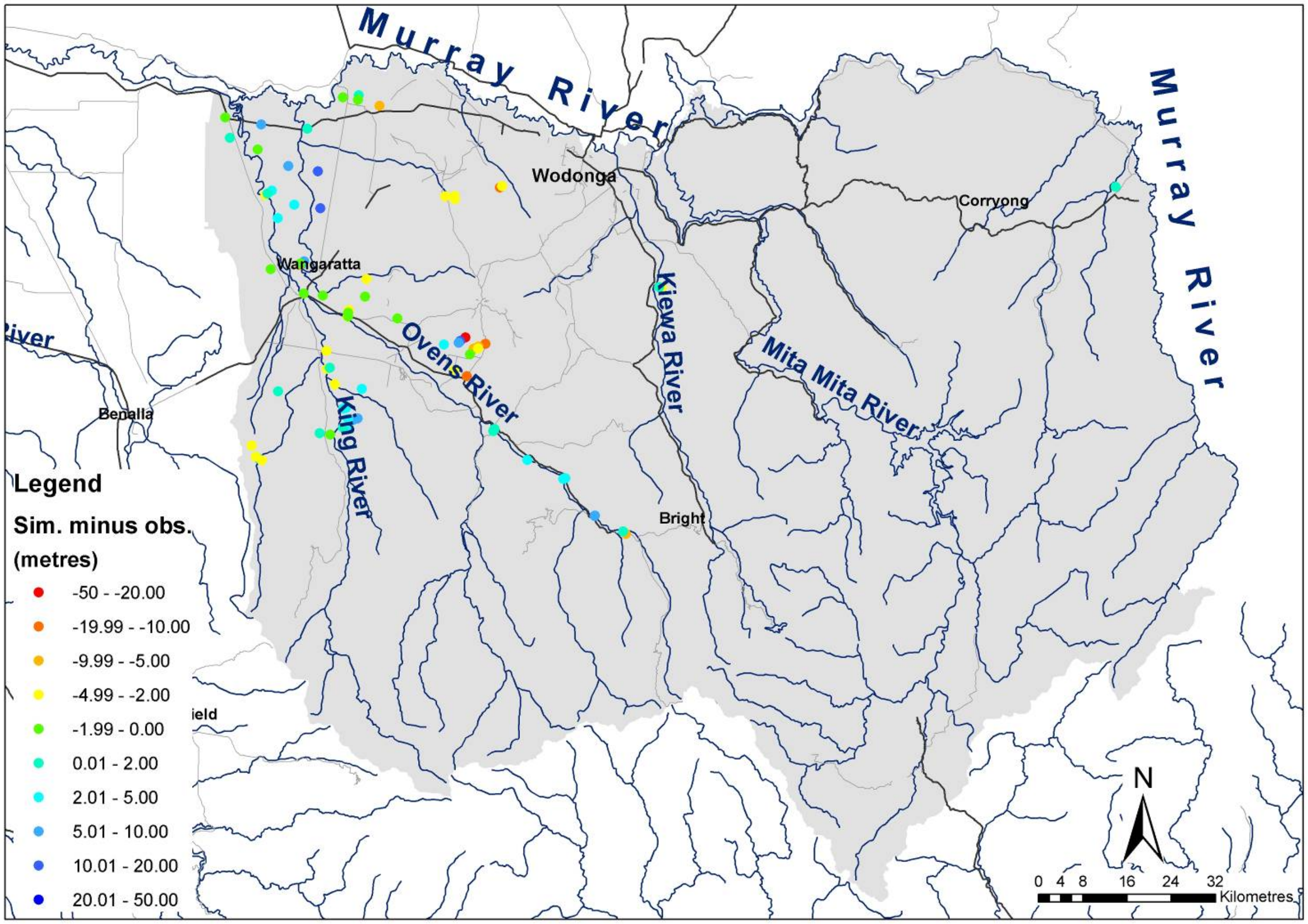
Model layer 6

Appendix 6 Simulated versus observed water level data

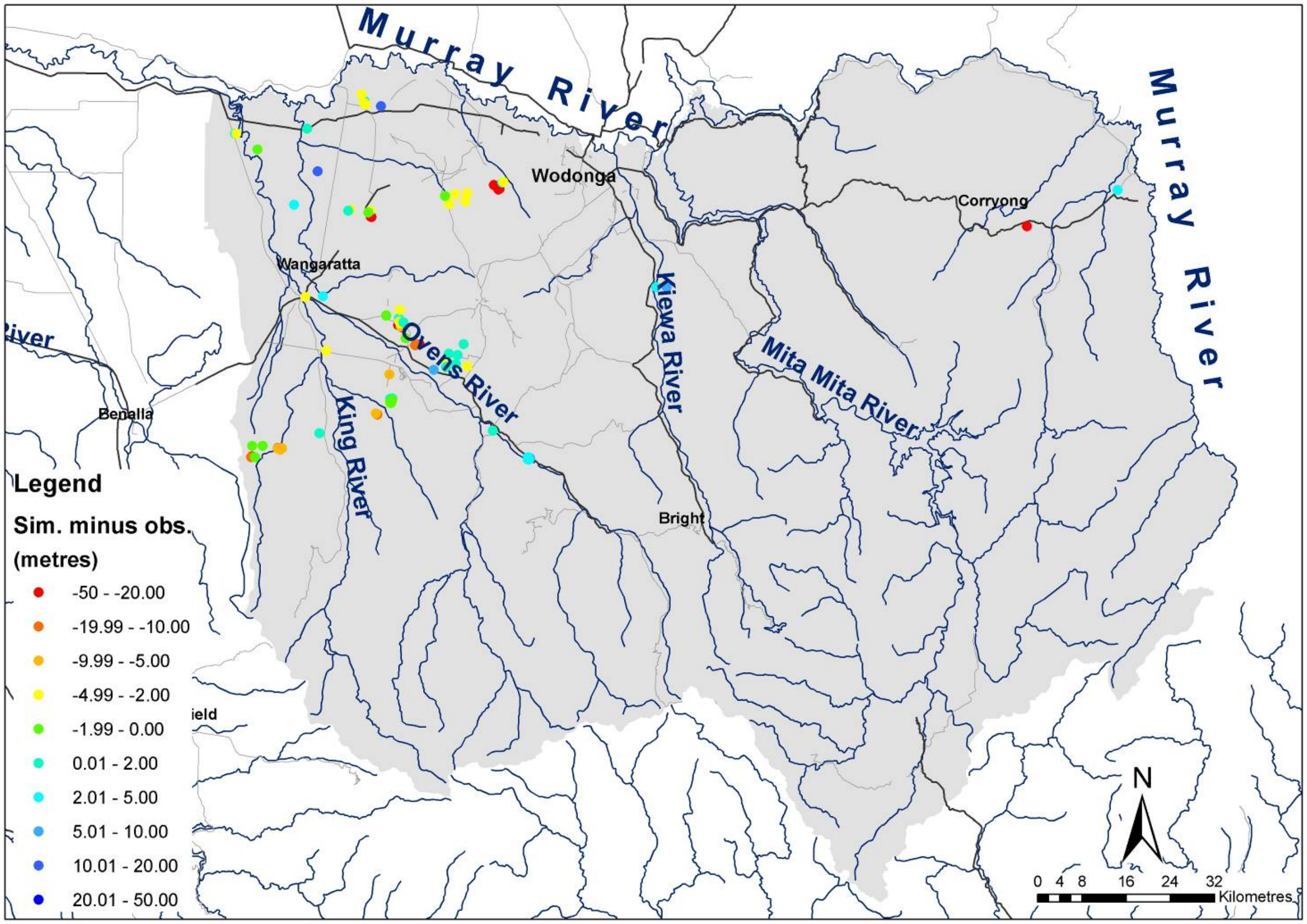
Layer 1 (Coonambidgal Formation)



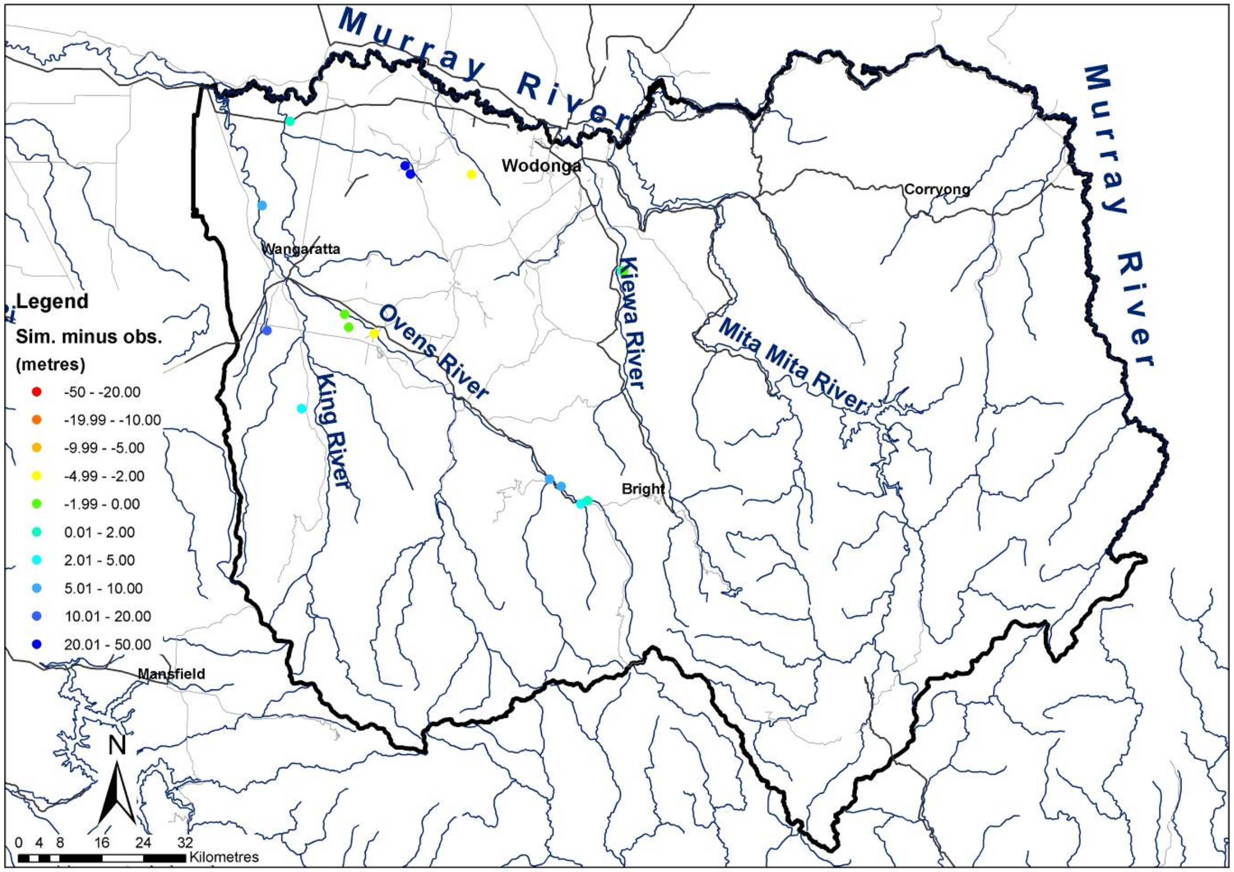
Layer 2 (upper Shepparton Formation)



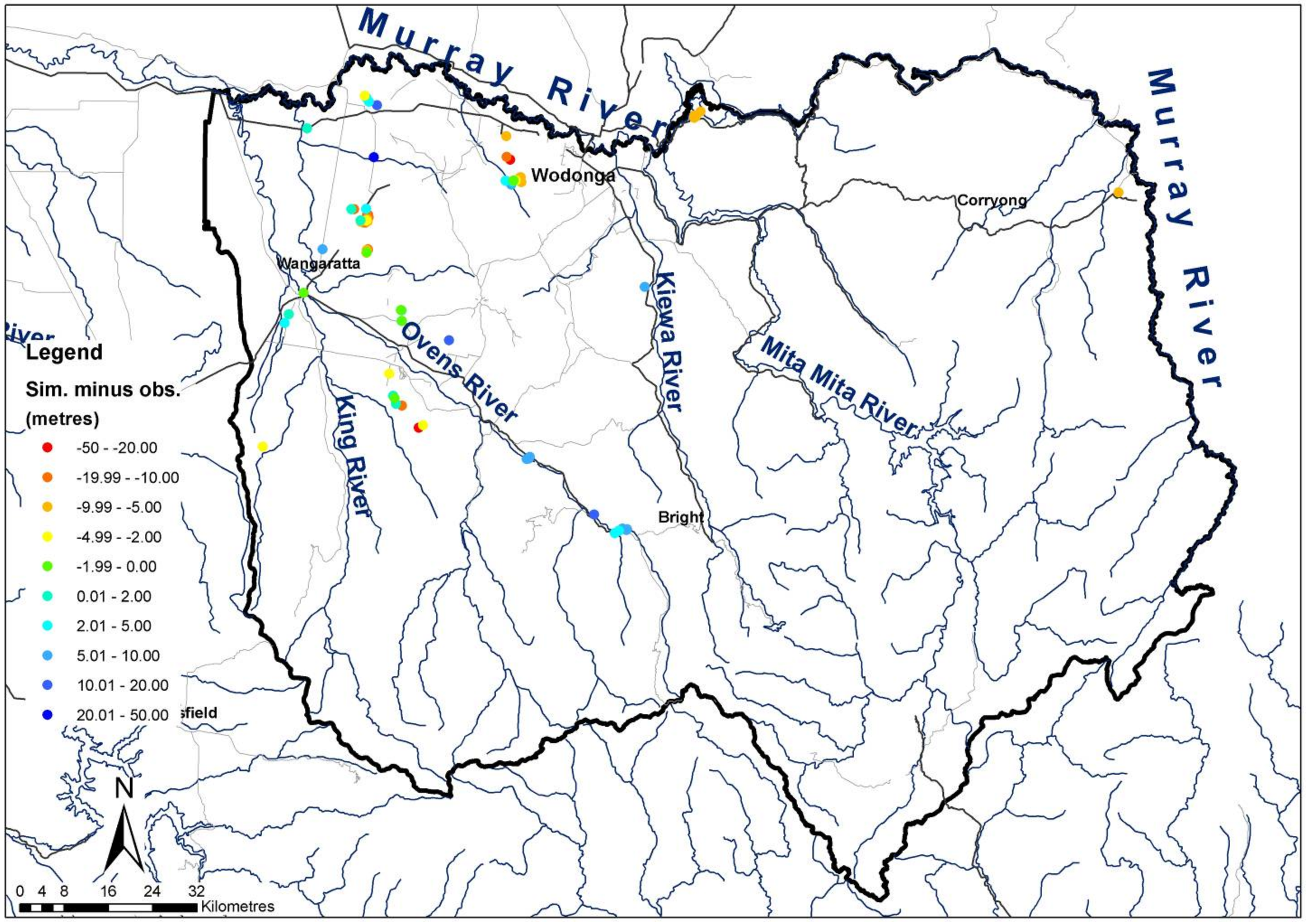
Layer 3 (lower Shepparton Formation)



Layer 4 (Calivil Formation)



Layer 6 (Palaeozoic meta sediments)



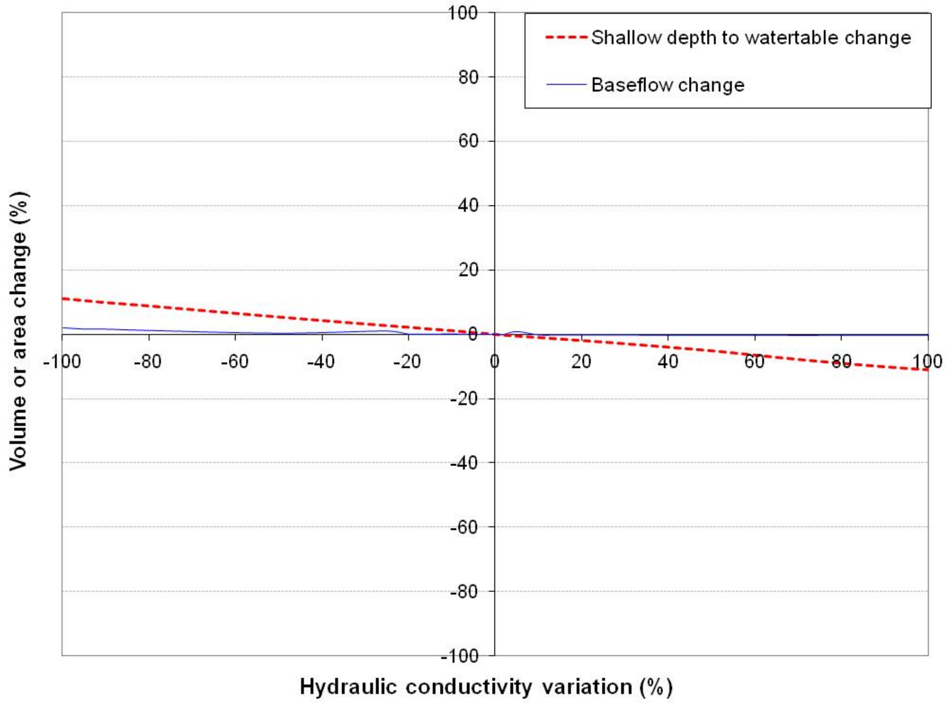
Appendix 7 Model sensitivity analysis

Model sensitivity analysis was undertaken to demonstrate the implications varying model parameters have relative to the model result. Depth to watertable area less than 2m has been used as the reference for model sensitivity and multiplied by values presented below. Attribute sensitivity to scale RMS was undertaken to identify the impact attribute variance had on observed versus simulated groundwater levels.

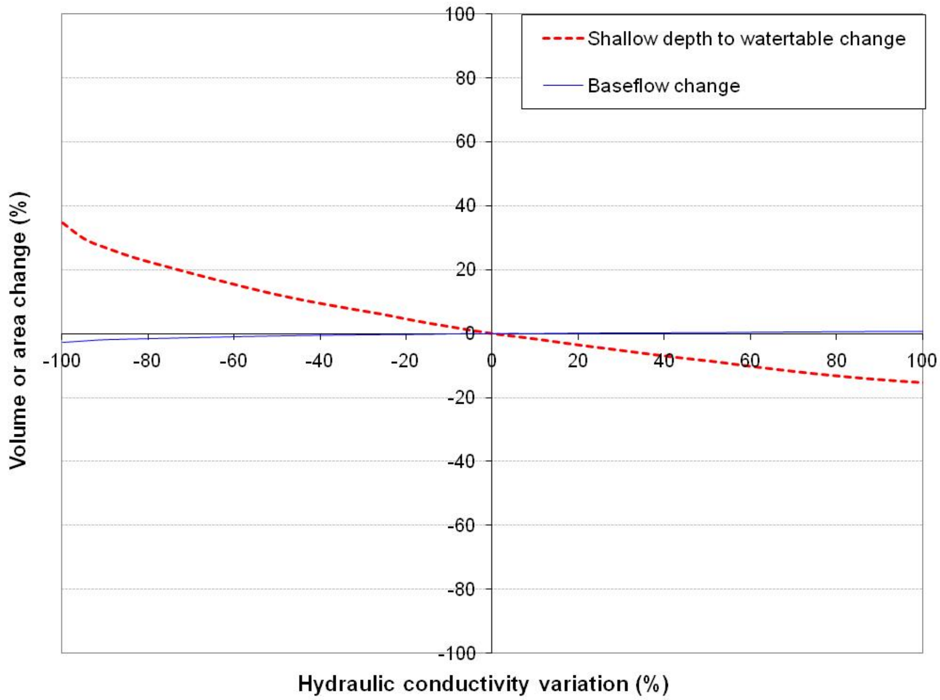
Model attribute difference (%)
-100
-95
-90
-80
-50
-25
-20
-15
-10
-5
-2
-1
1
2
5
10
15
20
25
50
80
90
95
100

Hydraulic conductivity

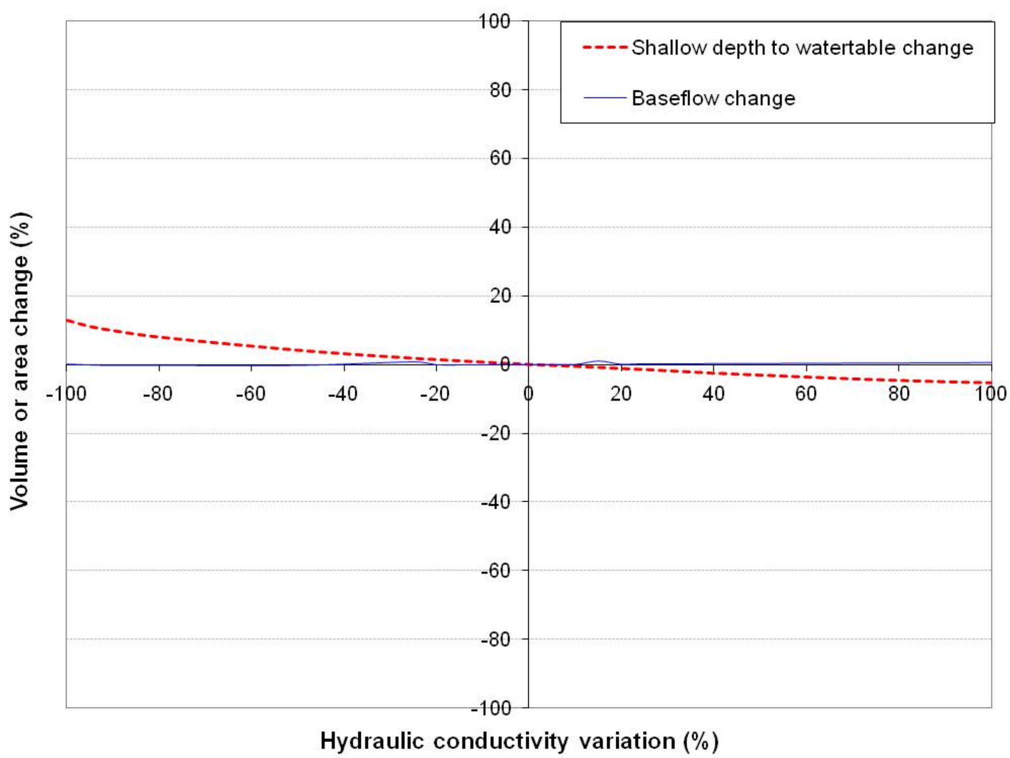
Hydraulic conductivity – layer 1



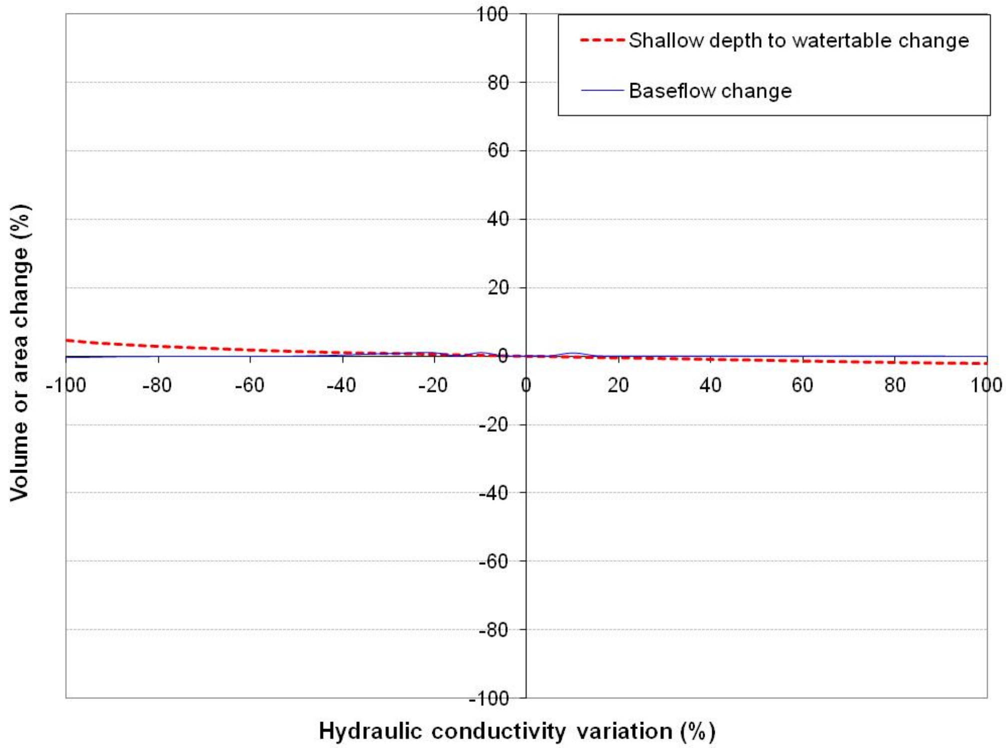
Hydraulic conductivity – layer 2



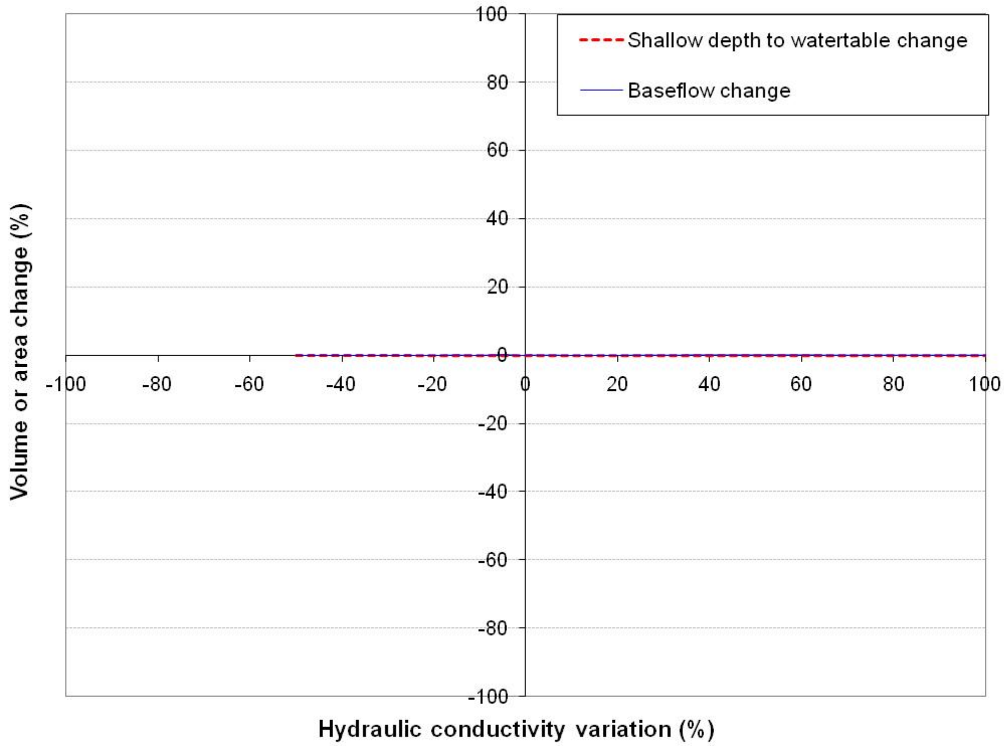
Hydraulic conductivity – layer 3



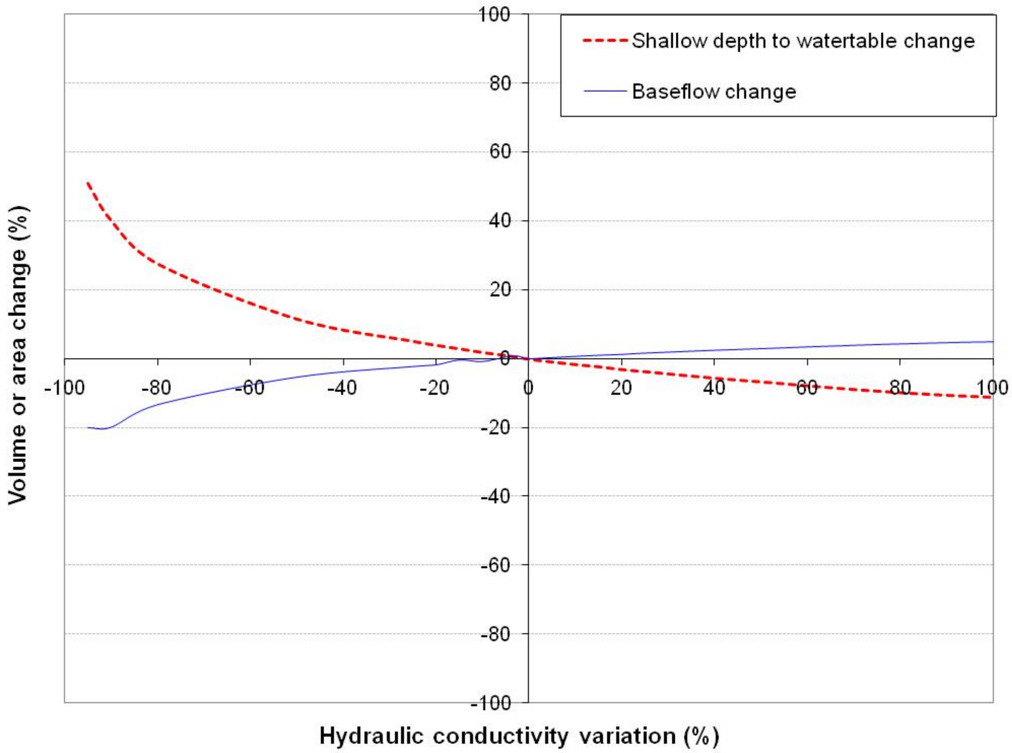
Hydraulic conductivity – layer 4



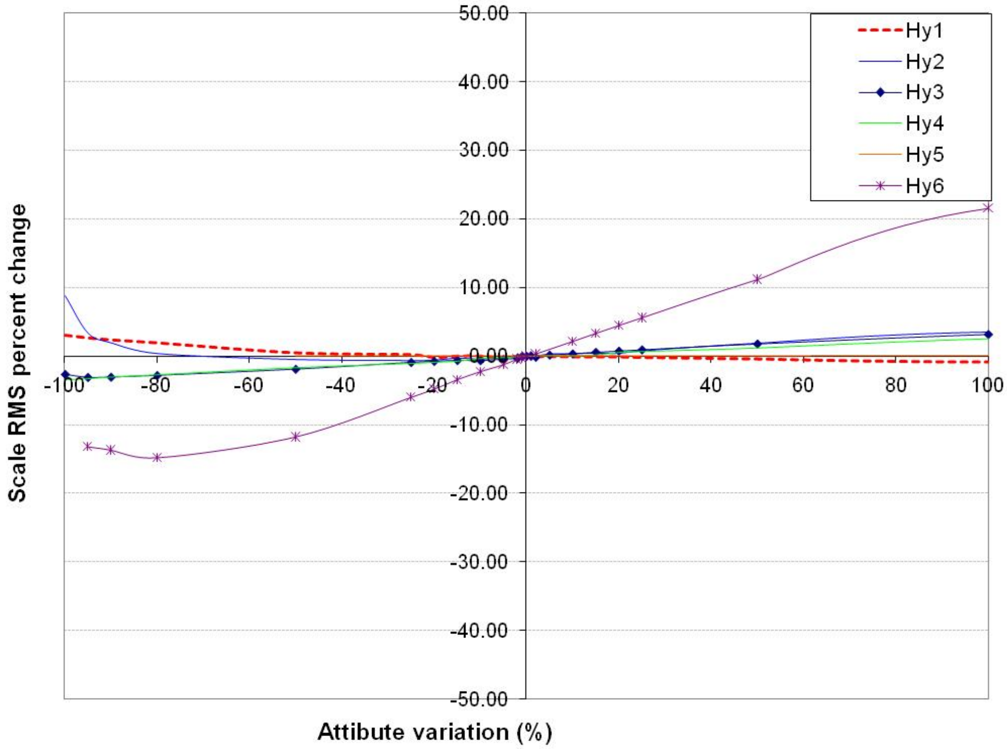
Hydraulic conductivity – layer 5



Hydraulic conductivity – layer 6

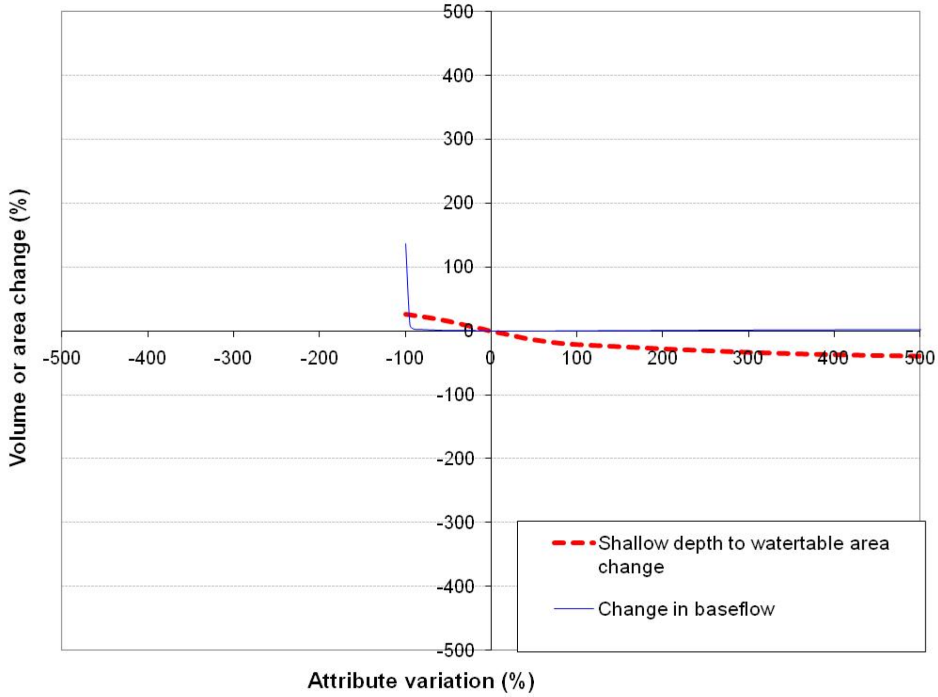


Hydraulic conductivity impact on Scale RMS

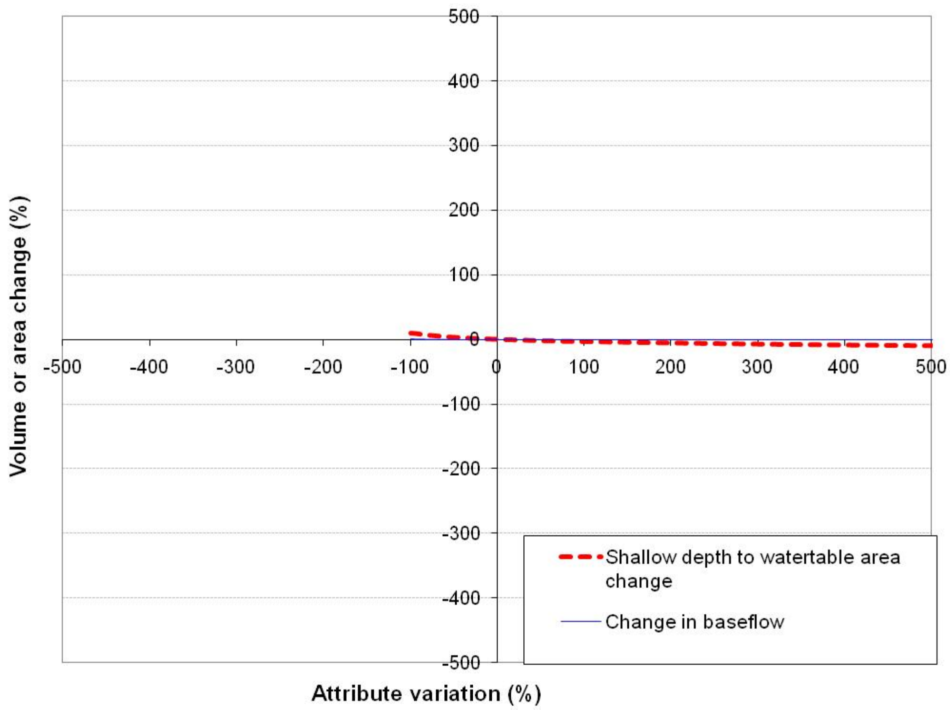


Vcont

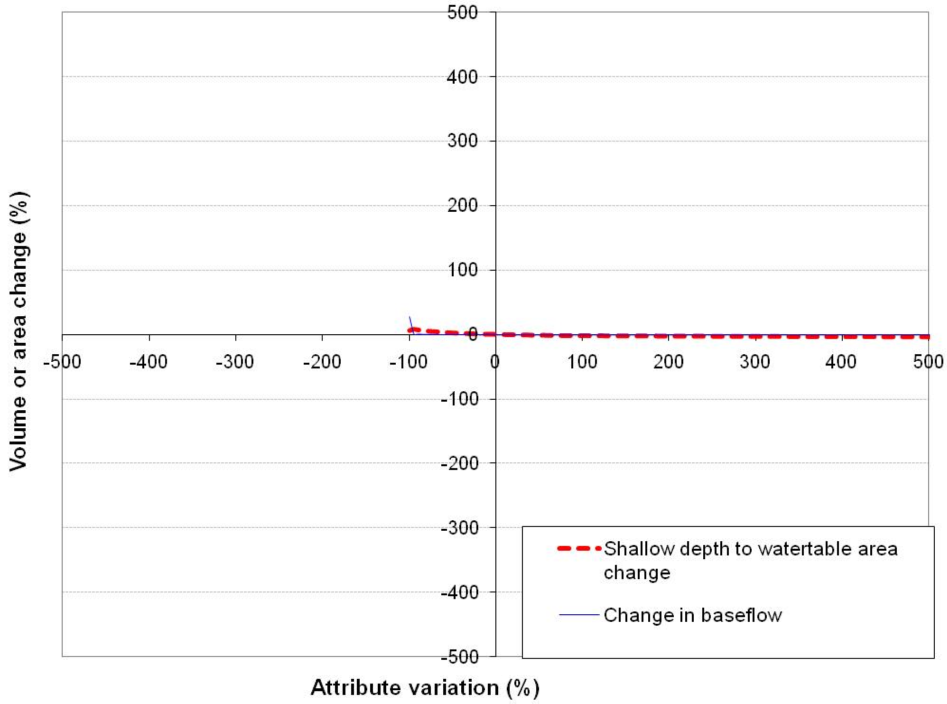
Vcont – layer 1



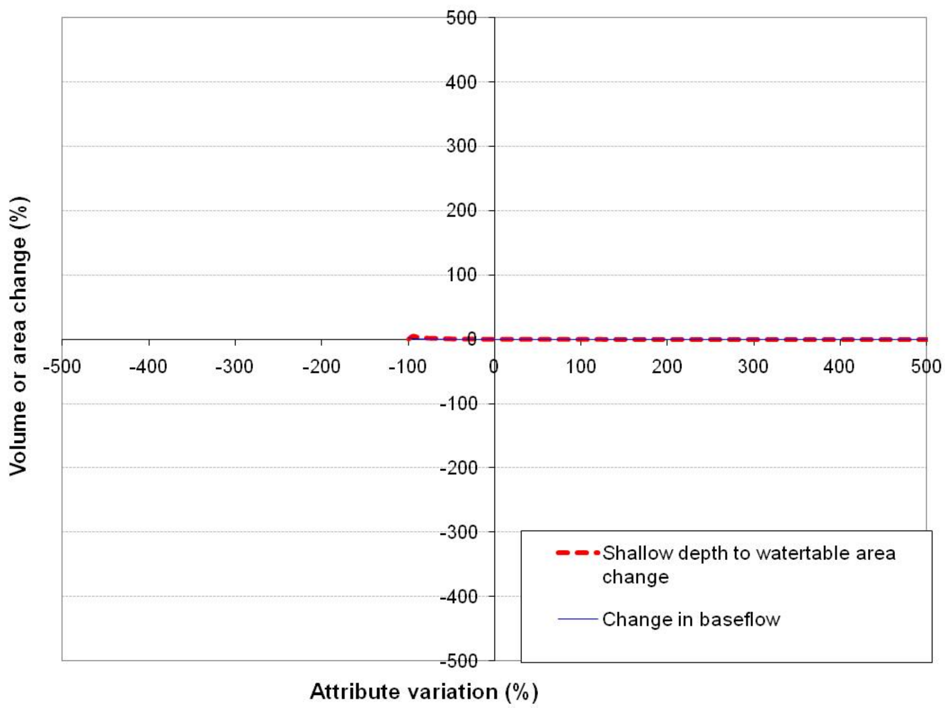
Vcont – layer 2



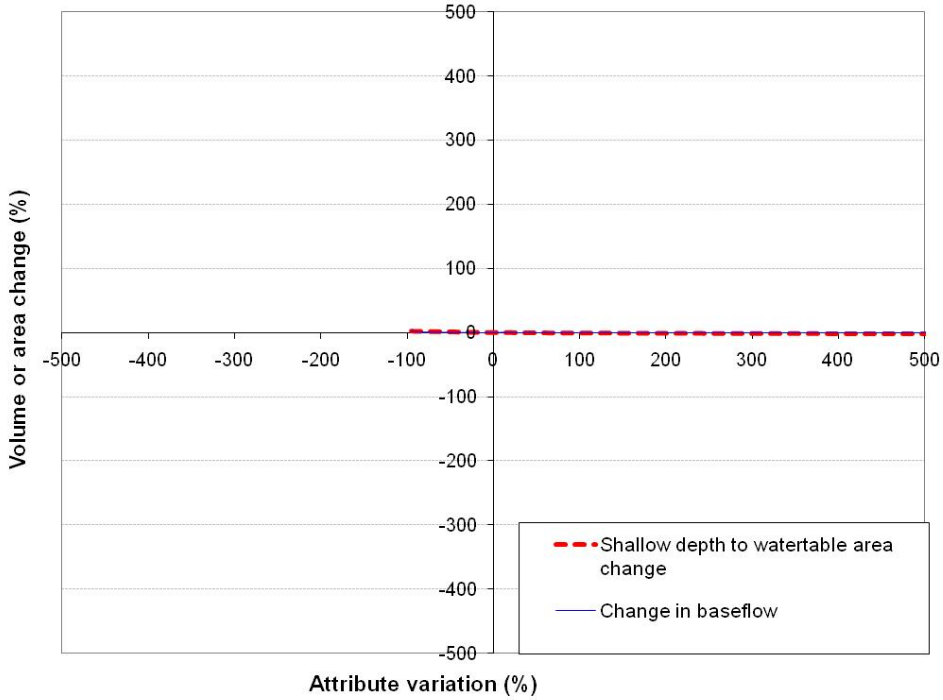
Vcont – layer 3



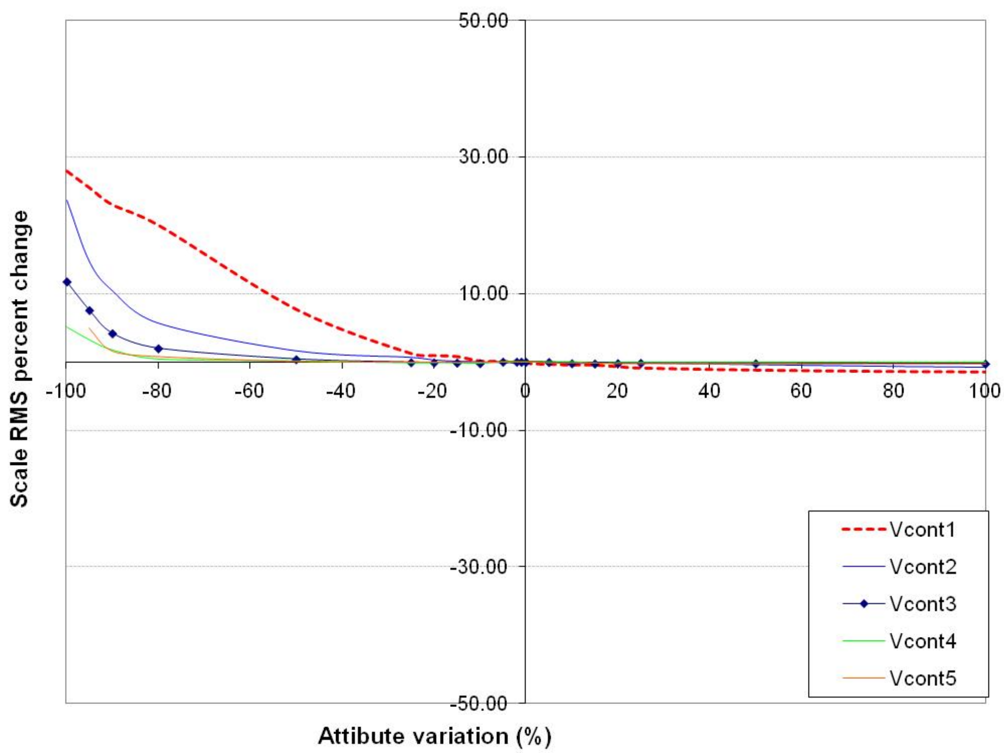
Vcont – layer 4



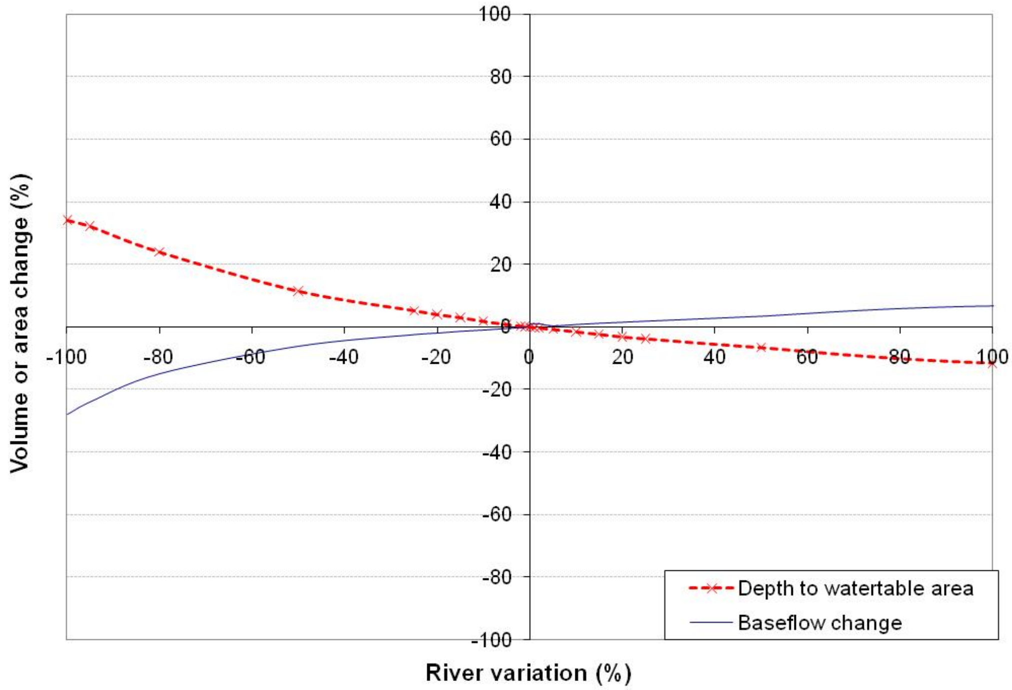
Vcont – layer 5



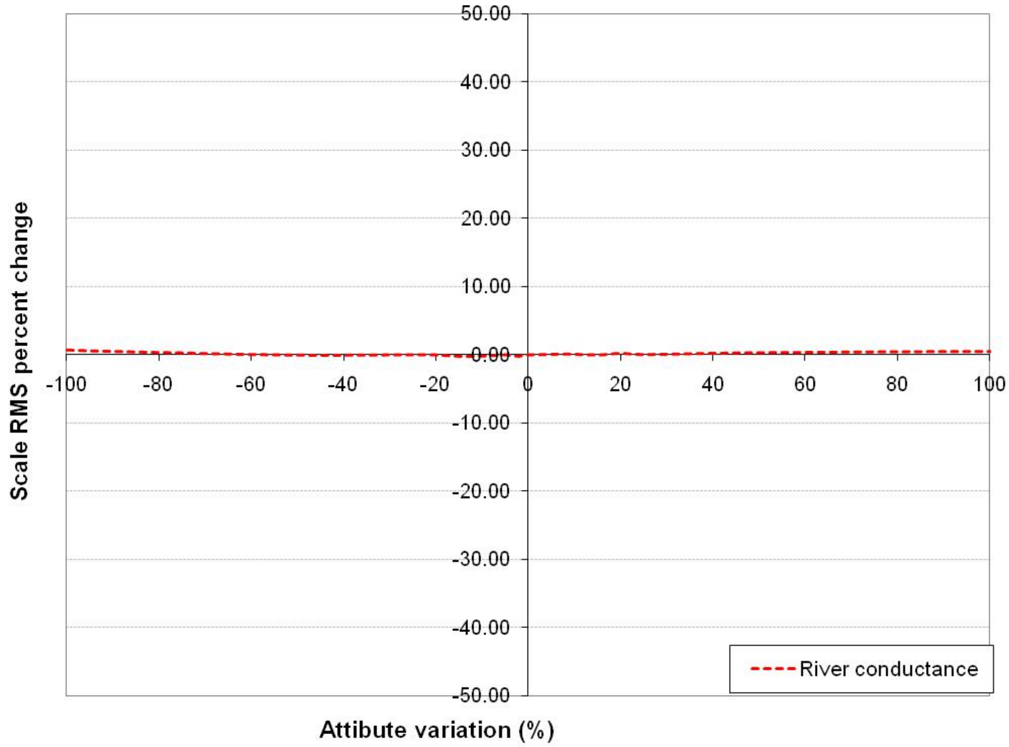
Vcont impact on Scale RMS



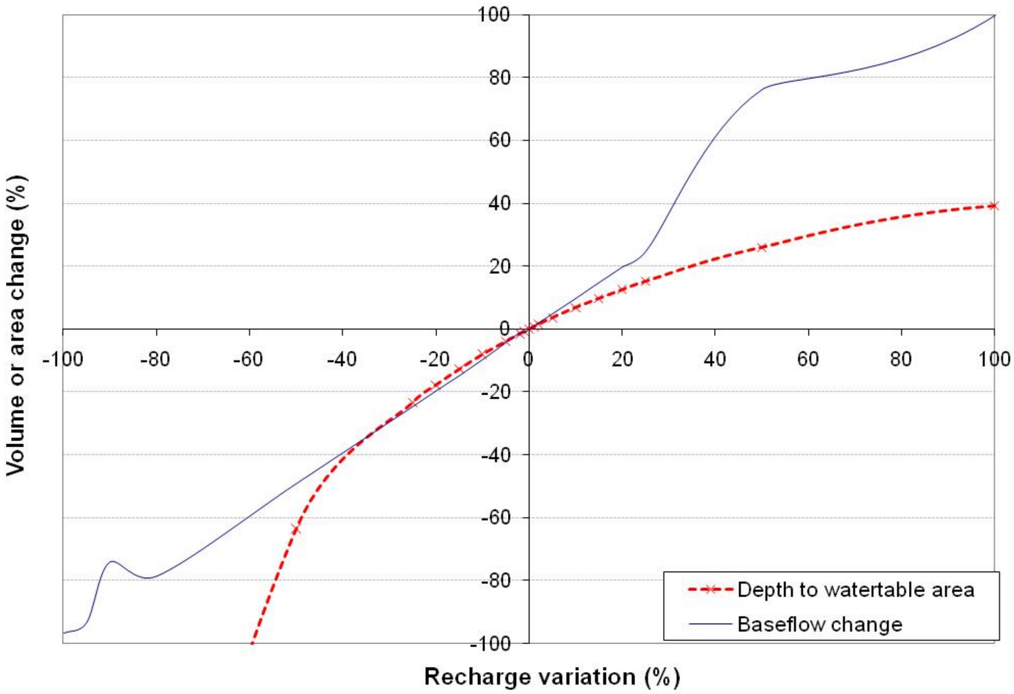
River bed conductivity



River impact on Scale RMS

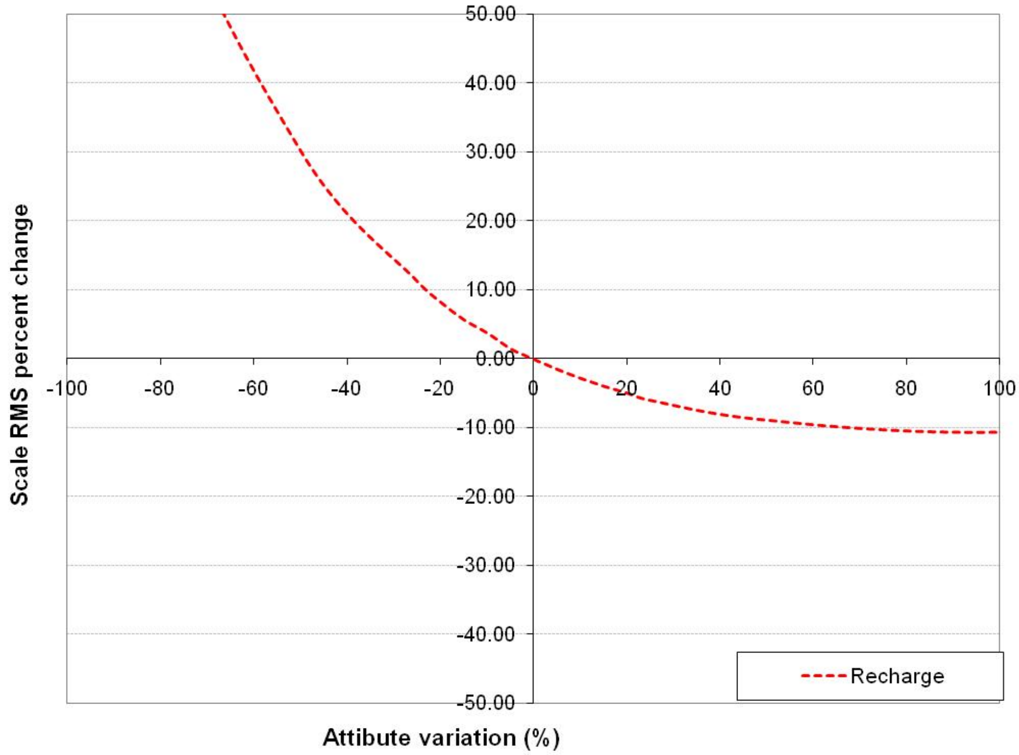


Recharge



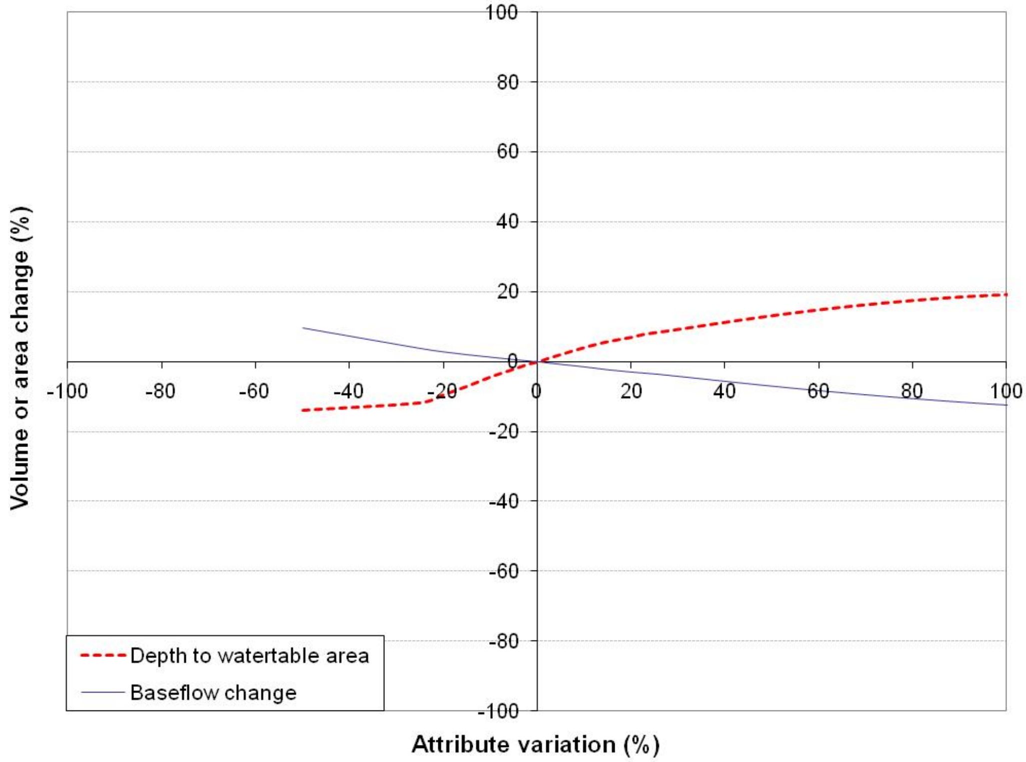
Volume or area change (%)
Recharge variation (%)
Depth to watertable area
Baseflow change
100
80
60
40
20
0
-20
-40
-60
-80
-100
-100
-80
-60
-40
-20
0
20
40
60
80
100

Recharge impact on Scale RMS

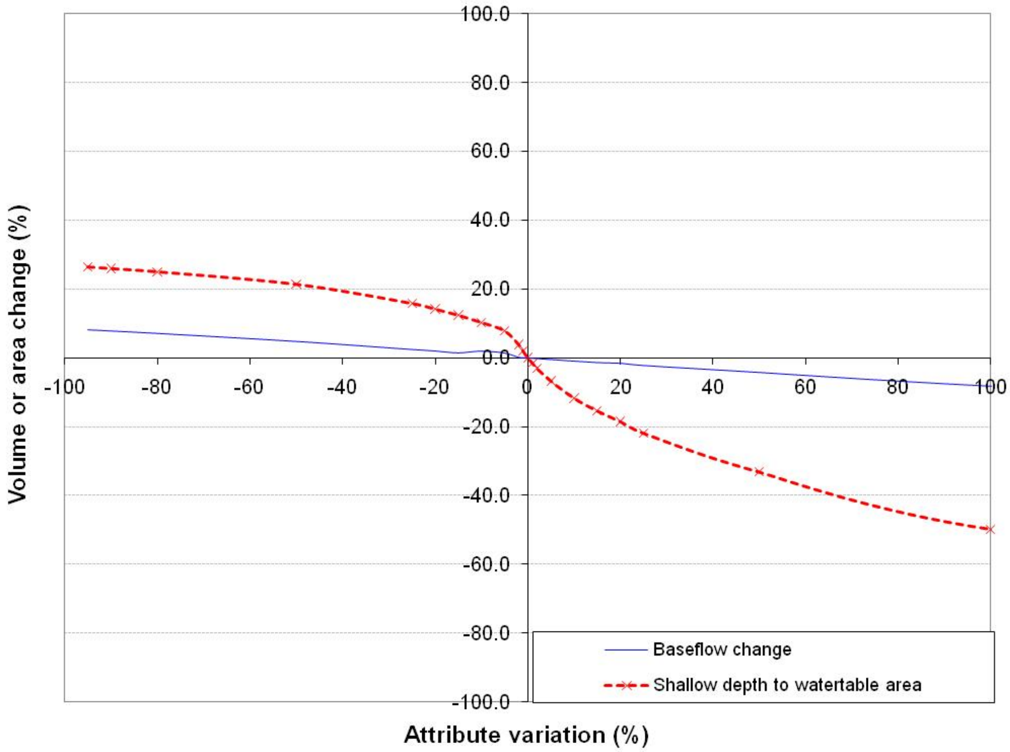


Evaporation features

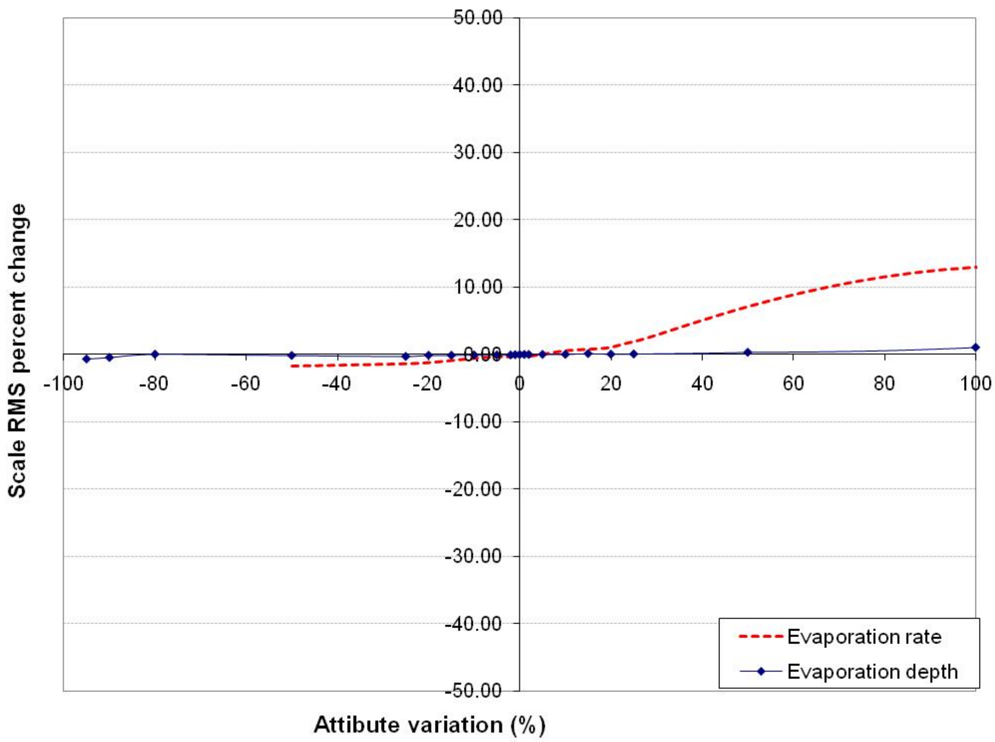
Evaporation rate



Evaporation depth



Evaporation impact on Scale RMS

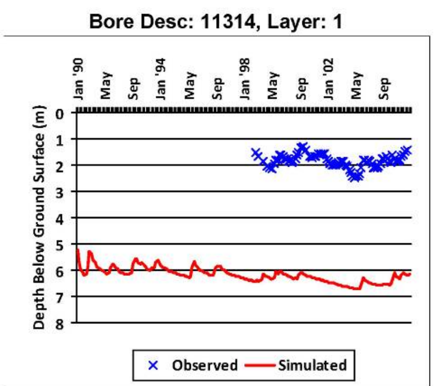


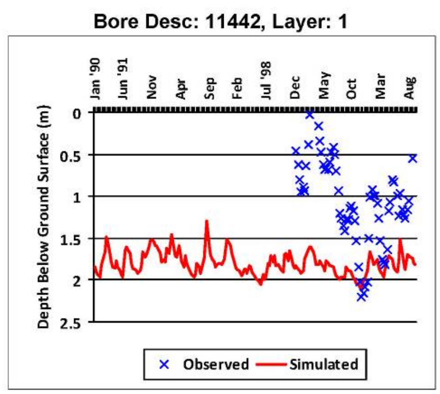
Appendix 8 Time series simulated versus observed depth to watertable data

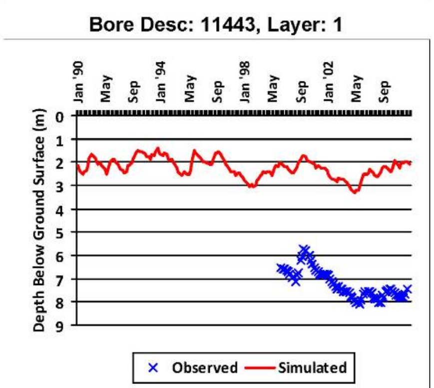
GHB bores

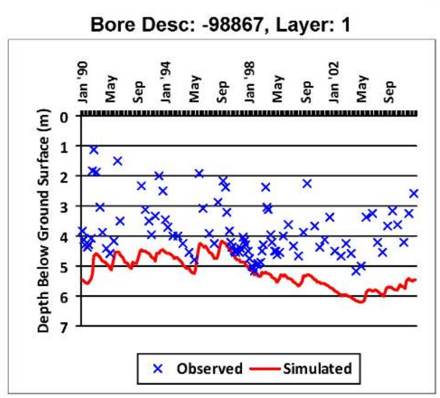
Boreid	layer	Boreid	layer	Boreid	layer	Boreid	layer
11178	2	11132	3	-86160	4	11137	6
11319	2	11133	3	11161	4	11228	6
11320	2	11177	3			11232	6
11321	2	-50893	3			11237	6
11339	2	11227	3			-86160	6
		-86160	3				

Layer 1 (Coonambidgal Formation)

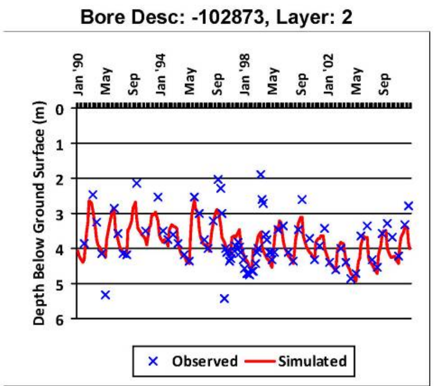


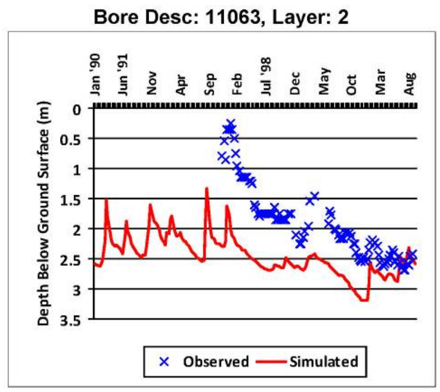


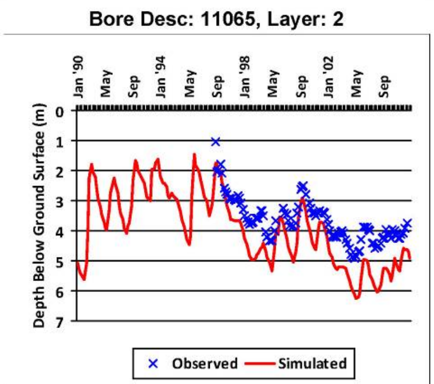


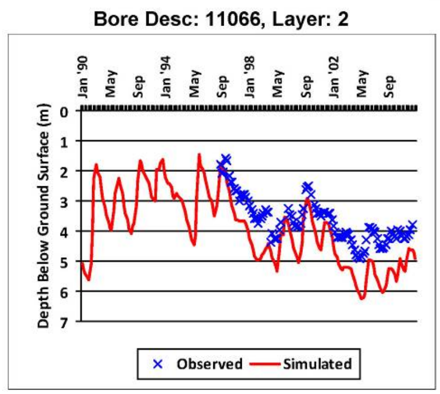


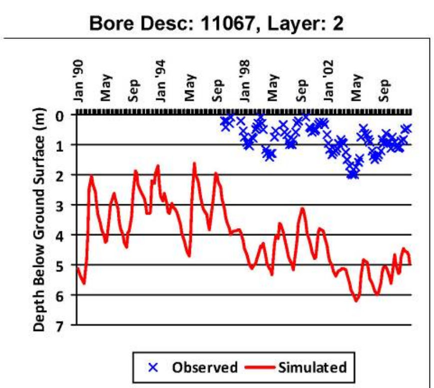
Layer 2 (upper Shepparton Formation)

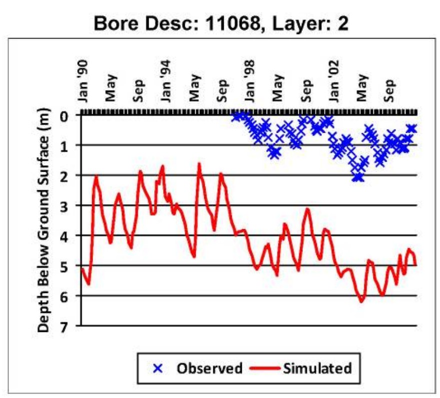




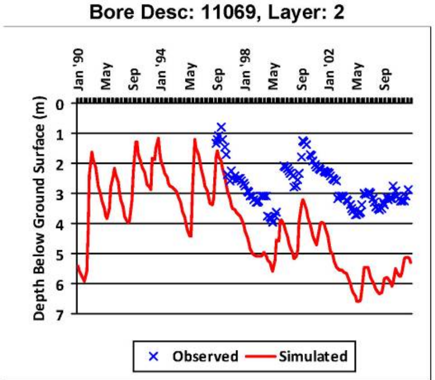




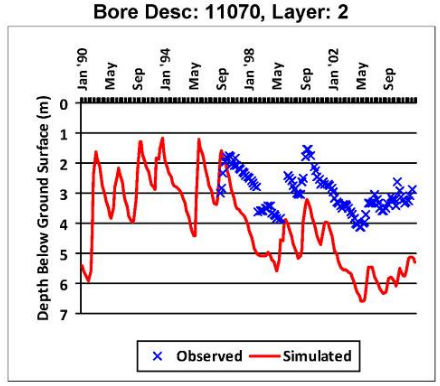




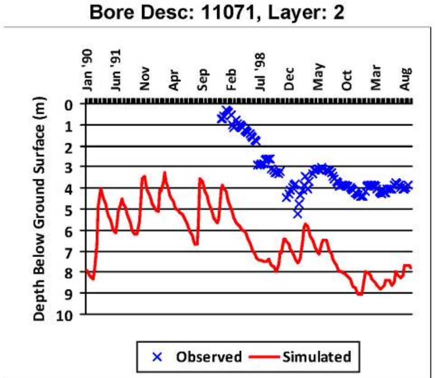
Bore Desc: 11069, Layer: 2



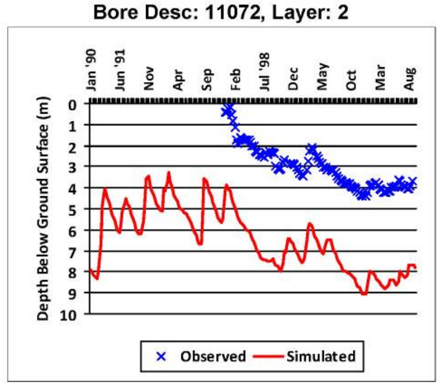
Bore Desc: 11070, Layer: 2



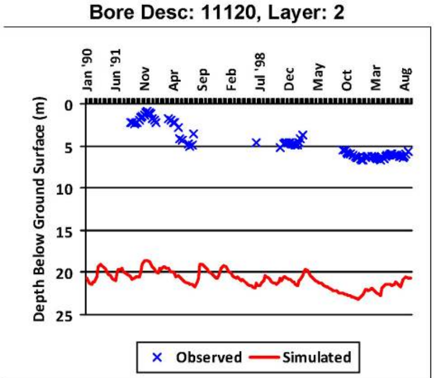
Bore Desc: 11071, Layer: 2



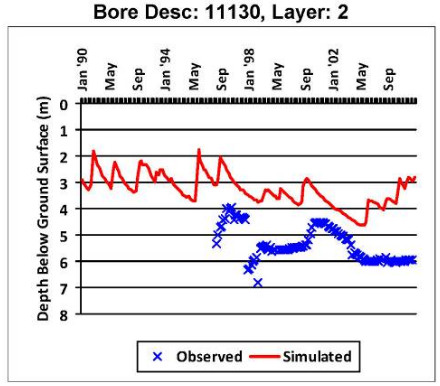
Bore Desc: 11072, Layer: 2



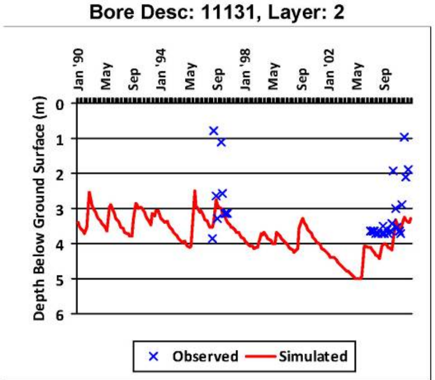
Bore Desc: 11120, Layer: 2



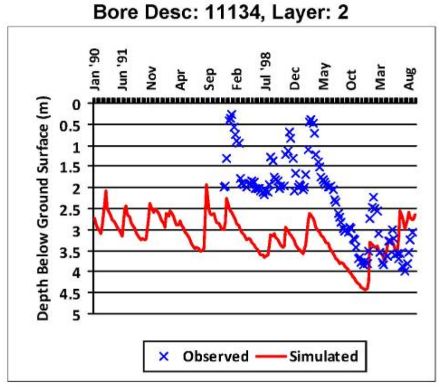
Bore Desc: 11130, Layer: 2



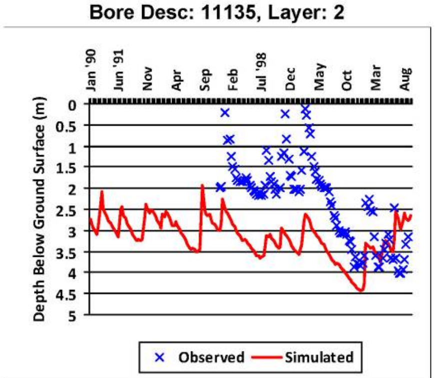
Bore Desc: 11131, Layer: 2



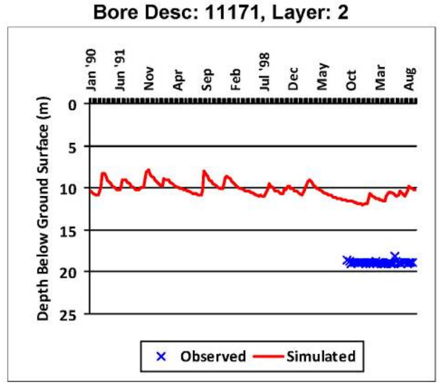
Bore Desc: 11134, Layer: 2



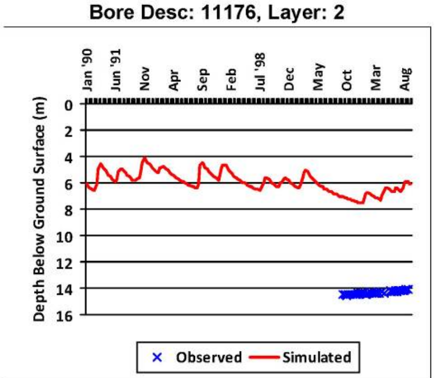
Bore Desc: 11135, Layer: 2



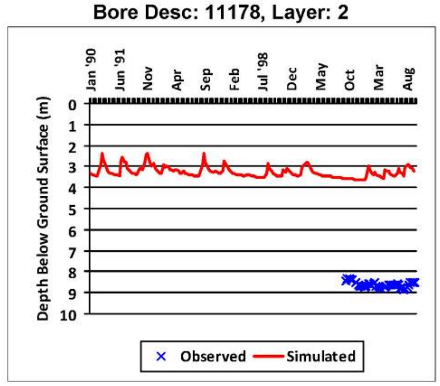
Bore Desc: 11171, Layer: 2



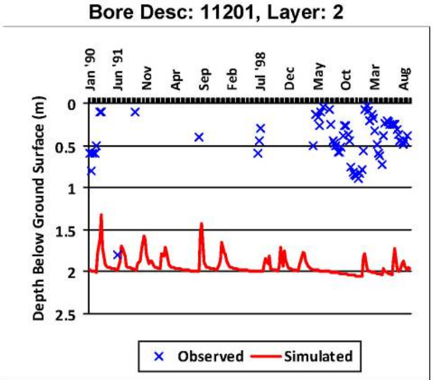
Bore Desc: 11176, Layer: 2



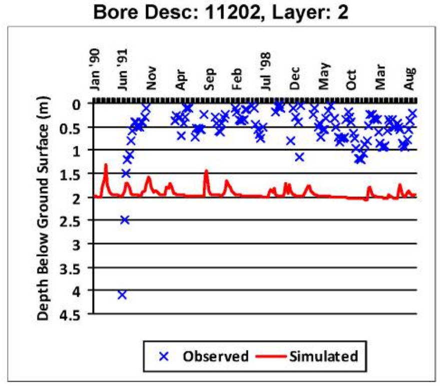
Bore Desc: 11178, Layer: 2



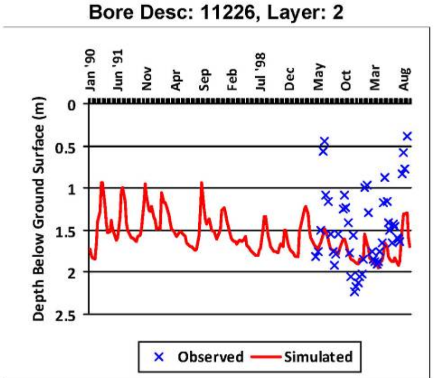
Bore Desc: 11201, Layer: 2



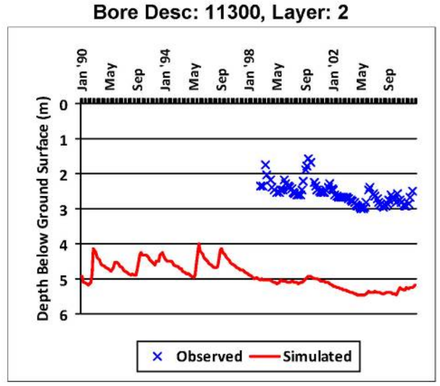
Bore Desc: 11202, Layer: 2



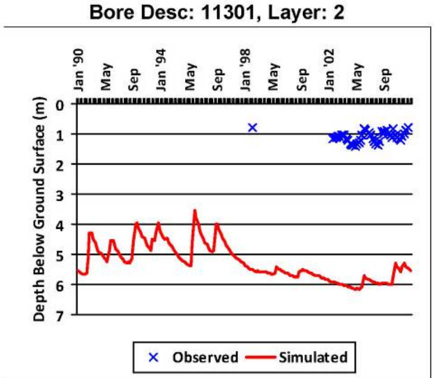
Bore Desc: 11226, Layer: 2



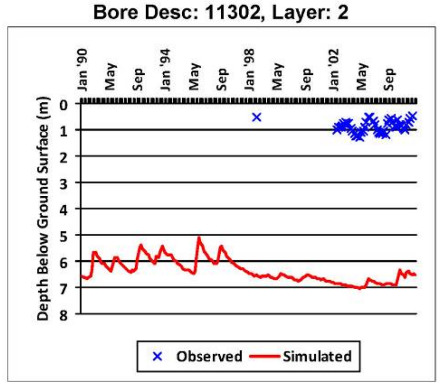
Bore Desc: 11300, Layer: 2



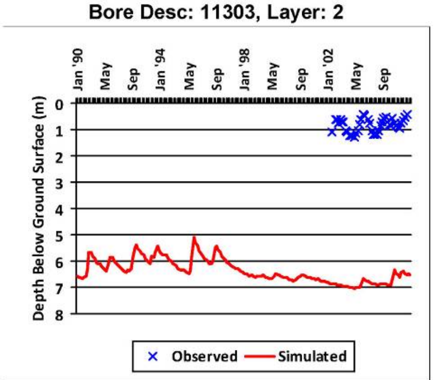
Bore Desc: 11301, Layer: 2



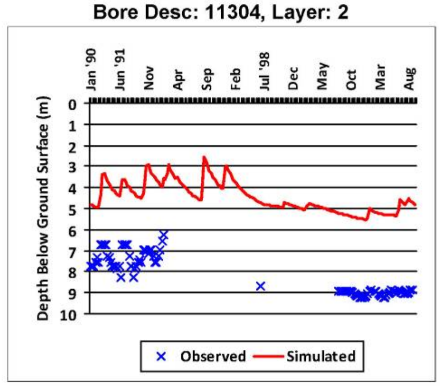
Bore Desc: 11302, Layer: 2



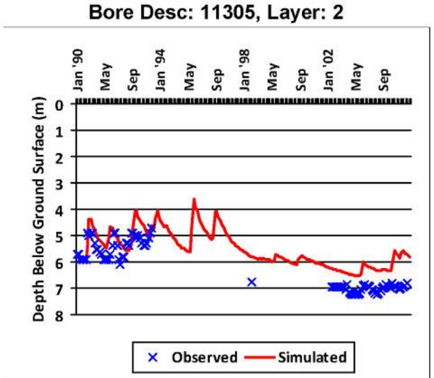
Bore Desc: 11303, Layer: 2



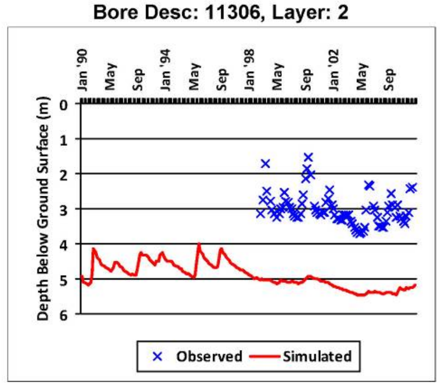
Bore Desc: 11304, Layer: 2



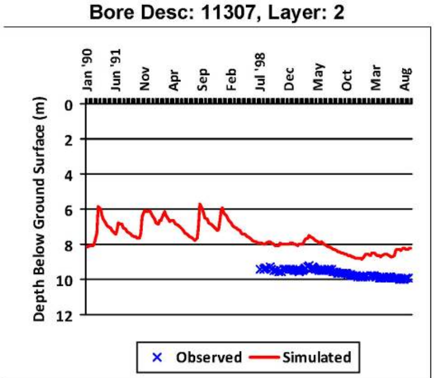
Bore Desc: 11305, Layer: 2



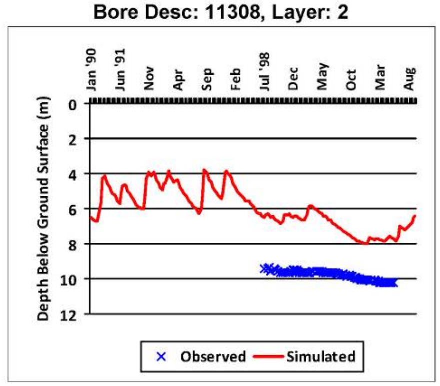
Bore Desc: 11306, Layer: 2



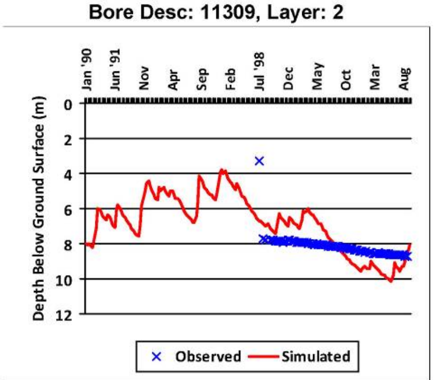
Bore Desc: 11307, Layer: 2



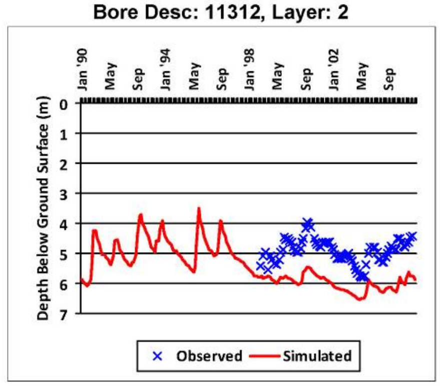
Bore Desc: 11308, Layer: 2



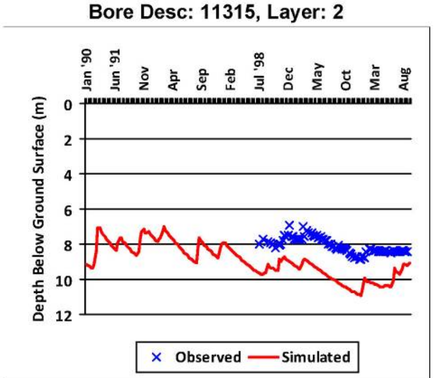
Bore Desc: 11309, Layer: 2



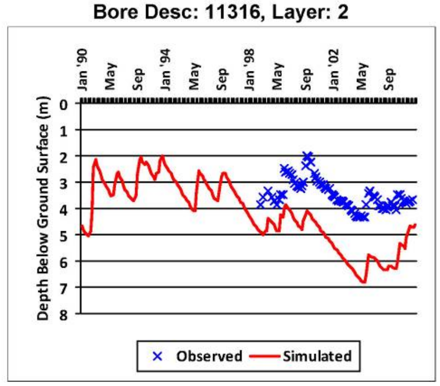
Bore Desc: 11312, Layer: 2



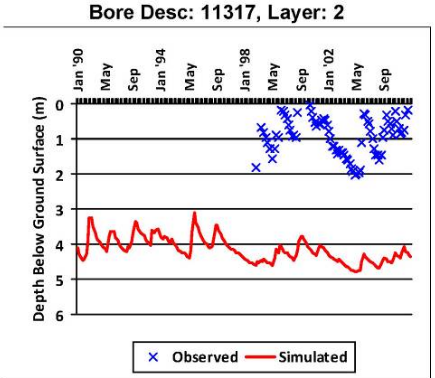
Bore Desc: 11315, Layer: 2



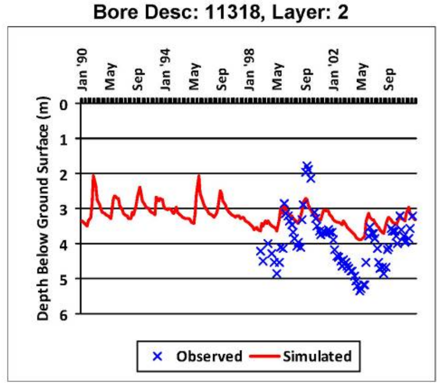
Bore Desc: 11316, Layer: 2

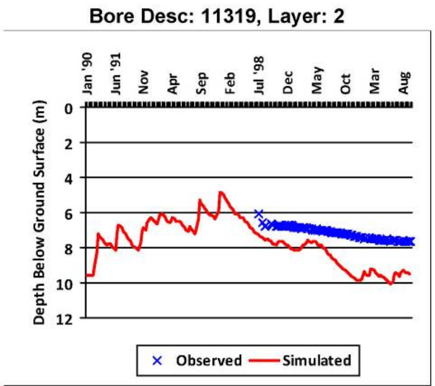


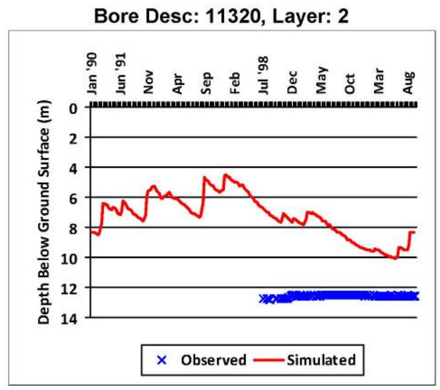
Bore Desc: 11317, Layer: 2

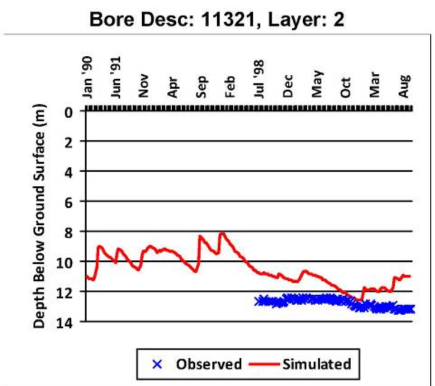


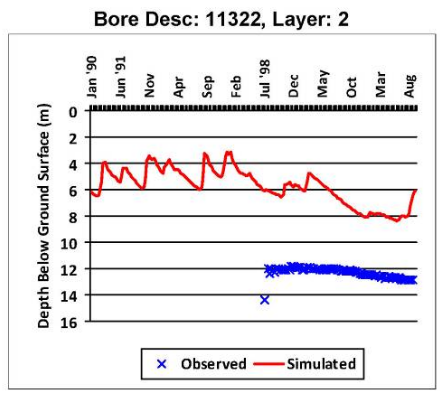
Bore Desc: 11318, Layer: 2

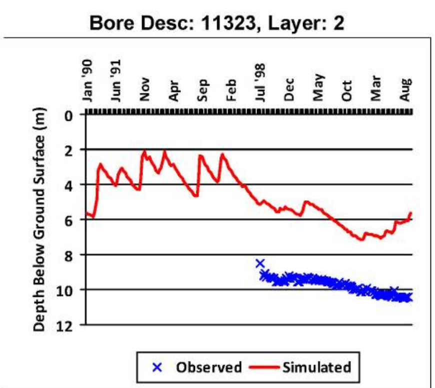


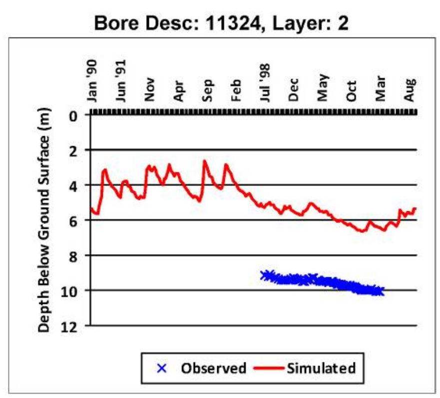

Bore Desc: 11319, Layer: 2
Jan '90
Jun '91
Nov
Apr
Sep
Feb
Jul '98
Dec
May
Oct
Mar
Aug
Depth Below Ground Surface (m)
Observed
Simulated


Bore Desc: 11320, Layer: 2
Depth Below Ground Surface (m)
Observed
Simulated

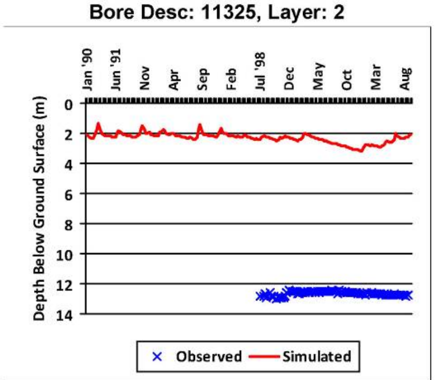

Bore Desc: 11321, Layer: 2
Depth Below Ground Surface (m)
Observed
Simulated


Bore Desc: 11322, Layer: 2
Depth Below Ground Surface (m)
Observed
Simulated

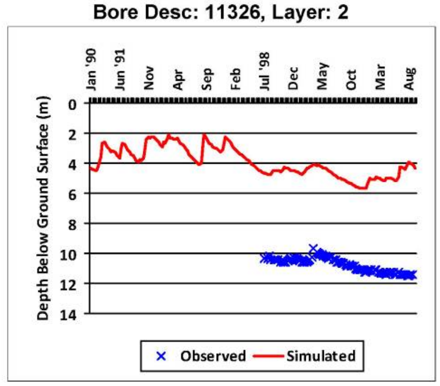

Bore Desc: 11323, Layer: 2
Depth Below Ground Surface (m)
Observed
Simulated


Bore Desc: 11324, Layer: 2
Depth Below Ground Surface (m)
Observed
Simulated

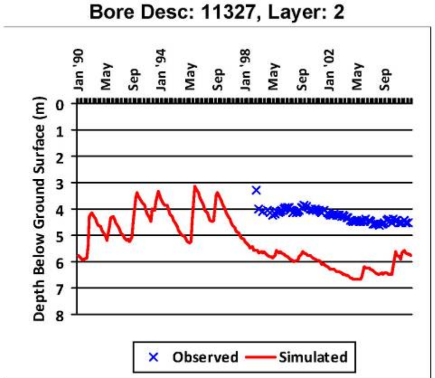
Bore Desc: 11325, Layer: 2



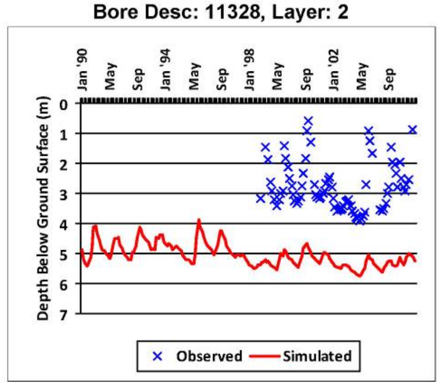
Bore Desc: 11326, Layer: 2



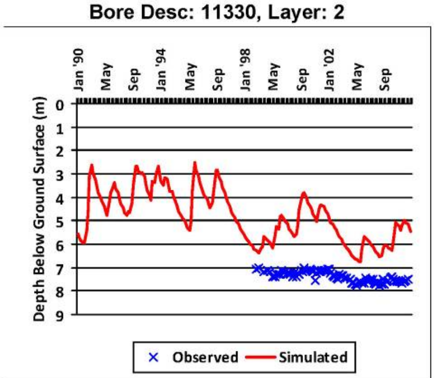
Bore Desc: 11327, Layer: 2



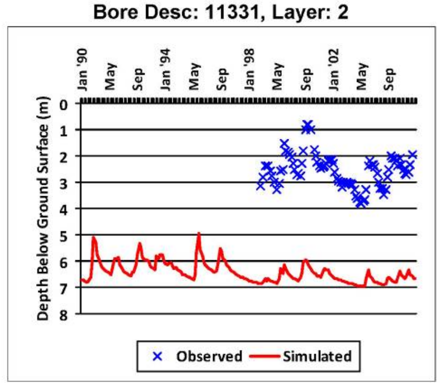
Bore Desc: 11328, Layer: 2



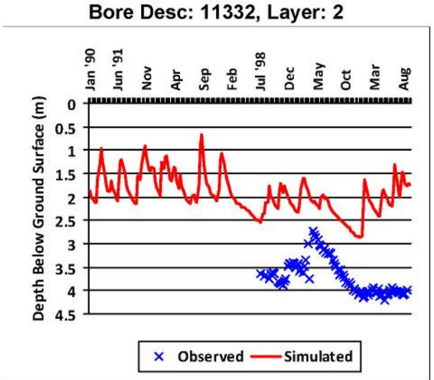
Bore Desc: 11330, Layer: 2



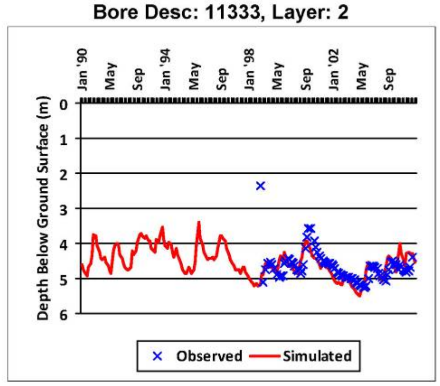
Bore Desc: 11331, Layer: 2



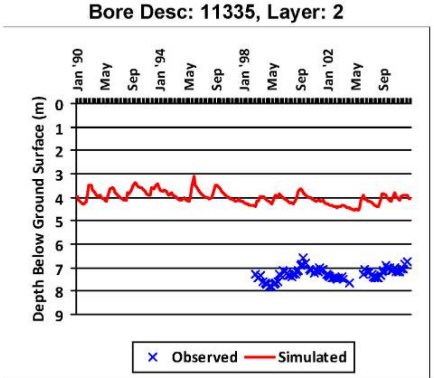
Bore Desc: 11332, Layer: 2



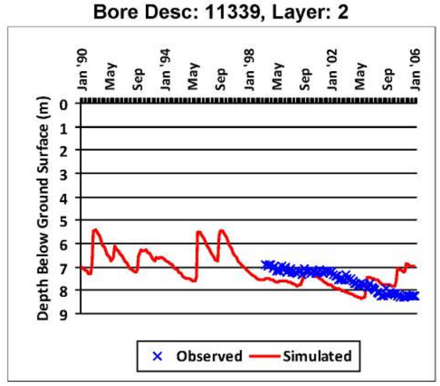
Bore Desc: 11333, Layer: 2



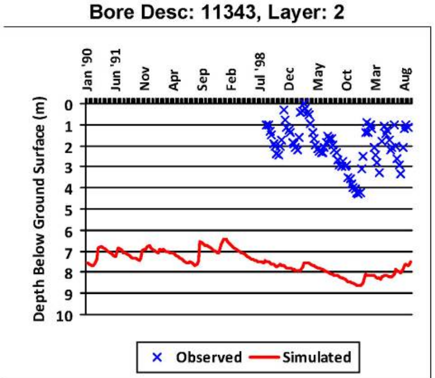
Bore Desc: 11335, Layer: 2



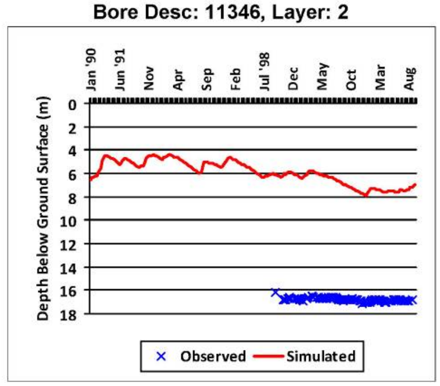
Bore Desc: 11339, Layer: 2



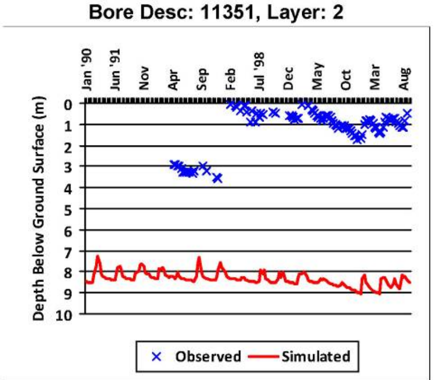
Bore Desc: 11343, Layer: 2



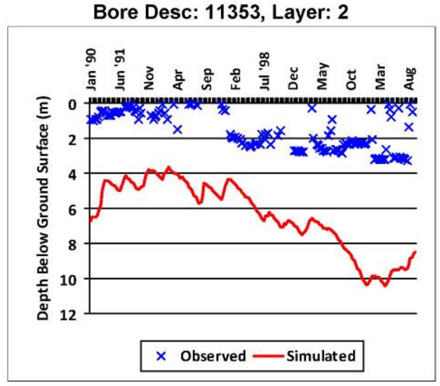
Bore Desc: 11346, Layer: 2



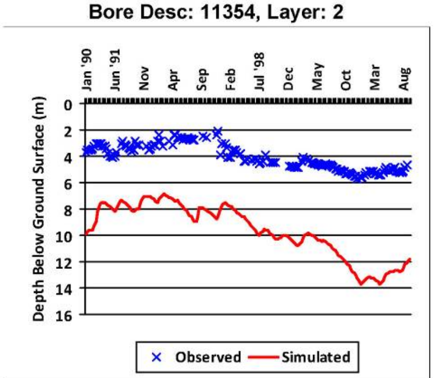
Bore Desc: 11351, Layer: 2



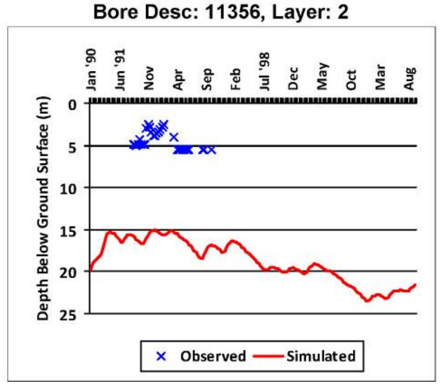
Bore Desc: 11353, Layer: 2



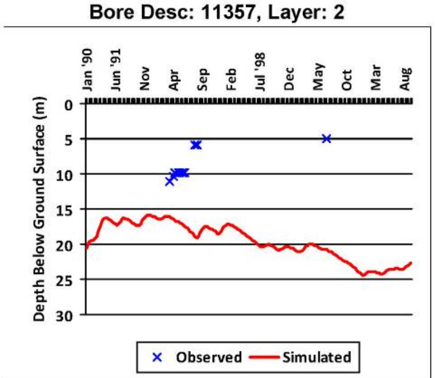
Bore Desc: 11354, Layer: 2



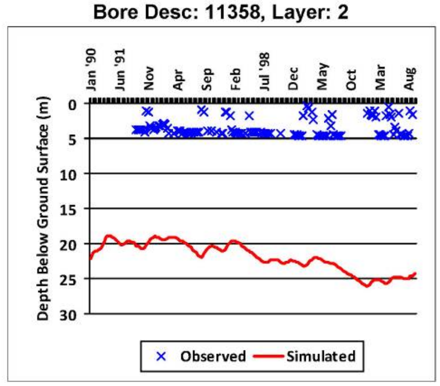
Bore Desc: 11356, Layer: 2



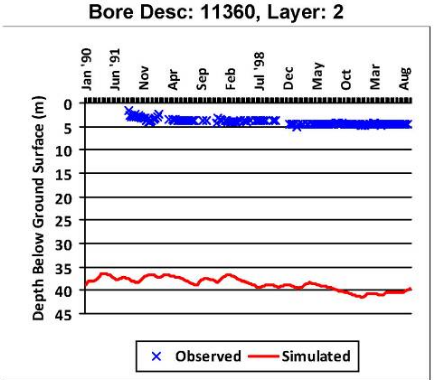
Bore Desc: 11357, Layer: 2



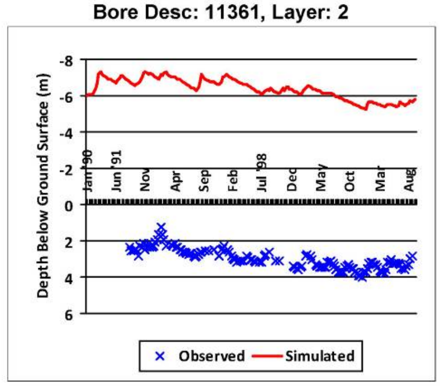
Bore Desc: 11358, Layer: 2



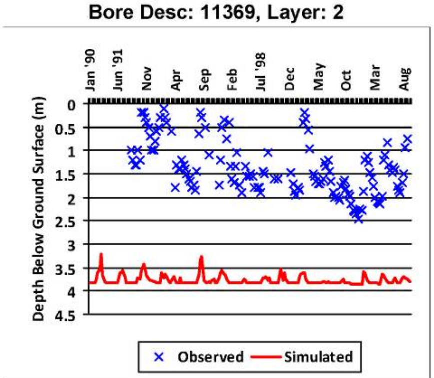
Bore Desc: 11360, Layer: 2



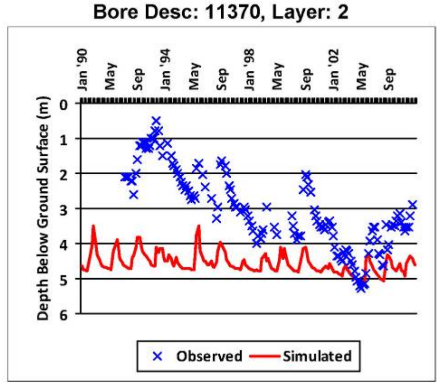
Bore Desc: 11361, Layer: 2



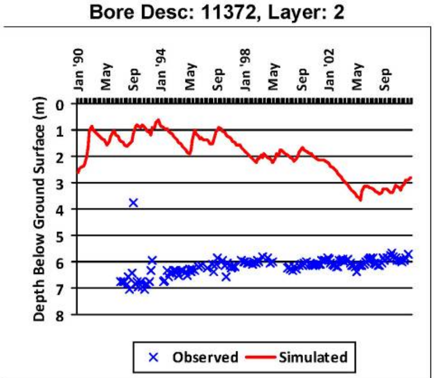
Bore Desc: 11369, Layer: 2



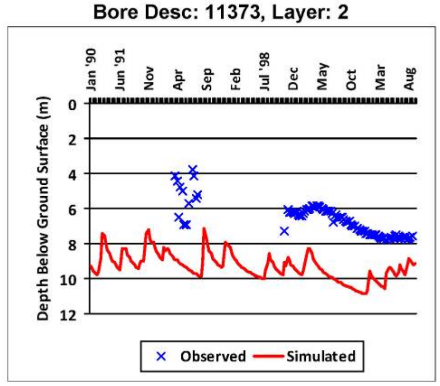
Bore Desc: 11370, Layer: 2



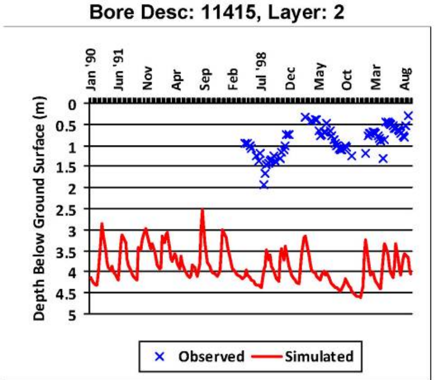
Bore Desc: 11372, Layer: 2



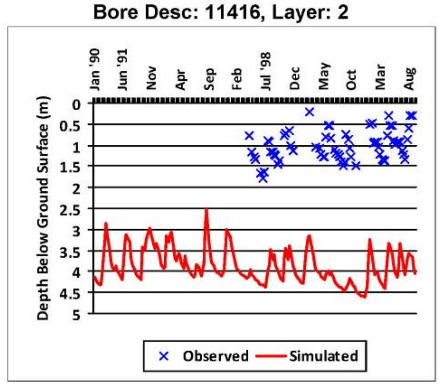
Bore Desc: 11373, Layer: 2



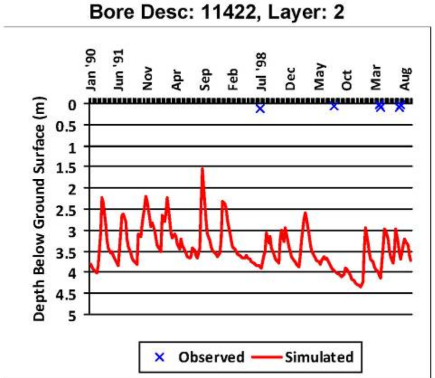
Bore Desc: 11415, Layer: 2



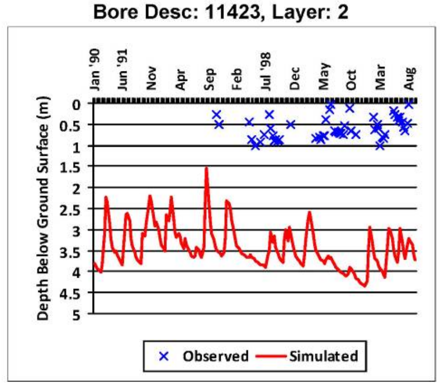
Bore Desc: 11416, Layer: 2



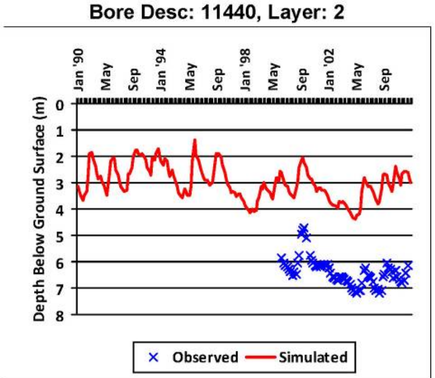
Bore Desc: 11422, Layer: 2



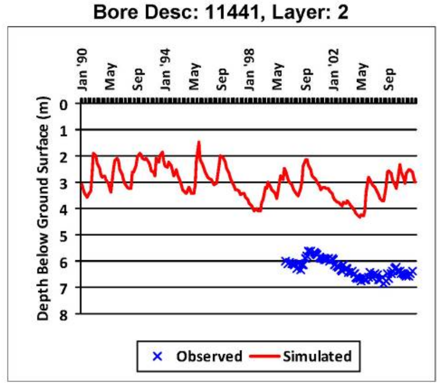
Bore Desc: 11423, Layer: 2



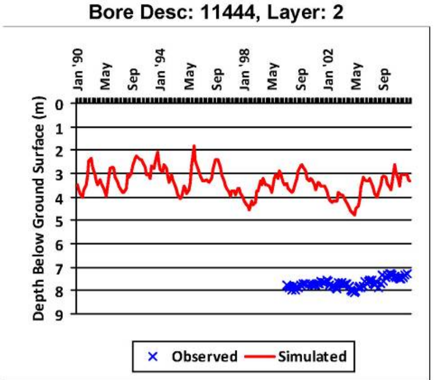
Bore Desc: 11440, Layer: 2



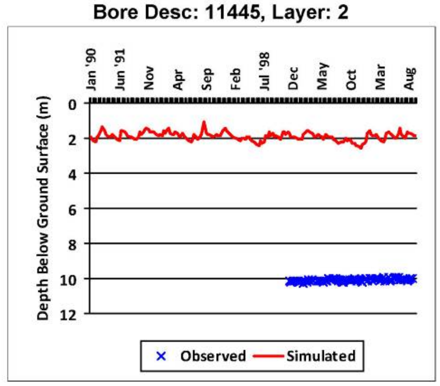
Bore Desc: 11441, Layer: 2



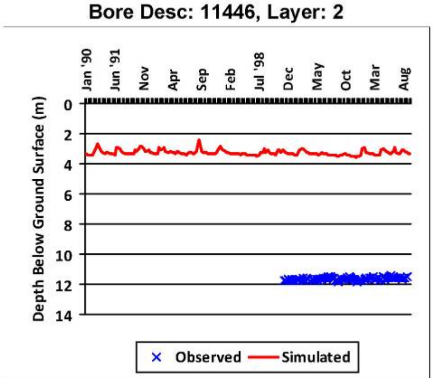
Bore Desc: 11444, Layer: 2



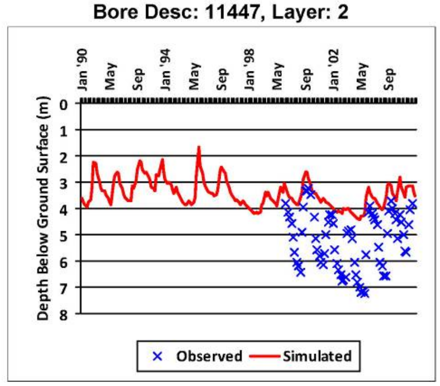
Bore Desc: 11445, Layer: 2



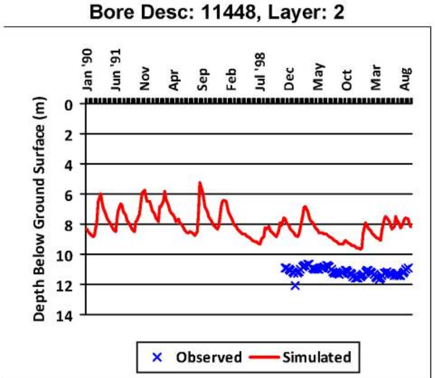
Bore Desc: 11446, Layer: 2



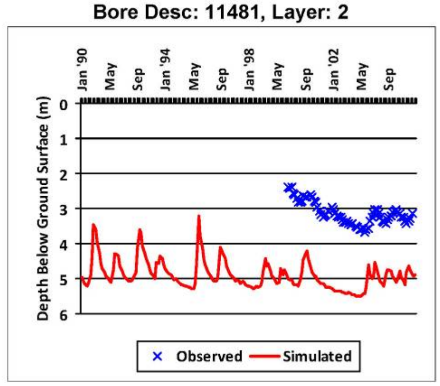
Bore Desc: 11447, Layer: 2

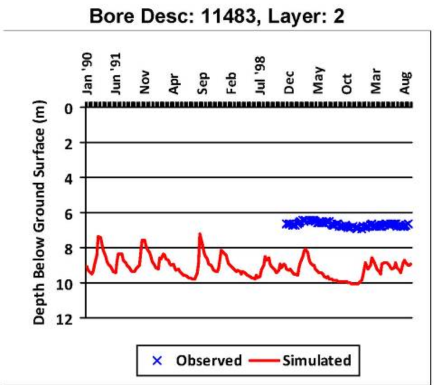


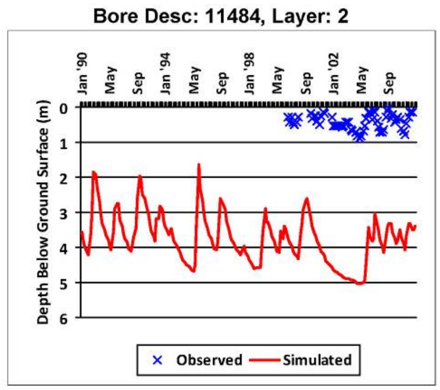
Bore Desc: 11448, Layer: 2

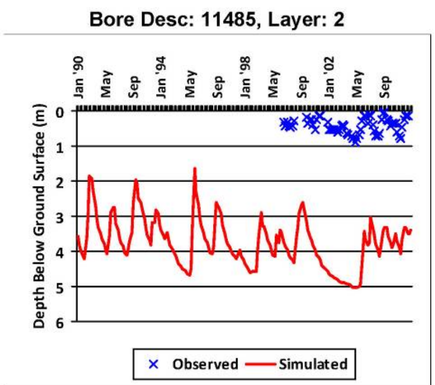


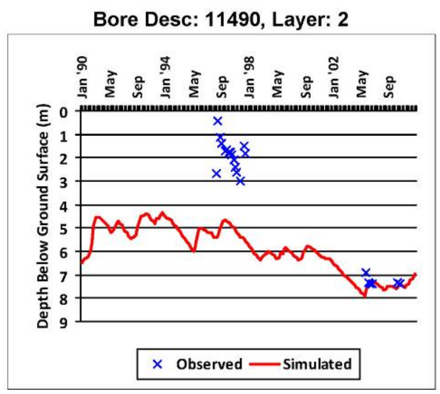
Bore Desc: 11481, Layer: 2

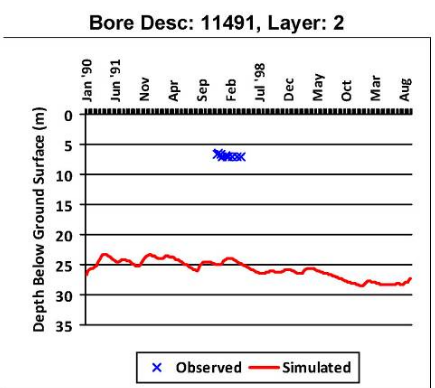


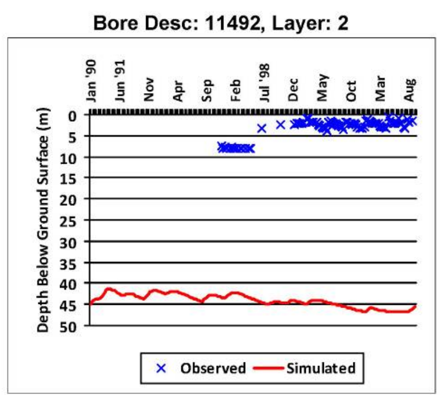

Bore Desc: 11483, Layer: 2
Depth Below Ground Surface (m)
Jan '90
Jun '91
Nov
Apr
Sep
Feb
Jul '98
Dec
May
Oct
Mar
Aug
0
2
4
6
8
10
12
Observed
Simulated


Bore Desc: 11484, Layer: 2
Depth Below Ground Surface (m)
Jan '90
May
Sep
Jan '94
May
Sep
Jan '98
May
Sep
Jan '02
May
Sep
0
1
2
3
4
5
6
Observed
Simulated

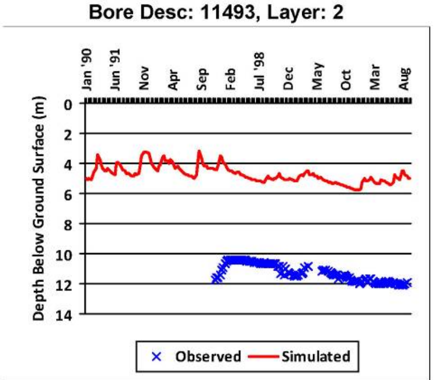

Bore Desc: 11485, Layer: 2
Depth Below Ground Surface (m)
Jan '90
May
Sep
Jan '94
May
Sep
Jan '98
May
Sep
Jan '02
May
Sep
0
1
2
3
4
5
6
Observed
Simulated


Bore Desc: 11490, Layer: 2
Depth Below Ground Surface (m)
Jan '90
May
Sep
Jan '94
May
Sep
Jan '98
May
Sep
Jan '02
May
Sep
0
1
2
3
4
5
6
7
8
9
Observed
Simulated

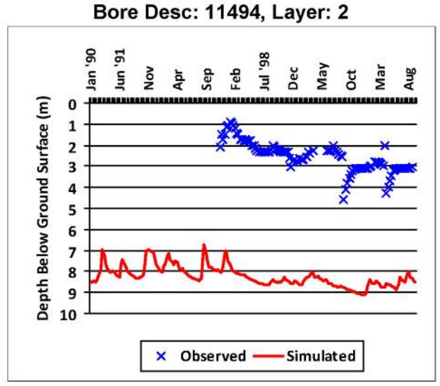

Bore Desc: 11491, Layer: 2
Depth Below Ground Surface (m)
Jan '90
Jun '91
Nov
Apr
Sep
Feb
Jul '98
Dec
May
Oct
Mar
Aug
0
5
10
15
20
25
30
35
Observed
Simulated


Bore Desc: 11492, Layer: 2
Depth Below Ground Surface (m)
Jan '90
Jun '91
Nov
Apr
Sep
Feb
Jul '98
Dec
May
Oct
Mar
Aug
0
5
10
15
20
25
30
35
40
45
50
Observed
Simulated

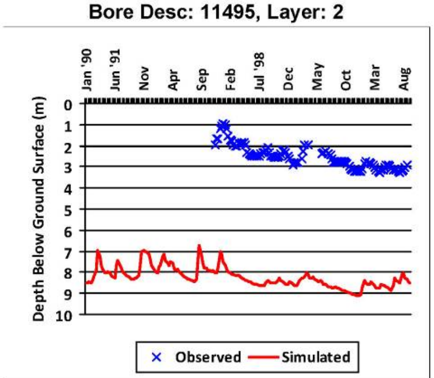
Bore Desc: 11493, Layer: 2



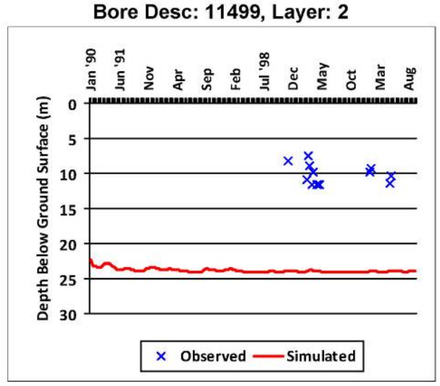
Bore Desc: 11494, Layer: 2



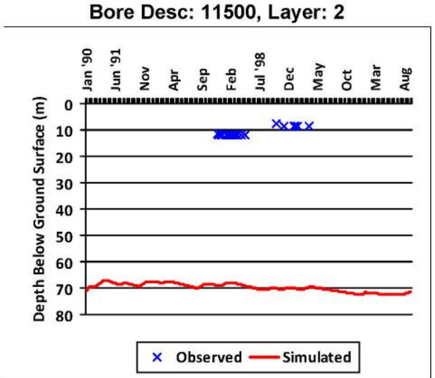
Bore Desc: 11495, Layer: 2



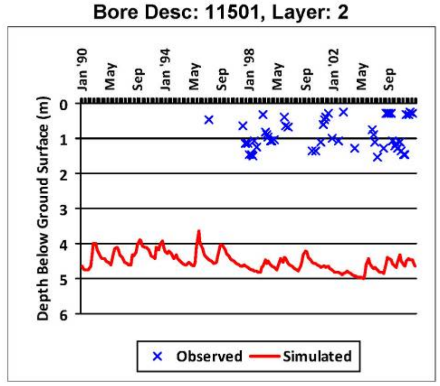
Bore Desc: 11499, Layer: 2



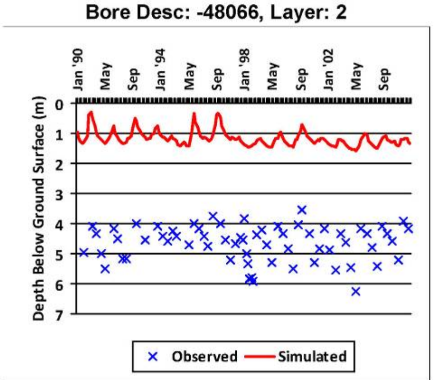
Bore Desc: 11500, Layer: 2



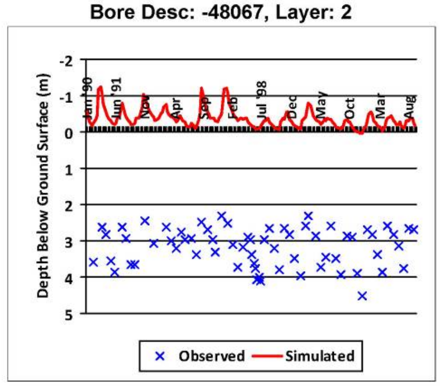
Bore Desc: 11501, Layer: 2



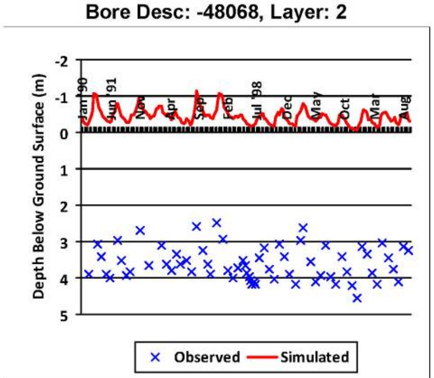
Bore Desc: -48066, Layer: 2



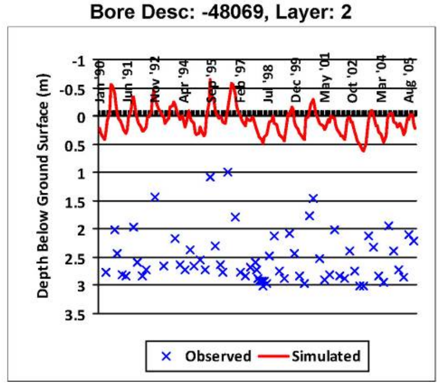
Bore Desc: -48067, Layer: 2



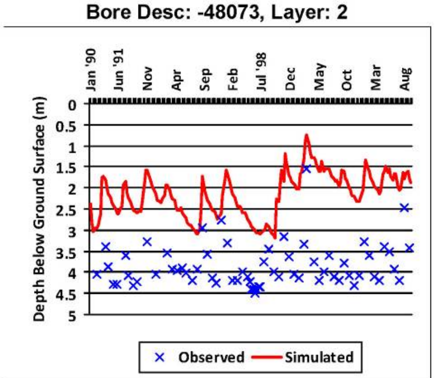
Bore Desc: -48068, Layer: 2



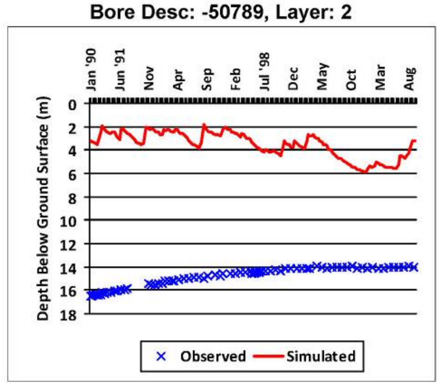
Bore Desc: -48069, Layer: 2



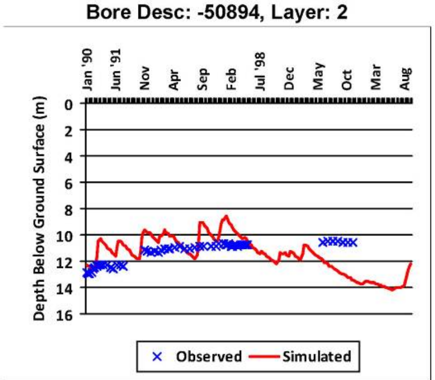
Bore Desc: -48073, Layer: 2



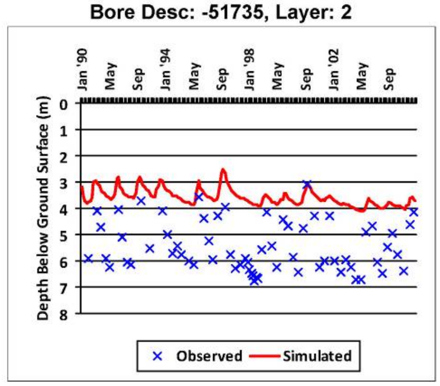
Bore Desc: -50789, Layer: 2



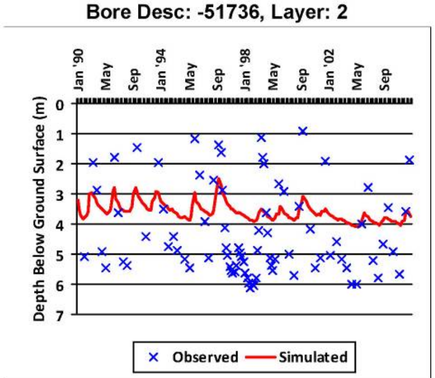
Bore Desc: -50894, Layer: 2



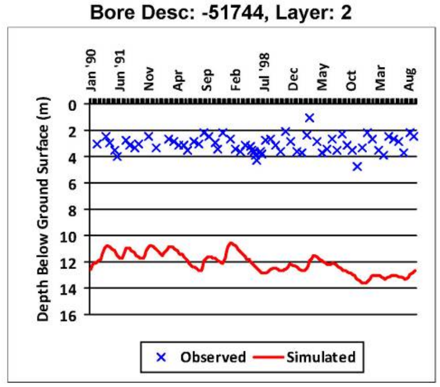
Bore Desc: -51735, Layer: 2



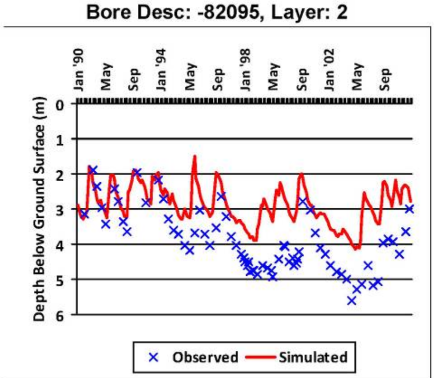
Bore Desc: -51736, Layer: 2



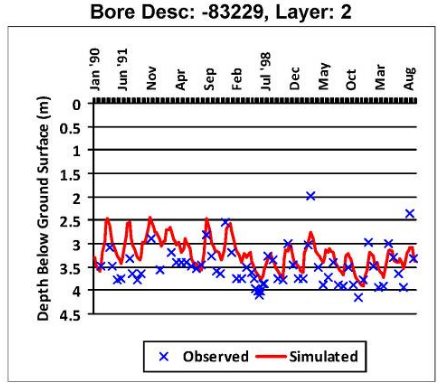
Bore Desc: -51744, Layer: 2



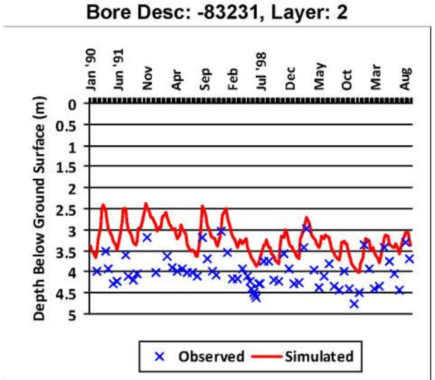
Bore Desc: -82095, Layer: 2



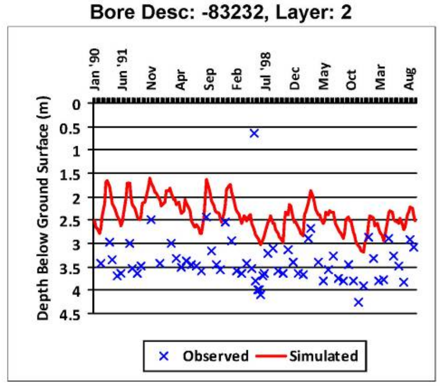
Bore Desc: -83229, Layer: 2



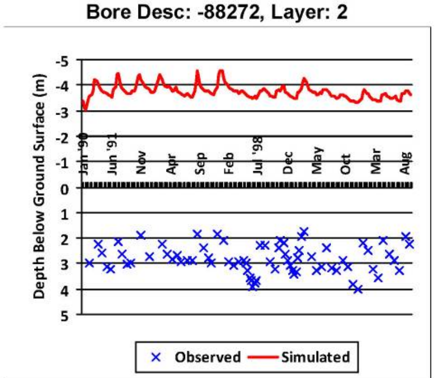
Bore Desc: -83231, Layer: 2



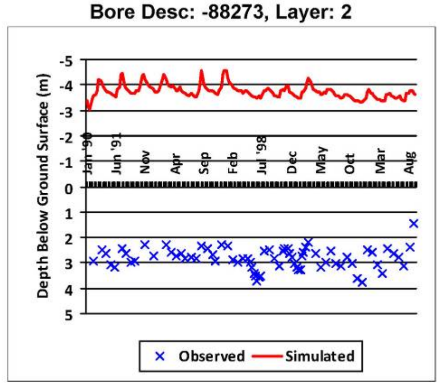
Bore Desc: -83232, Layer: 2



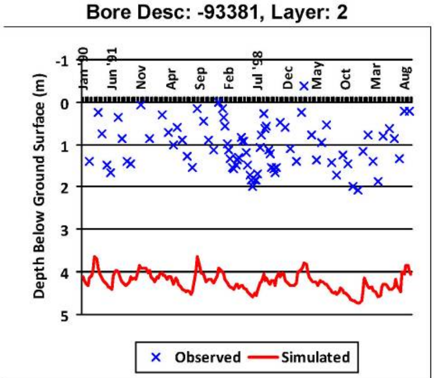
Bore Desc: -88272, Layer: 2



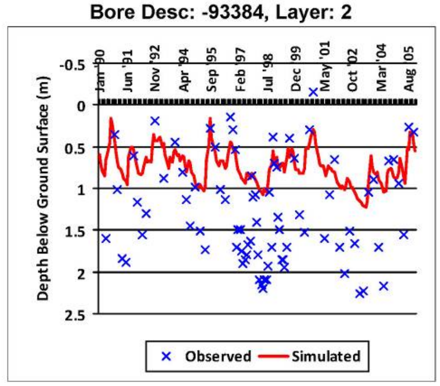
Bore Desc: -88273, Layer: 2

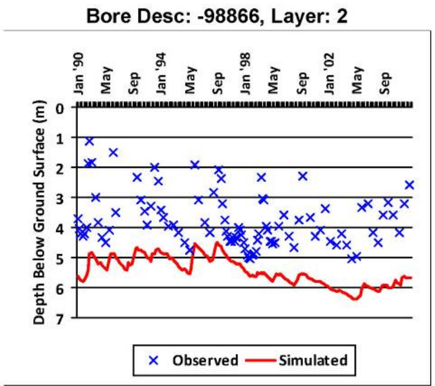


Bore Desc: -93381, Layer: 2



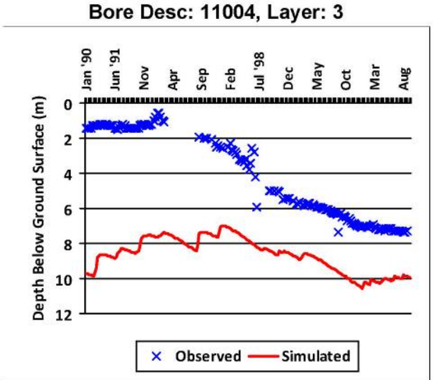
Bore Desc: -93384, Layer: 2



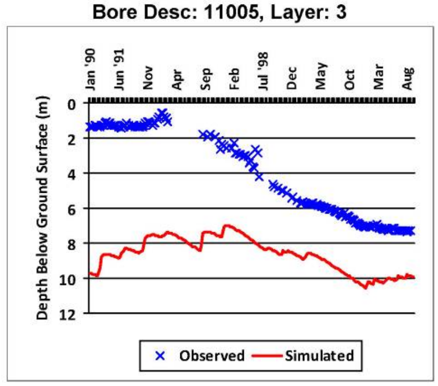

Bore Desc: -98866, Layer: 2
Depth Below Ground Surface (m)
Jan '90
May
Sep
Jan '94
May
Sep
Jan '98
May
Sep
Jan '02
May
Sep
0
1
2
3
4
5
6
7
Observed
Simulated

Layer 3 (lower Shepparton Formation)

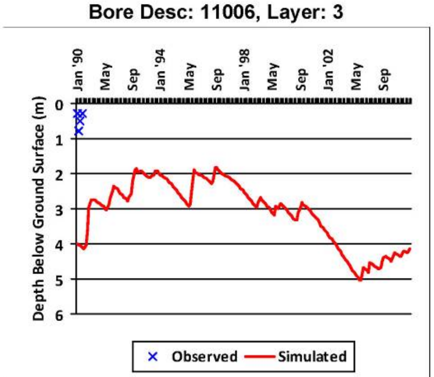
Bore Desc: 11004, Layer: 3



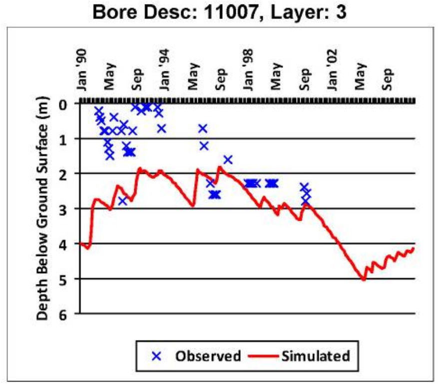
Bore Desc: 11005, Layer: 3



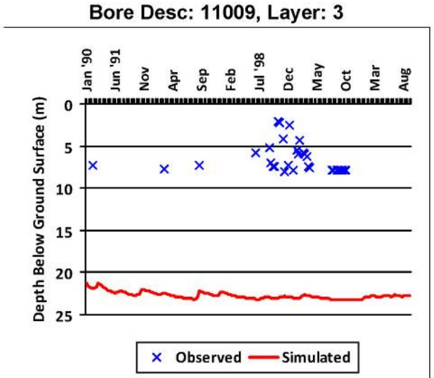
Bore Desc: 11006, Layer: 3



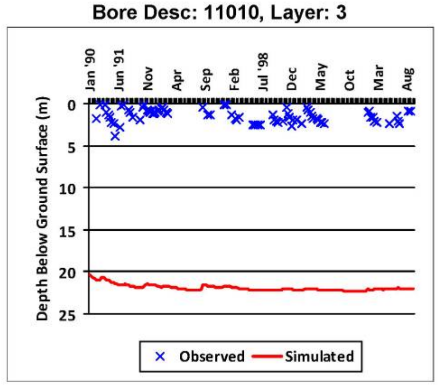
Bore Desc: 11007, Layer: 3



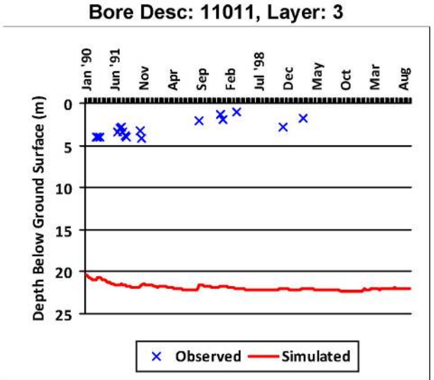
Bore Desc: 11009, Layer: 3



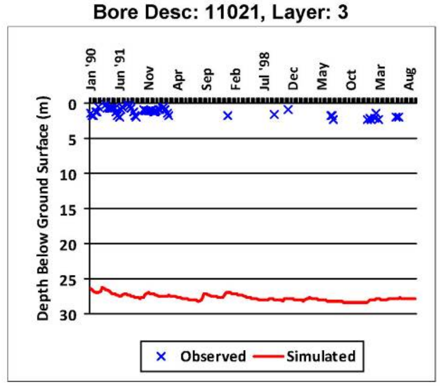
Bore Desc: 11010, Layer: 3



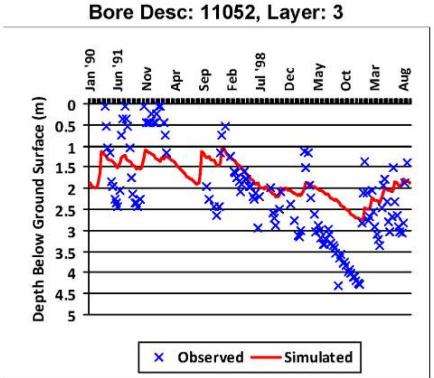
Bore Desc: 11011, Layer: 3



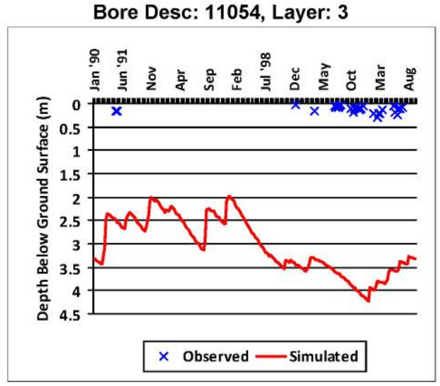
Bore Desc: 11021, Layer: 3



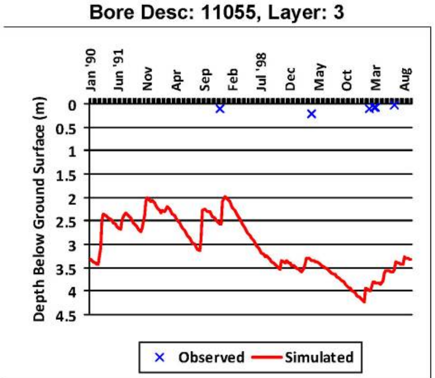
Bore Desc: 11052, Layer: 3



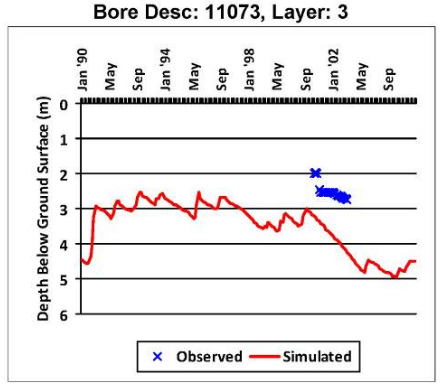
Bore Desc: 11054, Layer: 3



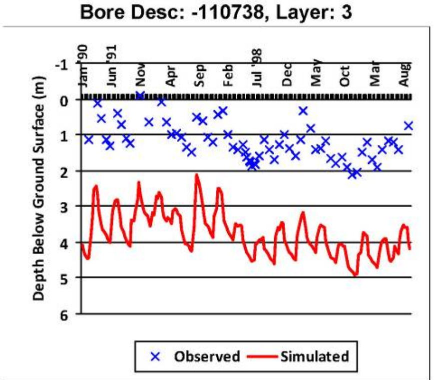
Bore Desc: 11055, Layer: 3



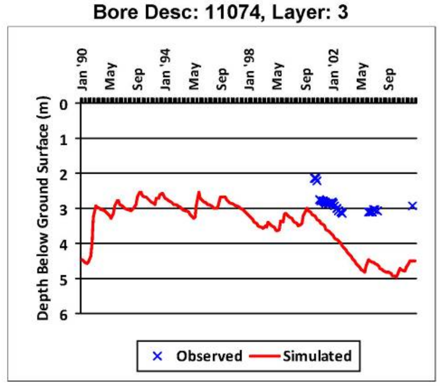
Bore Desc: 11073, Layer: 3



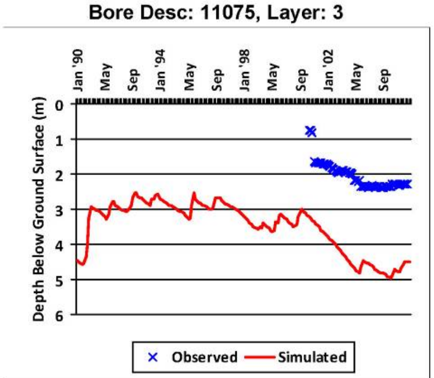
Bore Desc: -110738, Layer: 3



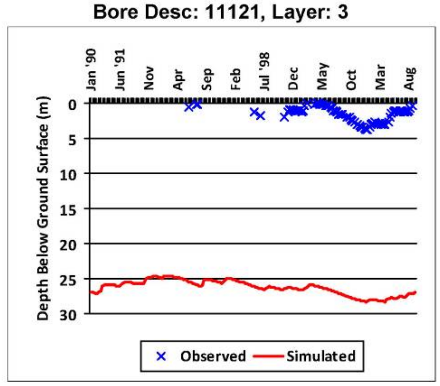
Bore Desc: 11074, Layer: 3



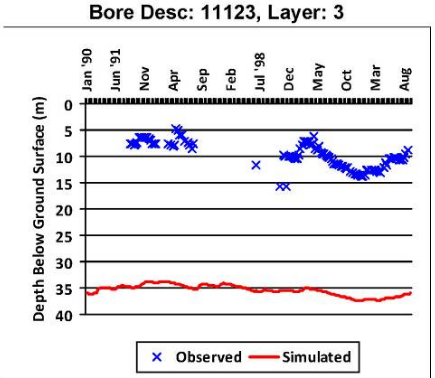
Bore Desc: 11075, Layer: 3



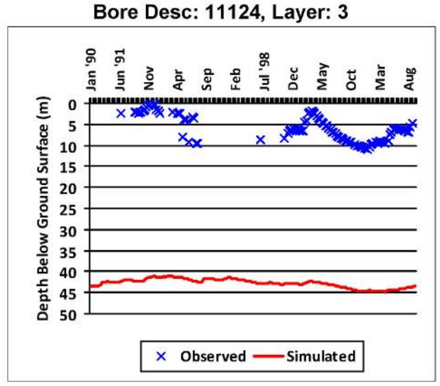
Bore Desc: 11121, Layer: 3



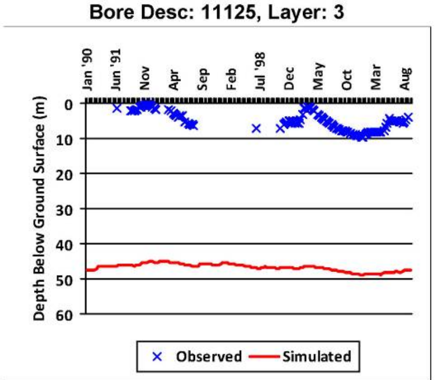
Bore Desc: 11123, Layer: 3



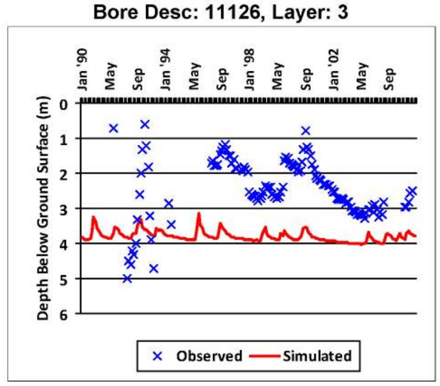
Bore Desc: 11124, Layer: 3



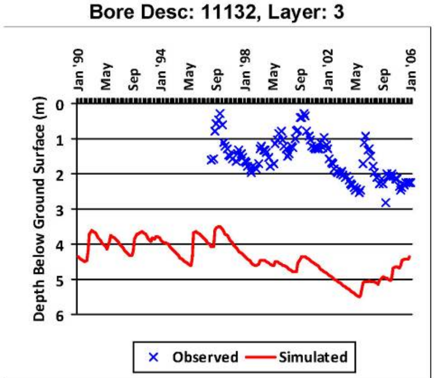
Bore Desc: 11125, Layer: 3



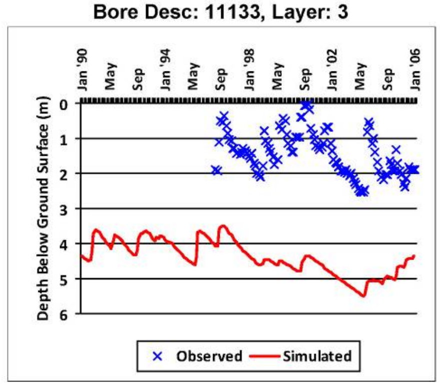
Bore Desc: 11126, Layer: 3



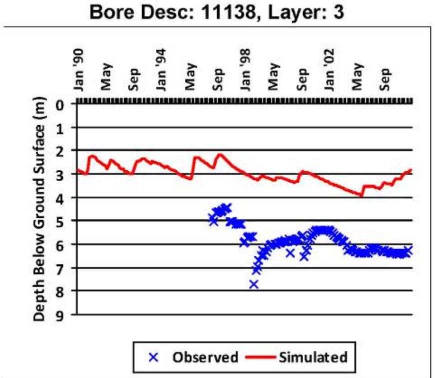
Bore Desc: 11132, Layer: 3



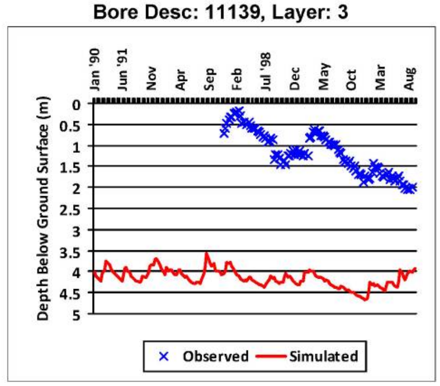
Bore Desc: 11133, Layer: 3



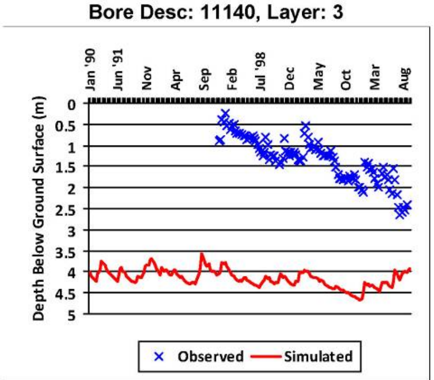
Bore Desc: 11138, Layer: 3



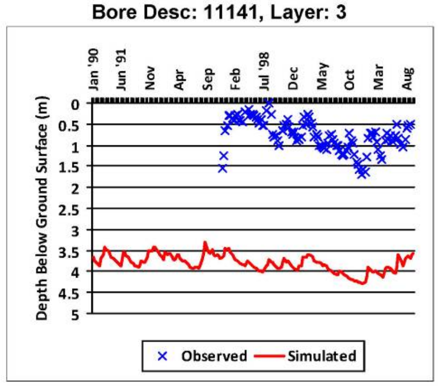
Bore Desc: 11139, Layer: 3



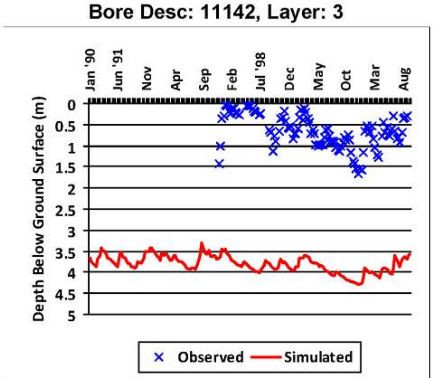
Bore Desc: 11140, Layer: 3



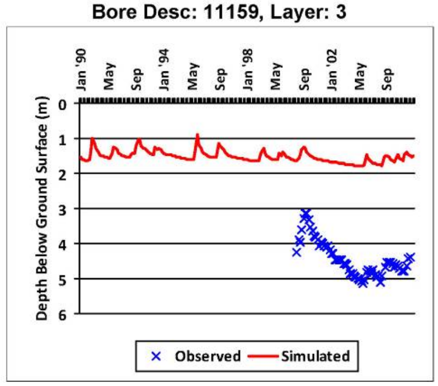
Bore Desc: 11141, Layer: 3



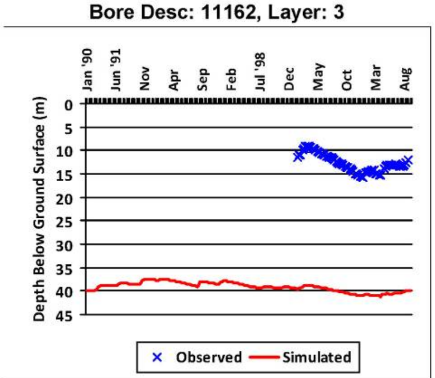
Bore Desc: 11142, Layer: 3



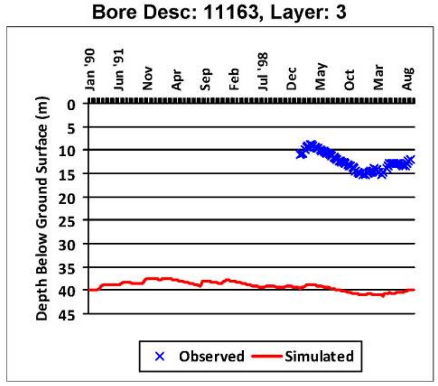
Bore Desc: 11159, Layer: 3



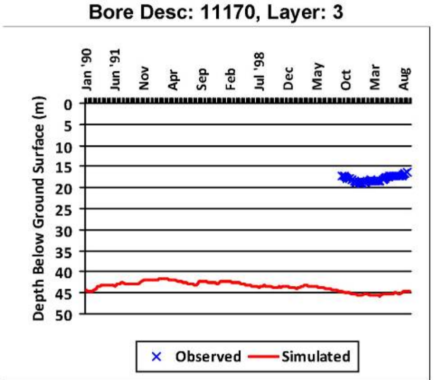
Bore Desc: 11162, Layer: 3



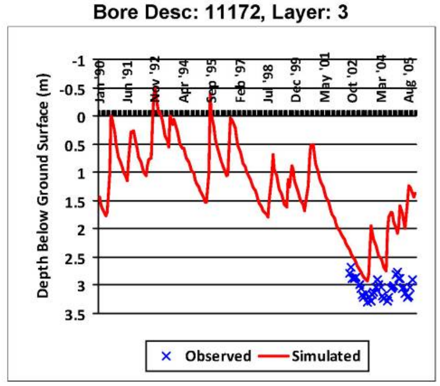
Bore Desc: 11163, Layer: 3



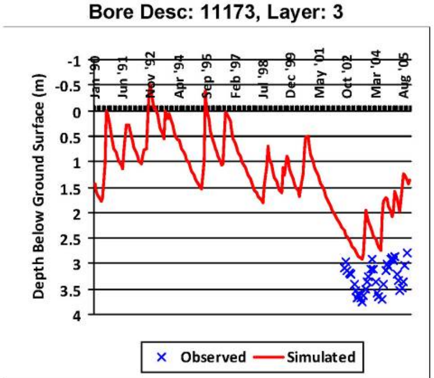
Bore Desc: 11170, Layer: 3



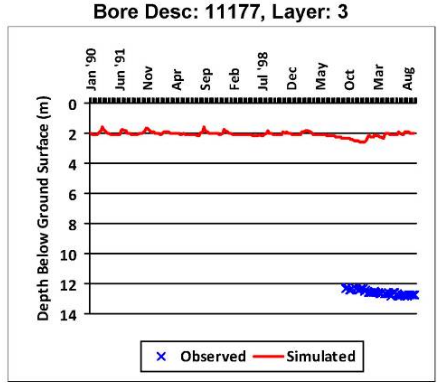
Bore Desc: 11172, Layer: 3



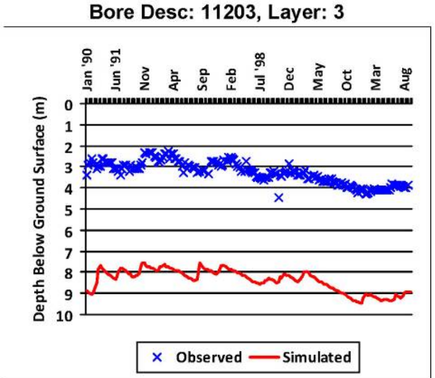
Bore Desc: 11173, Layer: 3



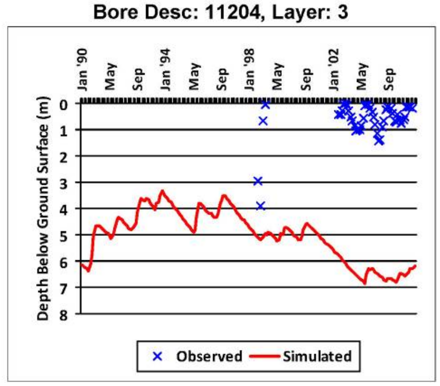
Bore Desc: 11177, Layer: 3



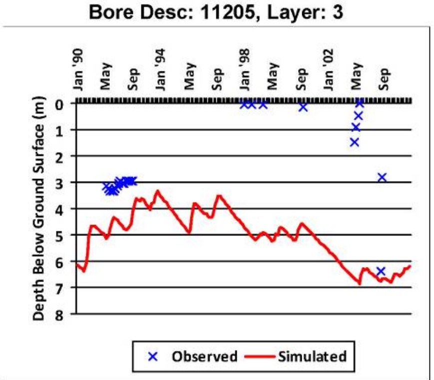
Bore Desc: 11203, Layer: 3



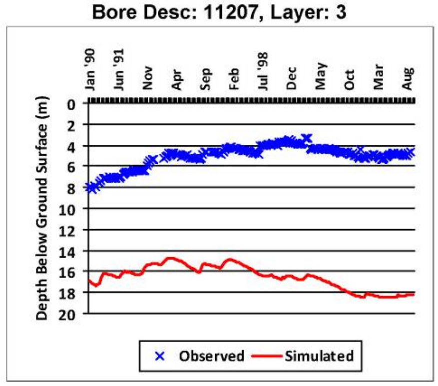
Bore Desc: 11204, Layer: 3



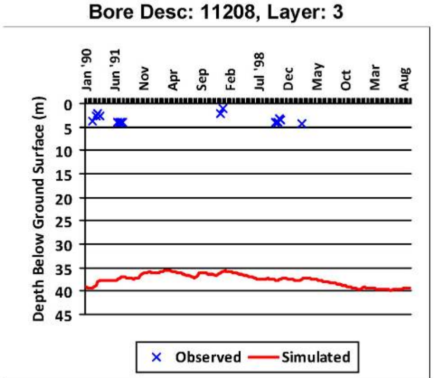
Bore Desc: 11205, Layer: 3



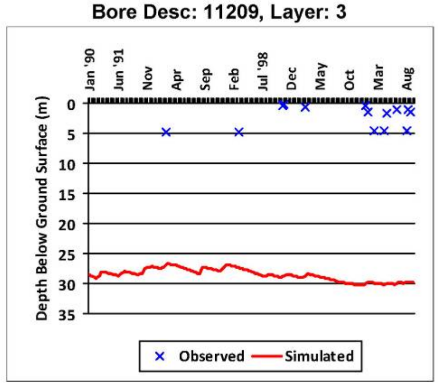
Bore Desc: 11207, Layer: 3



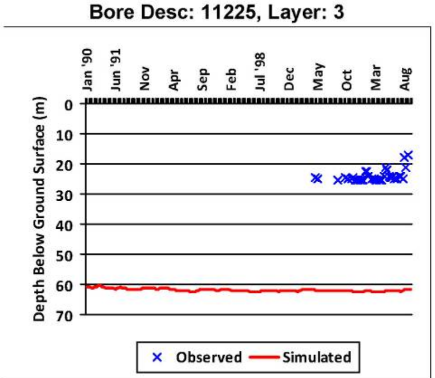
Bore Desc: 11208, Layer: 3



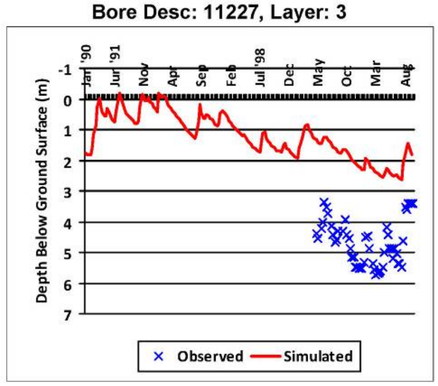
Bore Desc: 11209, Layer: 3



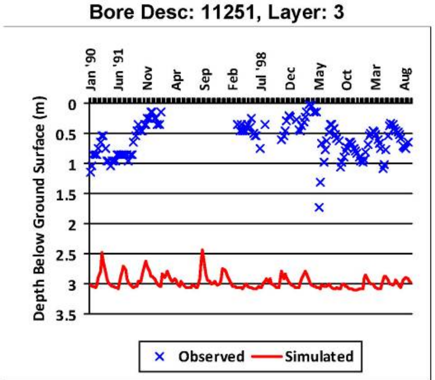
Bore Desc: 11225, Layer: 3



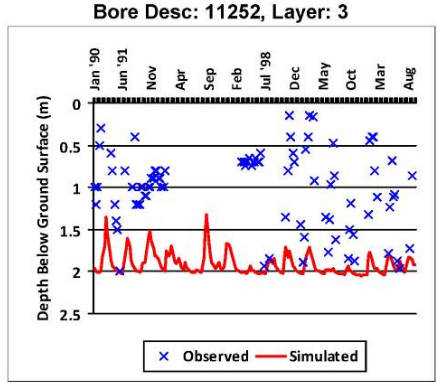
Bore Desc: 11227, Layer: 3



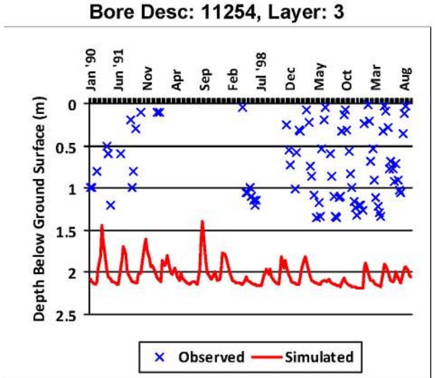
Bore Desc: 11251, Layer: 3



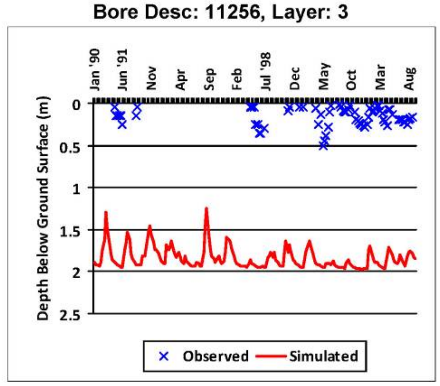
Bore Desc: 11252, Layer: 3



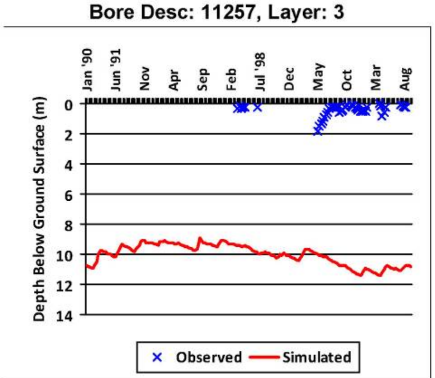
Bore Desc: 11254, Layer: 3



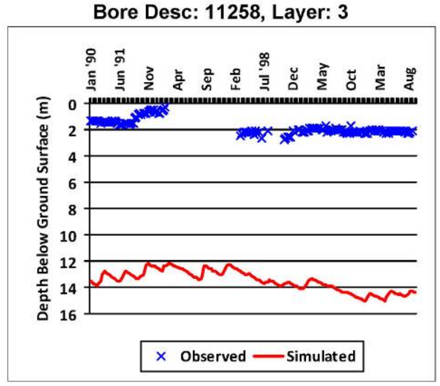
Bore Desc: 11256, Layer: 3



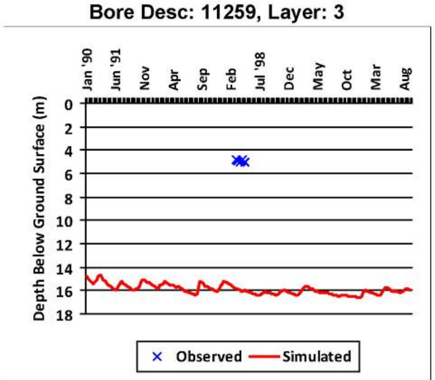
Bore Desc: 11257, Layer: 3



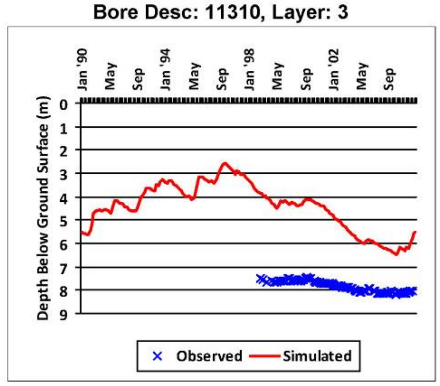
Bore Desc: 11258, Layer: 3



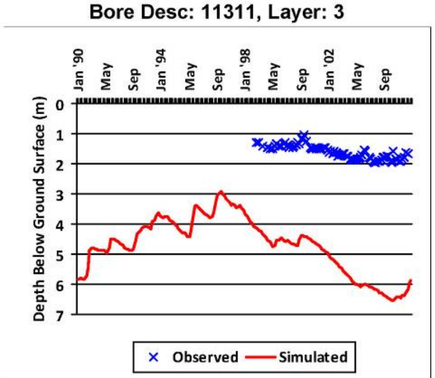
Bore Desc: 11259, Layer: 3



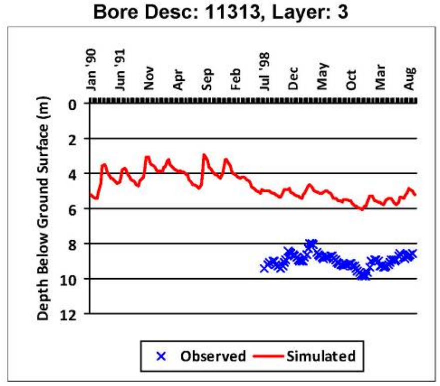
Bore Desc: 11310, Layer: 3



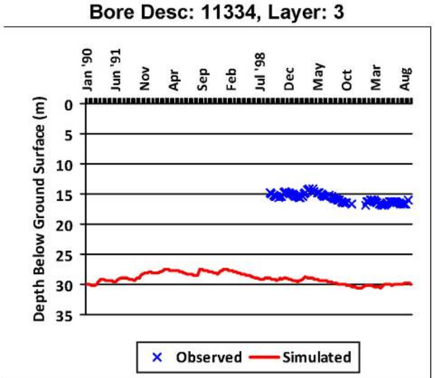
Bore Desc: 11311, Layer: 3



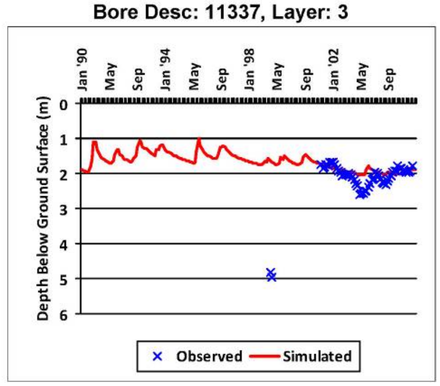
Bore Desc: 11313, Layer: 3



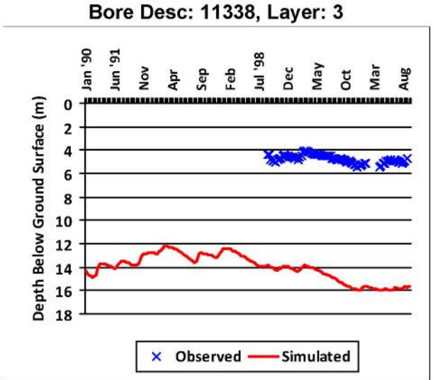
Bore Desc: 11334, Layer: 3



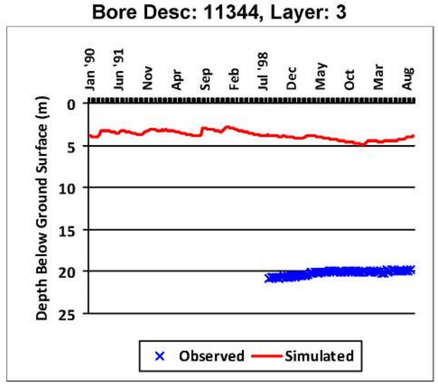
Bore Desc: 11337, Layer: 3



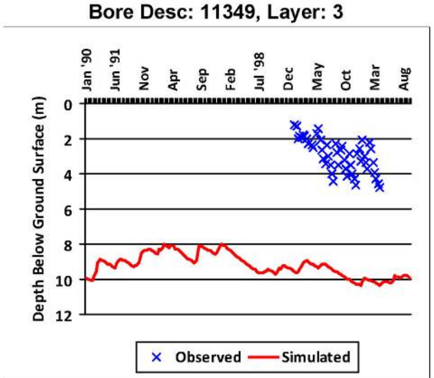
Bore Desc: 11338, Layer: 3



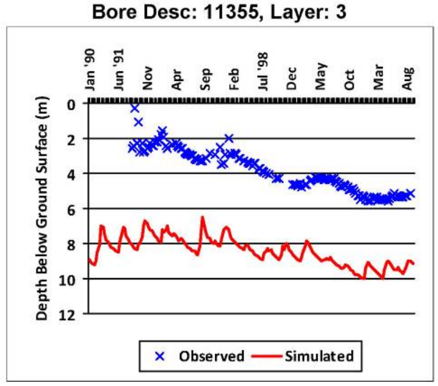
Bore Desc: 11344, Layer: 3



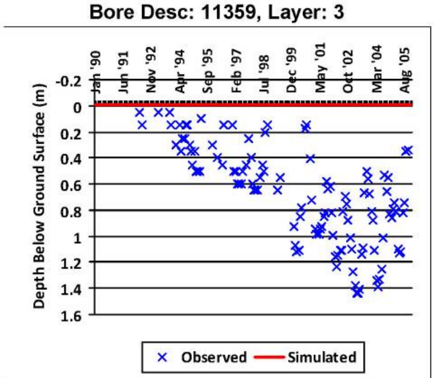
Bore Desc: 11349, Layer: 3



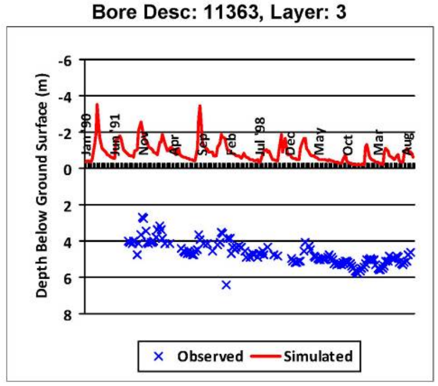
Bore Desc: 11355, Layer: 3



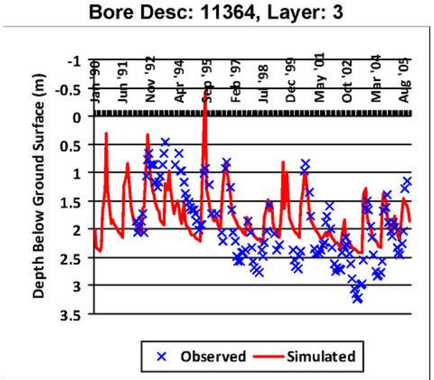
Bore Desc: 11359, Layer: 3



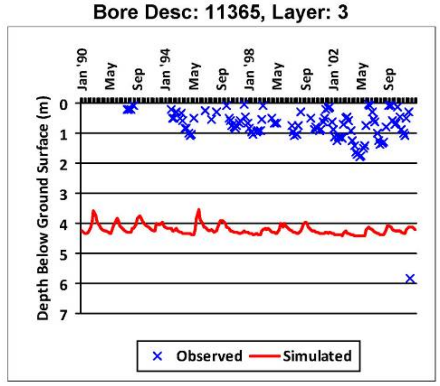
Bore Desc: 11363, Layer: 3



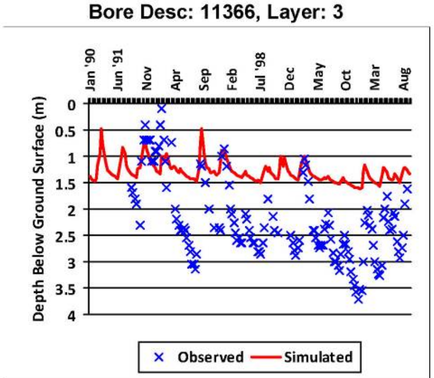
Bore Desc: 11364, Layer: 3



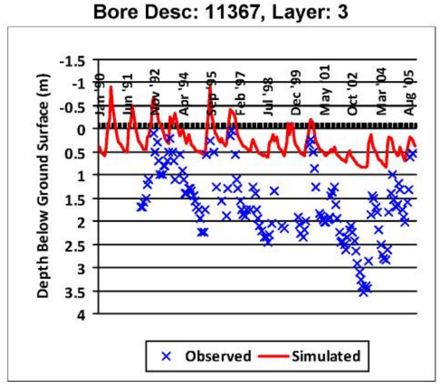
Bore Desc: 11365, Layer: 3



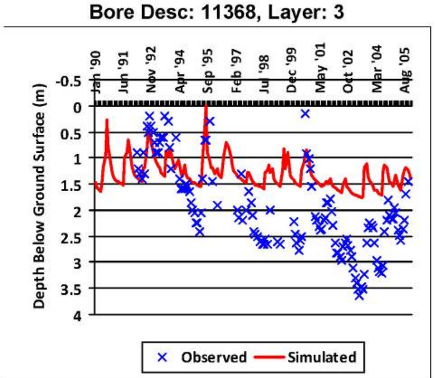
Bore Desc: 11366, Layer: 3



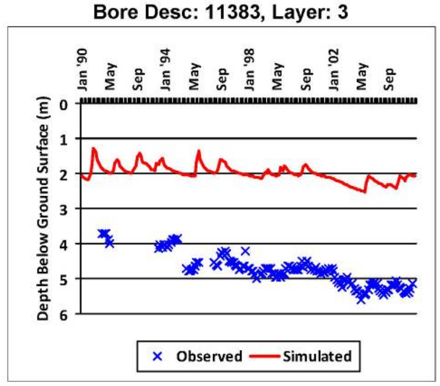
Bore Desc: 11367, Layer: 3



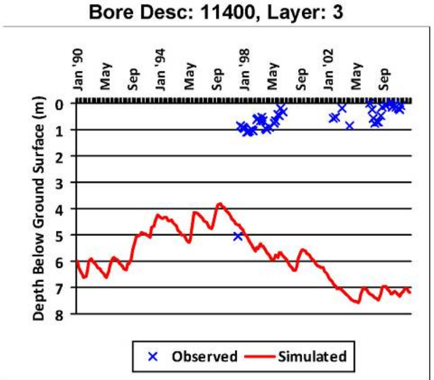
Bore Desc: 11368, Layer: 3



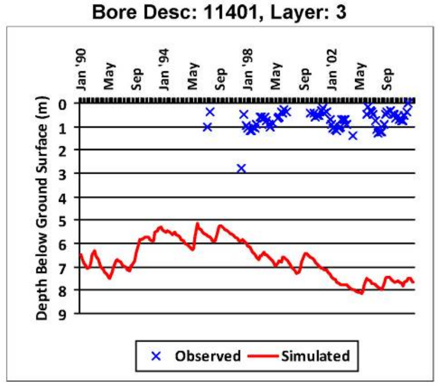
Bore Desc: 11383, Layer: 3



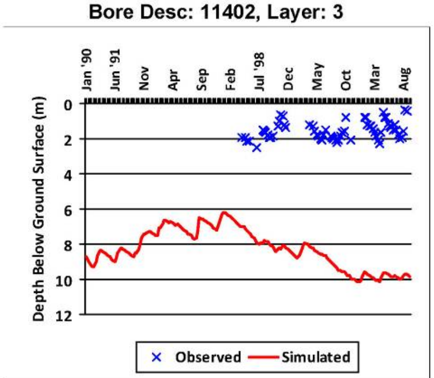
Bore Desc: 11400, Layer: 3



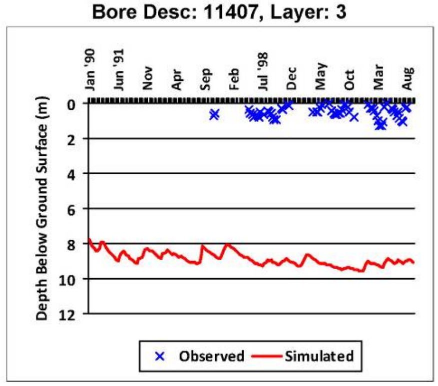
Bore Desc: 11401, Layer: 3



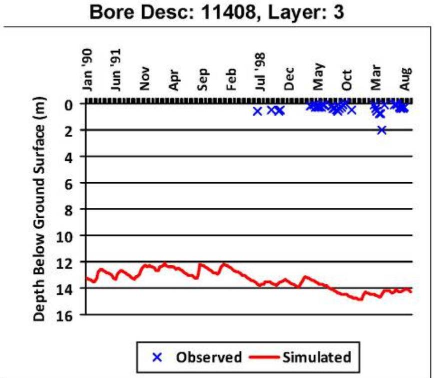
Bore Desc: 11402, Layer: 3



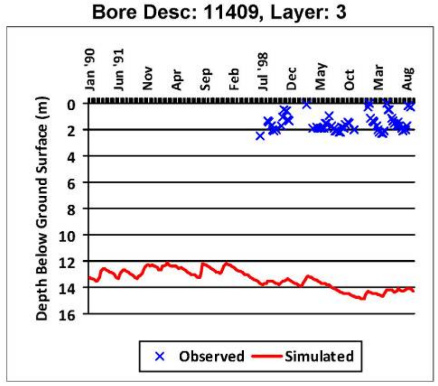
Bore Desc: 11407, Layer: 3



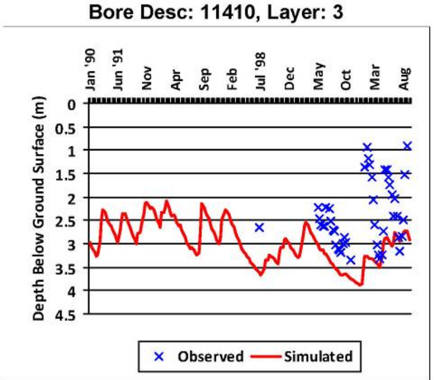
Bore Desc: 11408, Layer: 3



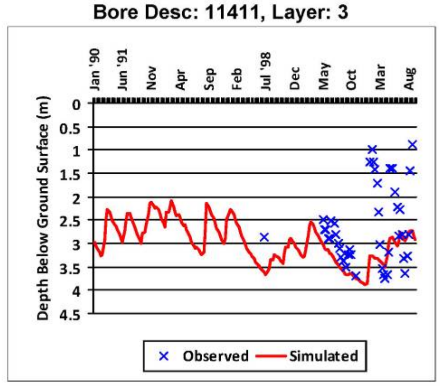
Bore Desc: 11409, Layer: 3



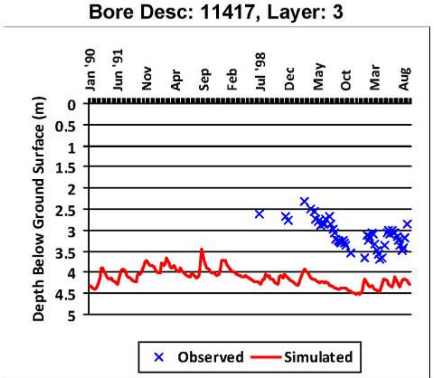
Bore Desc: 11410, Layer: 3



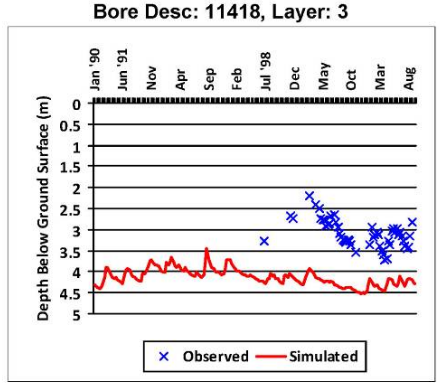
Bore Desc: 11411, Layer: 3



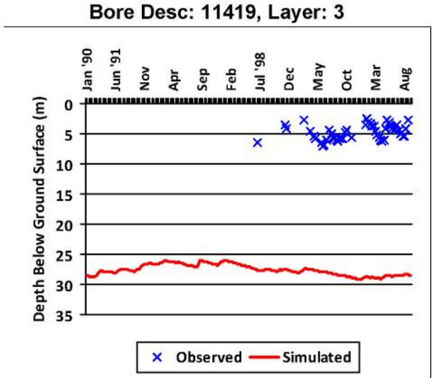
Bore Desc: 11417, Layer: 3



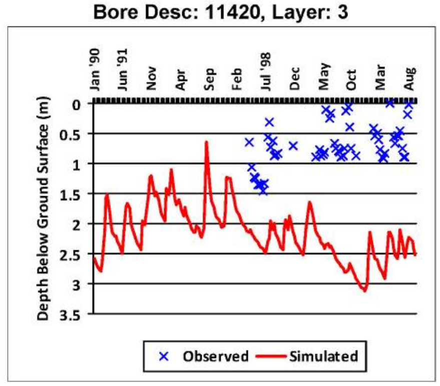
Bore Desc: 11418, Layer: 3

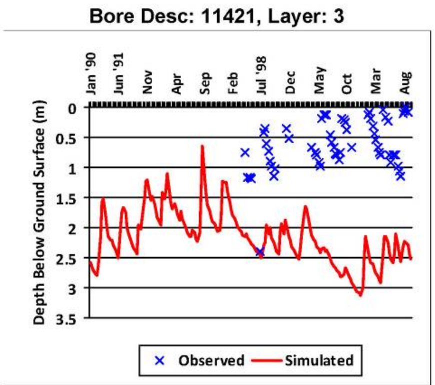


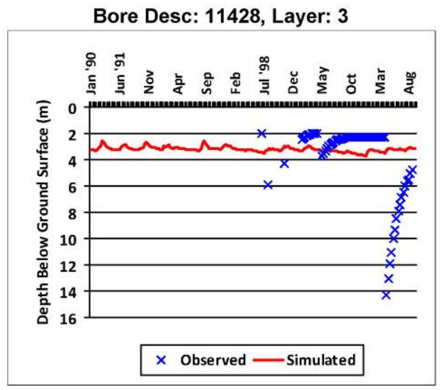
Bore Desc: 11419, Layer: 3

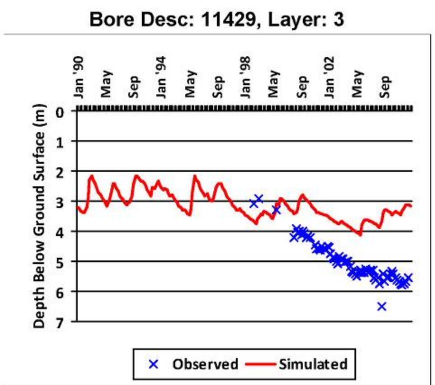


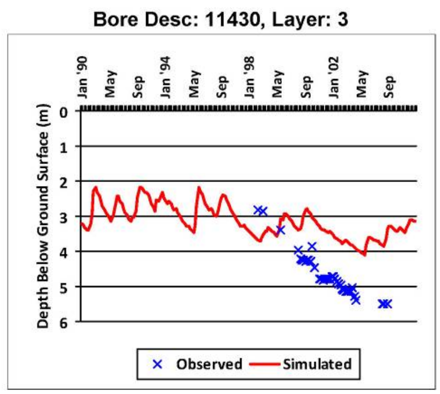
Bore Desc: 11420, Layer: 3

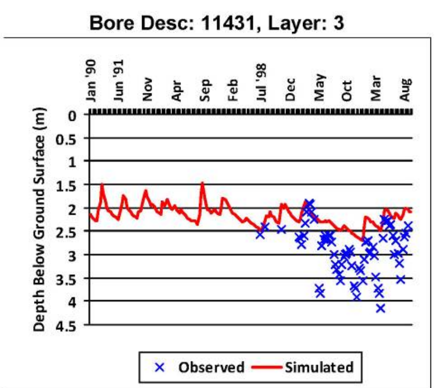


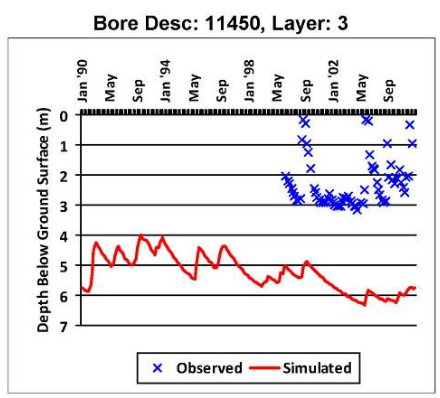

Bore Desc: 11421, Layer: 3
Depth Below Ground Surface (m)
Observed
Simulated

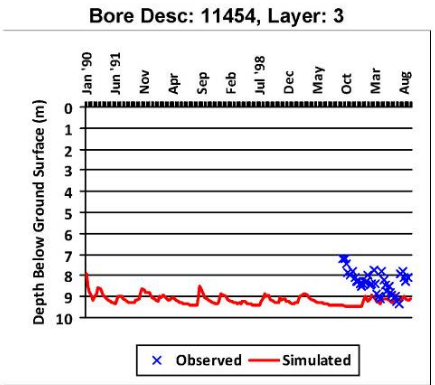

Bore Desc: 11428, Layer: 3
Depth Below Ground Surface (m)
Observed
Simulated

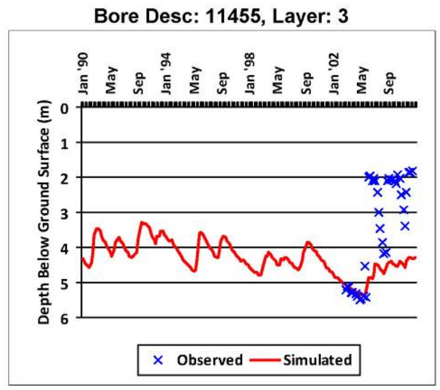

Bore Desc: 11429, Layer: 3
Depth Below Ground Surface (m)
Observed
Simulated

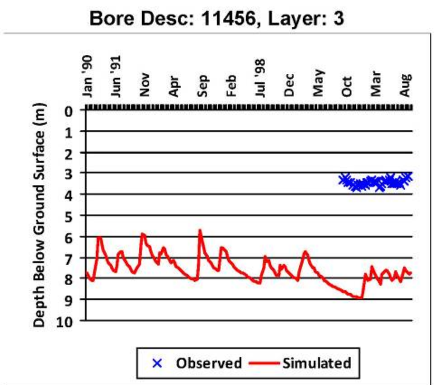

Bore Desc: 11430, Layer: 3
Depth Below Ground Surface (m)
Observed
Simulated

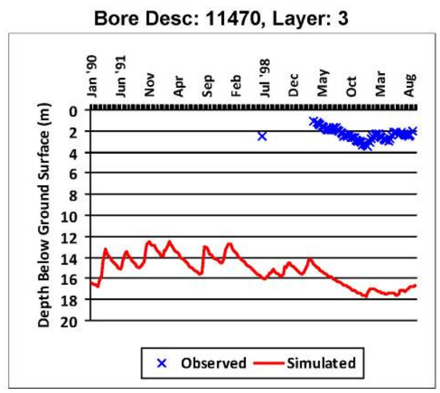

Bore Desc: 11431, Layer: 3
Depth Below Ground Surface (m)
Observed
Simulated

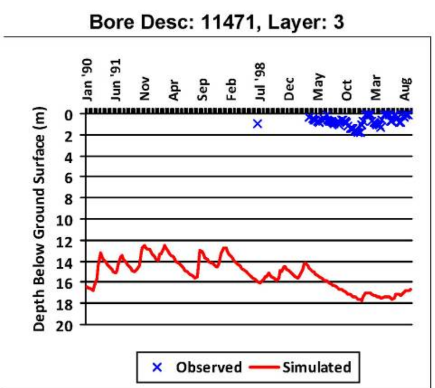

Bore Desc: 11450, Layer: 3
Depth Below Ground Surface (m)
Observed
Simulated

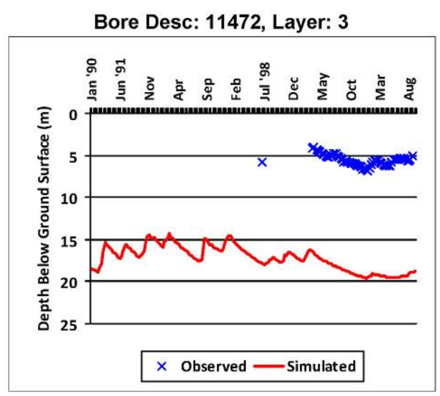

Bore Desc: 11454, Layer: 3
Jan '90
Jun '91
Nov
Apr
Sep
Feb
Jul '98
Dec
May
Oct
Mar
Aug
Depth Below Ground Surface (m)
0
1
2
3
4
5
6
7
8
9
10
Observed
Simulated


Bore Desc: 11455, Layer: 3
Jan '90
May
Sep
Jan '94
May
Sep
Jan '98
May
Sep
Jan '02
May
Sep
Depth Below Ground Surface (m)
0
1
2
3
4
5
6
Observed
Simulated

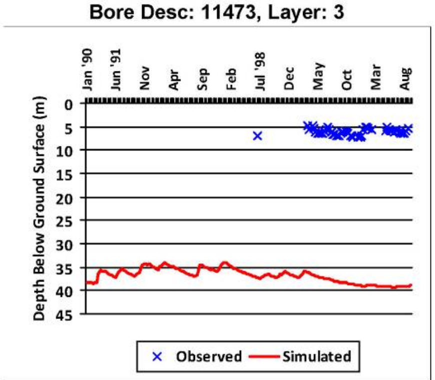

Bore Desc: 11456, Layer: 3
Jan '90
Jun '91
Nov
Apr
Sep
Feb
Jul '98
Dec
May
Oct
Mar
Aug
Depth Below Ground Surface (m)
0
1
2
3
4
5
6
7
8
9
10
Observed
Simulated


Bore Desc: 11470, Layer: 3
Jan '90
Jun '91
Nov
Apr
Sep
Feb
Jul '98
Dec
May
Oct
Mar
Aug
Depth Below Ground Surface (m)
0
2
4
6
8
10
12
14
16
18
20
Observed
Simulated

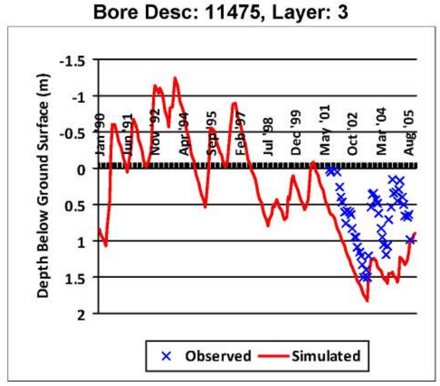

Bore Desc: 11471, Layer: 3
Jan '90
Jun '91
Nov
Apr
Sep
Feb
Jul '98
Dec
May
Oct
Mar
Aug
Depth Below Ground Surface (m)
0
2
4
6
8
10
12
14
16
18
20
Observed
Simulated


Bore Desc: 11472, Layer: 3
Jan '90
Jun '91
Nov
Apr
Sep
Feb
Jul '98
Dec
May
Oct
Mar
Aug
Depth Below Ground Surface (m)
0
5
10
15
20
25
Observed
Simulated

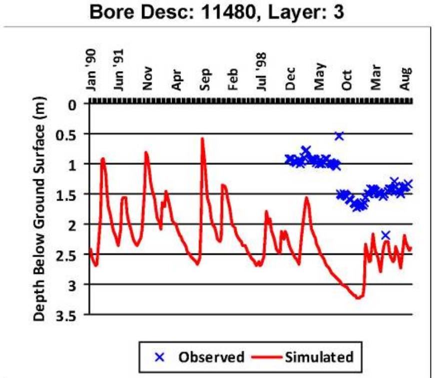
Bore Desc: 11473, Layer: 3



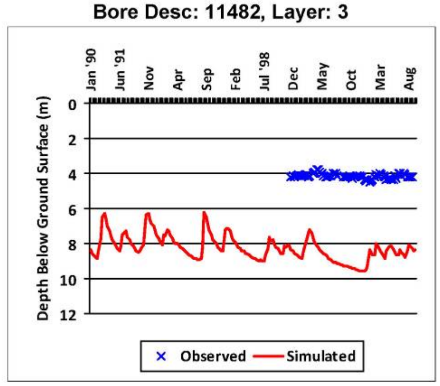
Bore Desc: 11475, Layer: 3



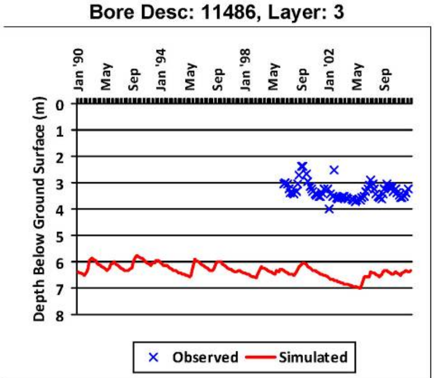
Bore Desc: 11480, Layer: 3



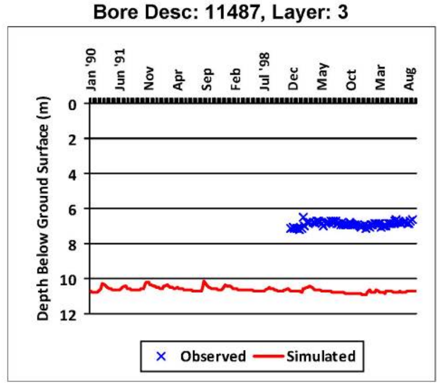
Bore Desc: 11482, Layer: 3



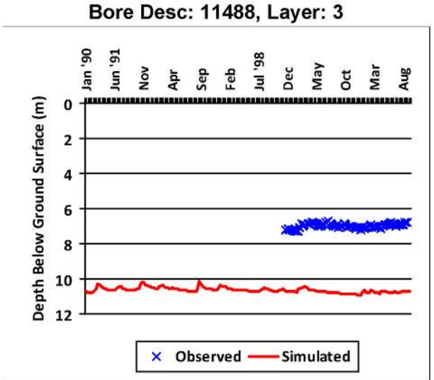
Bore Desc: 11486, Layer: 3



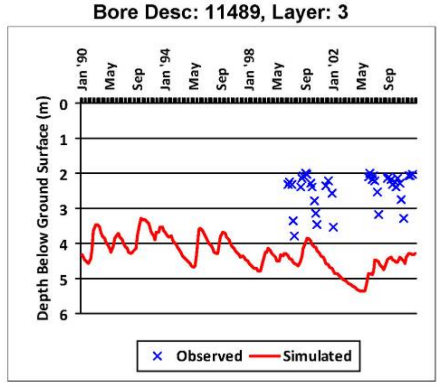
Bore Desc: 11487, Layer: 3



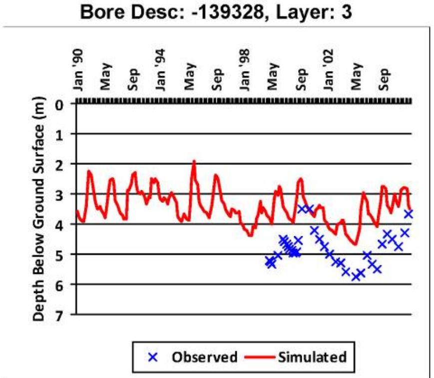
Bore Desc: 11488, Layer: 3



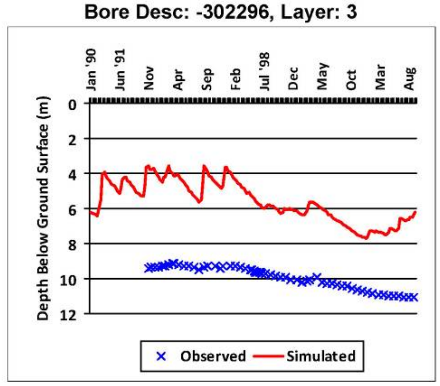
Bore Desc: 11489, Layer: 3



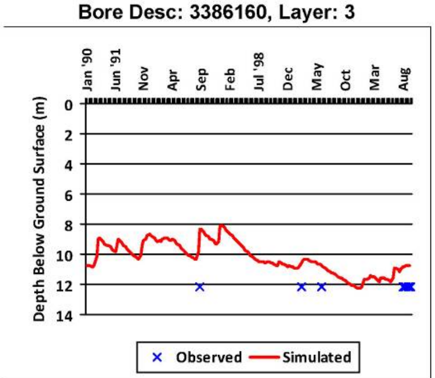
Bore Desc: -139328, Layer: 3



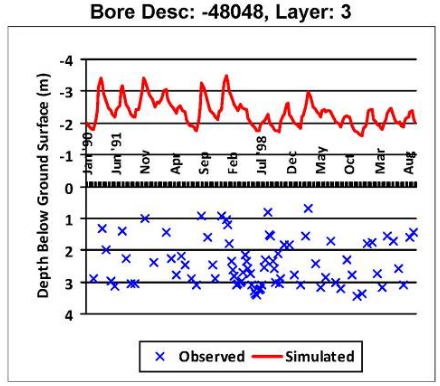
Bore Desc: -302296, Layer: 3



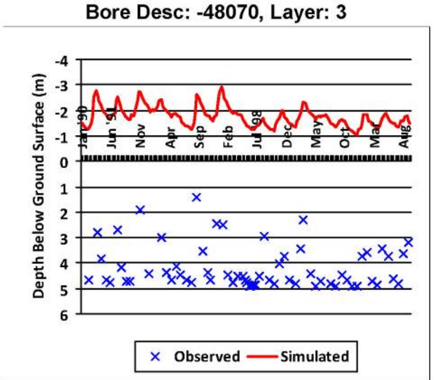
Bore Desc: 3386160, Layer: 3



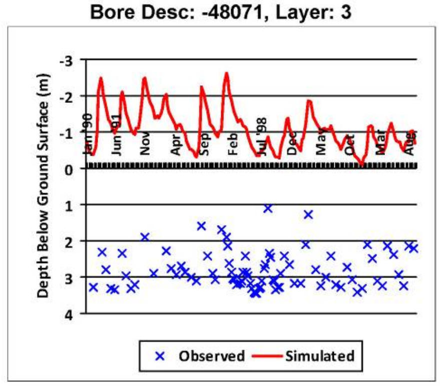
Bore Desc: -48048, Layer: 3



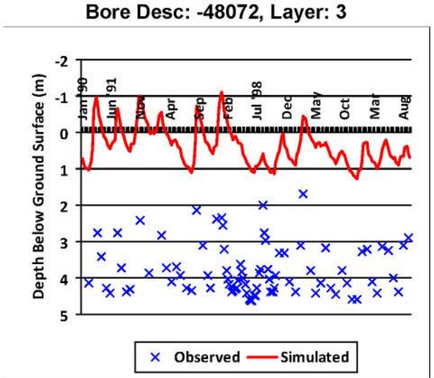
Bore Desc: -48070, Layer: 3



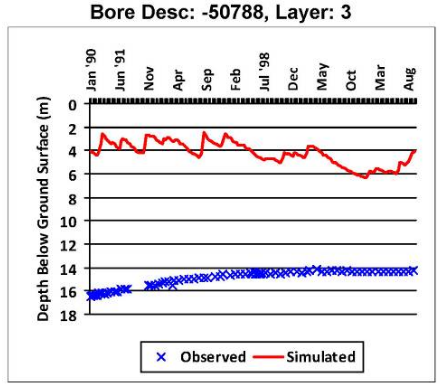
Bore Desc: -48071, Layer: 3



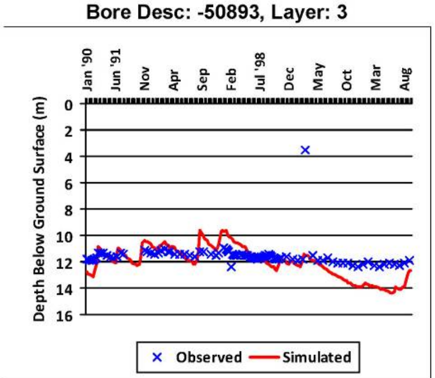
Bore Desc: -48072, Layer: 3



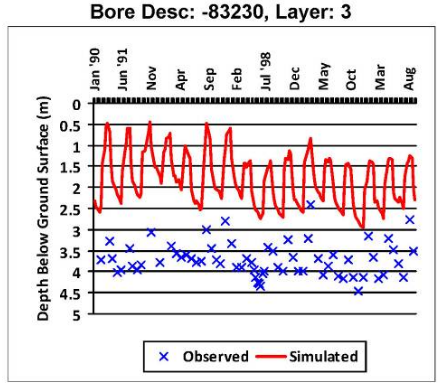
Bore Desc: -50788, Layer: 3



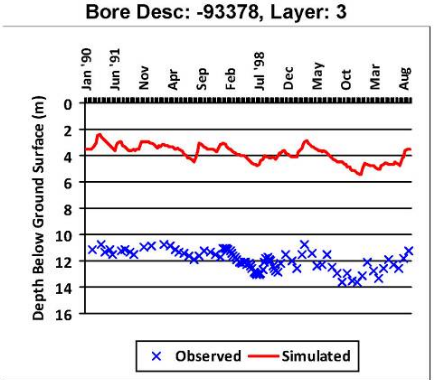
Bore Desc: -50893, Layer: 3



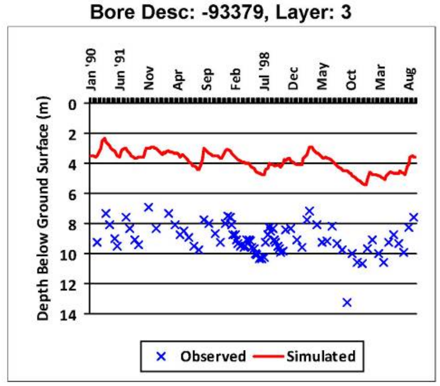
Bore Desc: -83230, Layer: 3



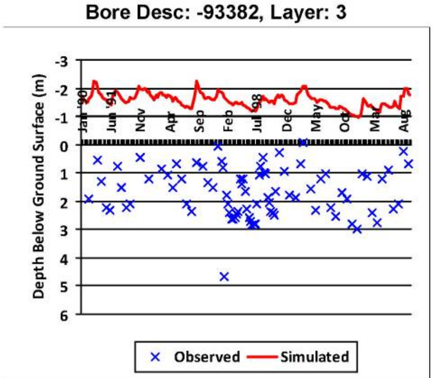
Bore Desc: -93378, Layer: 3



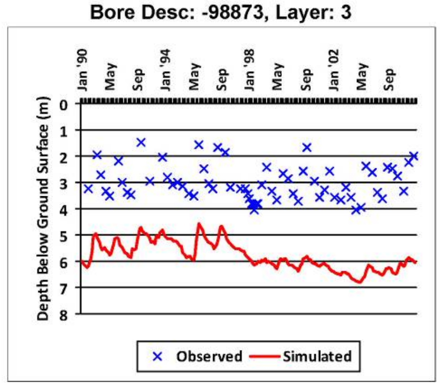
Bore Desc: -93379, Layer: 3



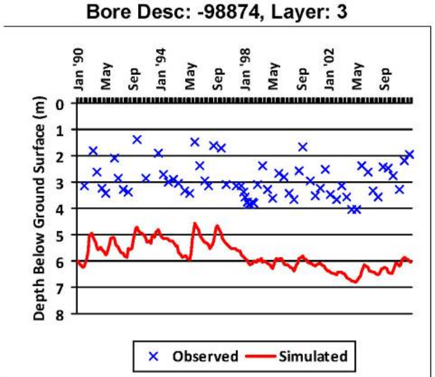
Bore Desc: -93382, Layer: 3



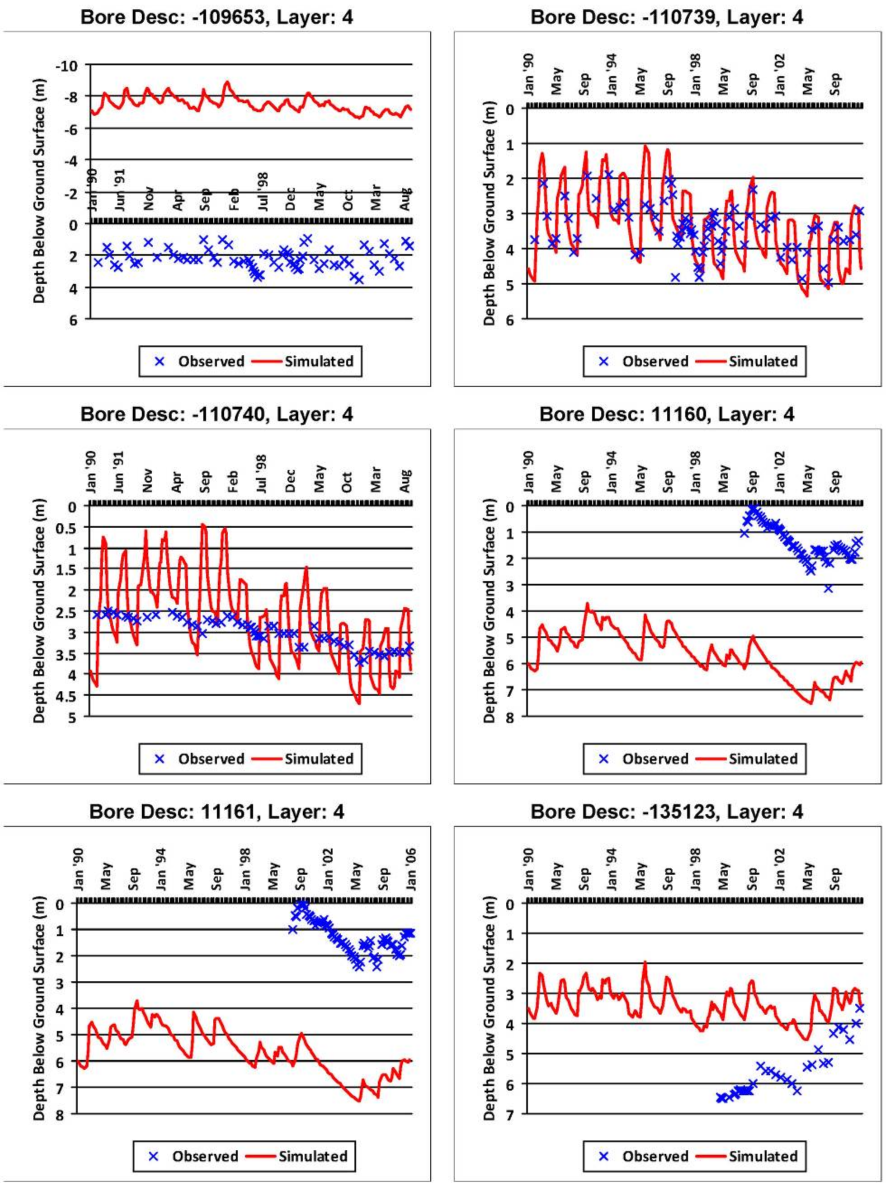
Bore Desc: -98873, Layer: 3



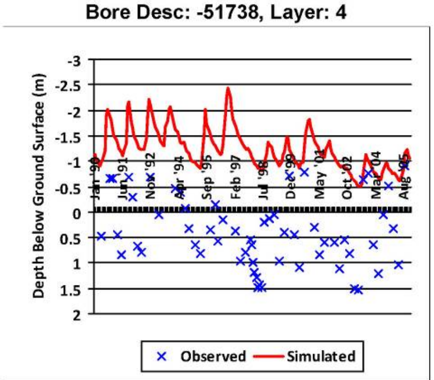
Bore Desc: -98874, Layer: 3



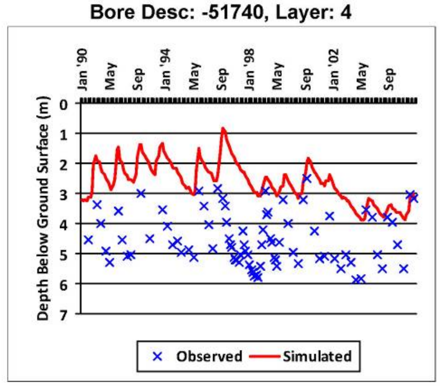
Layer 4 (Calivil Formation)



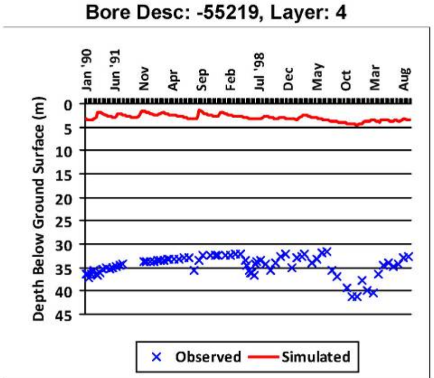
Bore Desc: -51738, Layer: 4



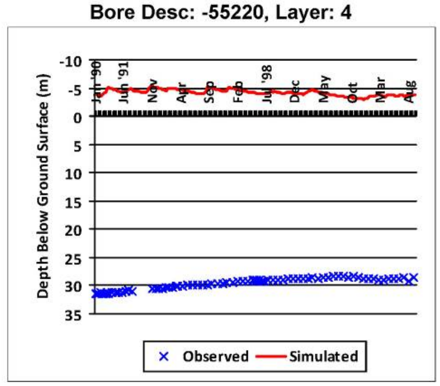
Bore Desc: -51740, Layer: 4



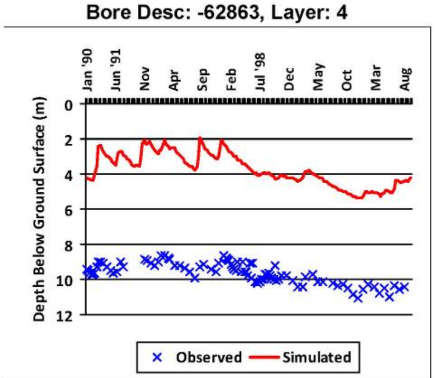
Bore Desc: -55219, Layer: 4



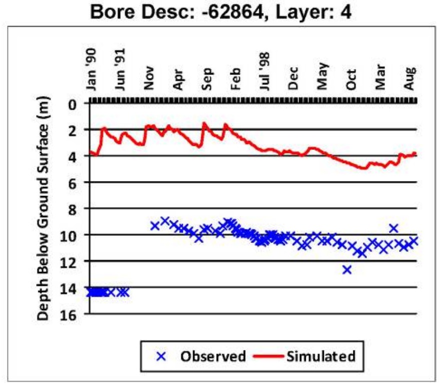
Bore Desc: -55220, Layer: 4



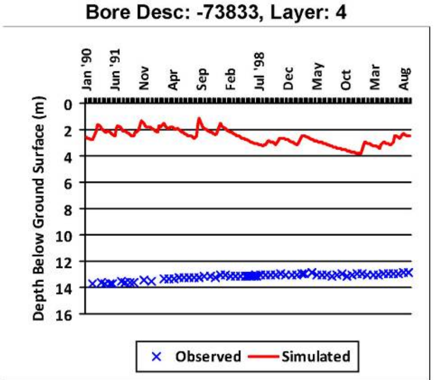
Bore Desc: -62863, Layer: 4



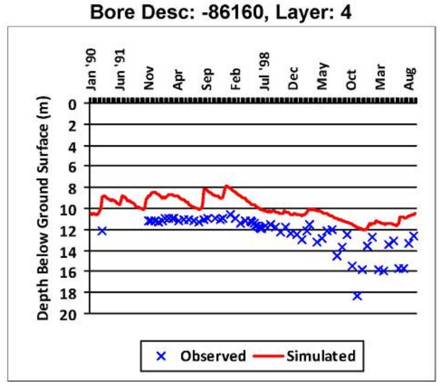
Bore Desc: -62864, Layer: 4



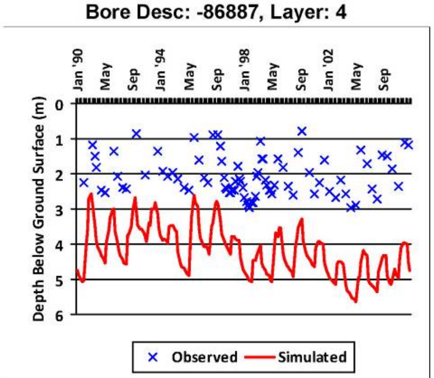
Bore Desc: -73833, Layer: 4



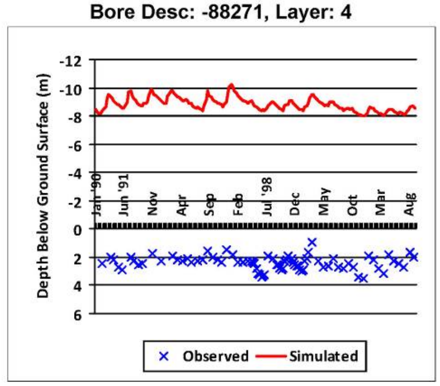
Bore Desc: -86160, Layer: 4



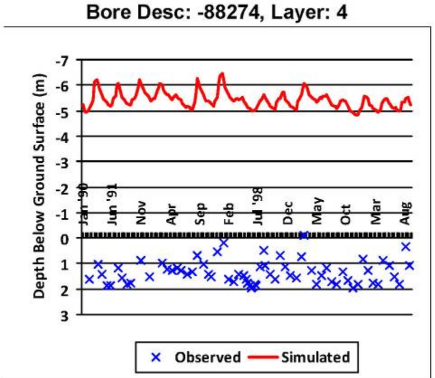
Bore Desc: -86887, Layer: 4



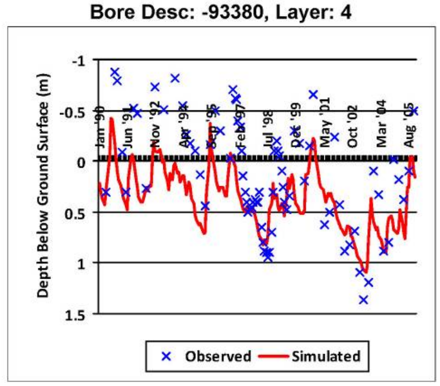
Bore Desc: -88271, Layer: 4



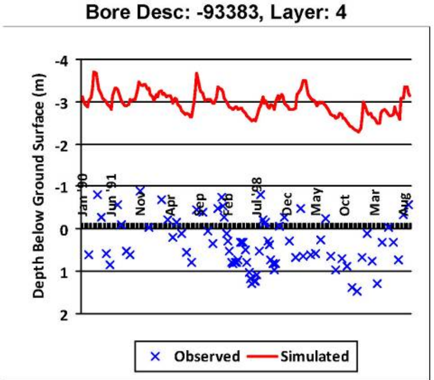
Bore Desc: -88274, Layer: 4



Bore Desc: -93380, Layer: 4

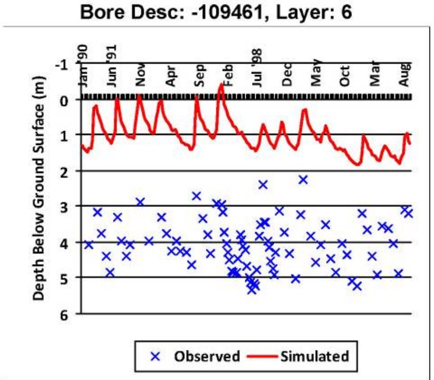


Bore Desc: -93383, Layer: 4

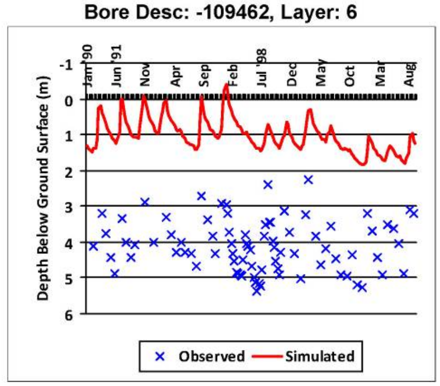


Layer 6 (Palaeozoic meta-sediments)

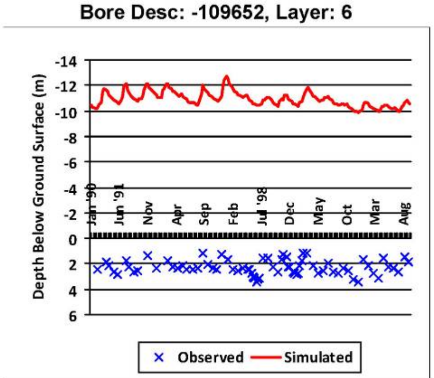
Bore Desc: -109461, Layer: 6



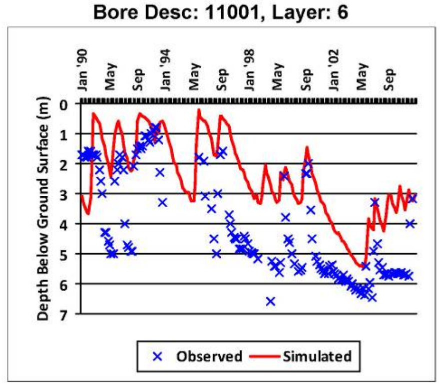
Bore Desc: -109462, Layer: 6



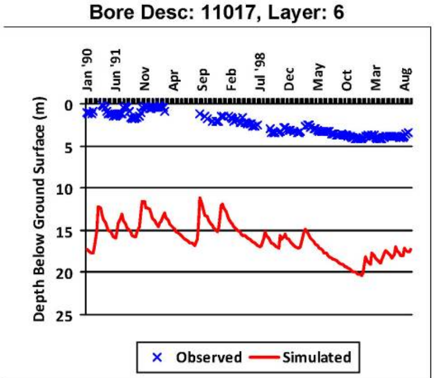
Bore Desc: -109652, Layer: 6



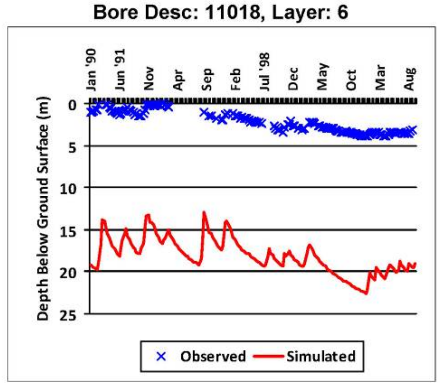
Bore Desc: 11001, Layer: 6



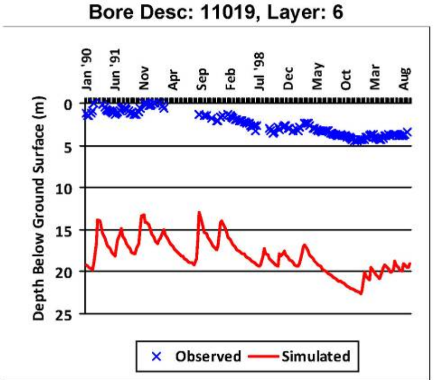
Bore Desc: 11017, Layer: 6



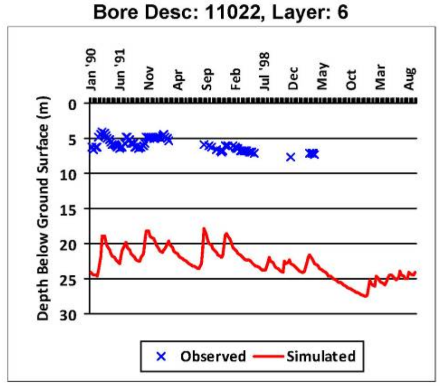
Bore Desc: 11018, Layer: 6



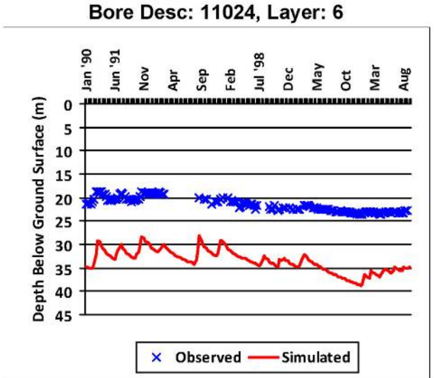
Bore Desc: 11019, Layer: 6



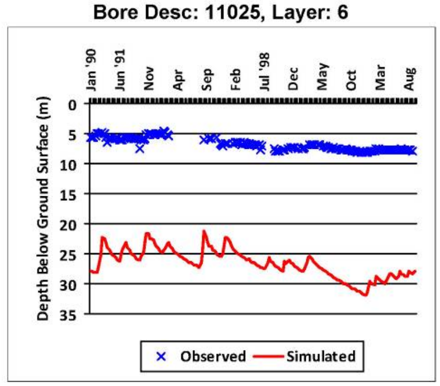
Bore Desc: 11022, Layer: 6



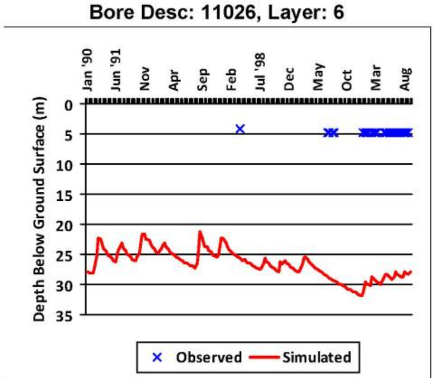
Bore Desc: 11024, Layer: 6



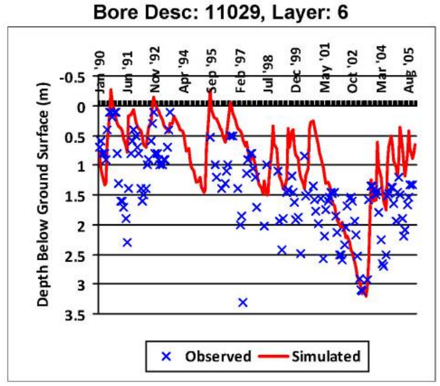
Bore Desc: 11025, Layer: 6



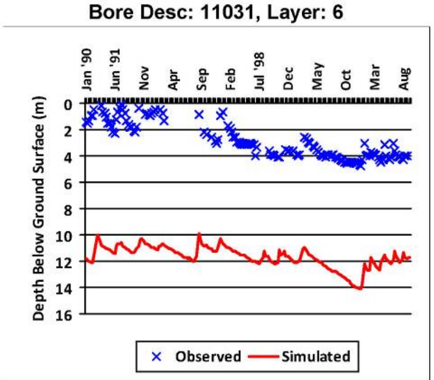
Bore Desc: 11026, Layer: 6



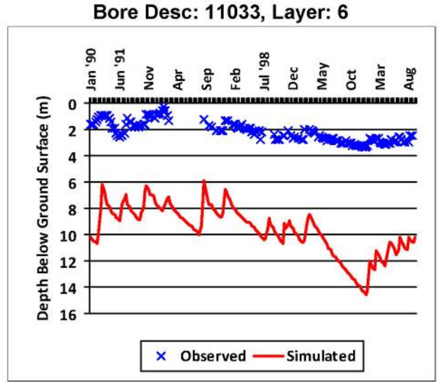
Bore Desc: 11029, Layer: 6



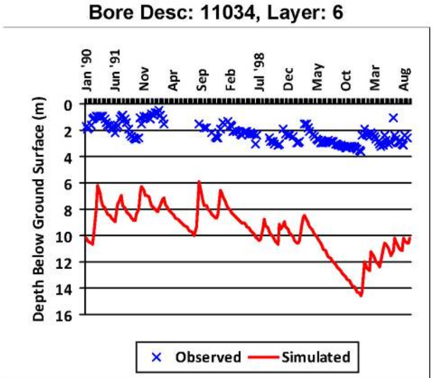
Bore Desc: 11031, Layer: 6



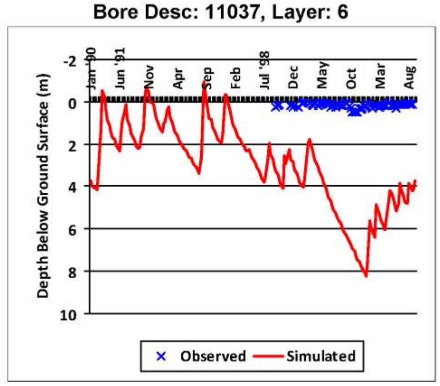
Bore Desc: 11033, Layer: 6



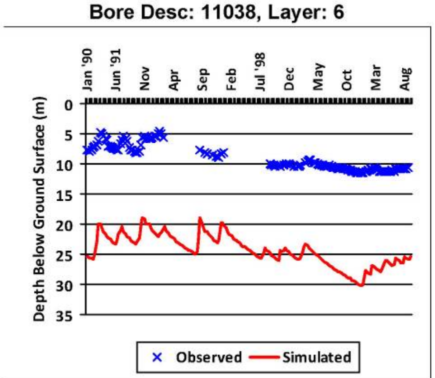
Bore Desc: 11034, Layer: 6



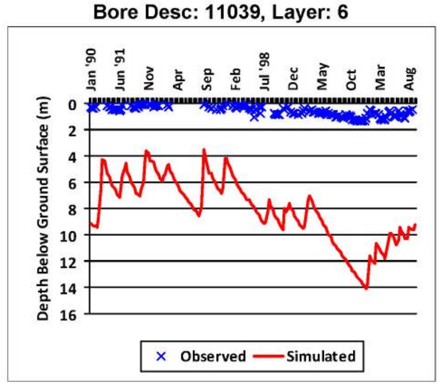
Bore Desc: 11037, Layer: 6



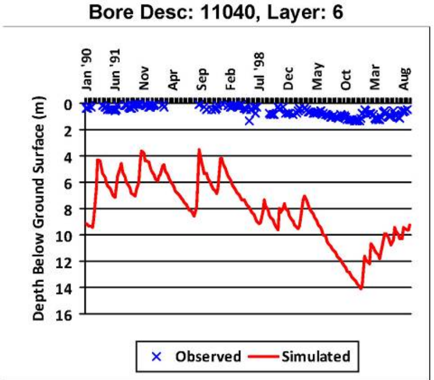
Bore Desc: 11038, Layer: 6



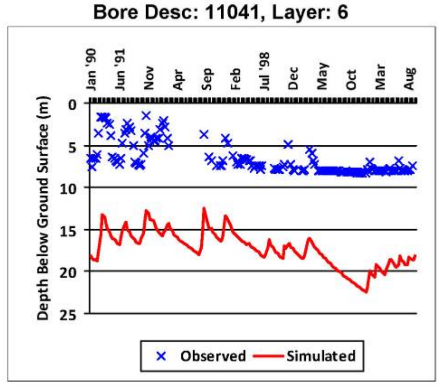
Bore Desc: 11039, Layer: 6



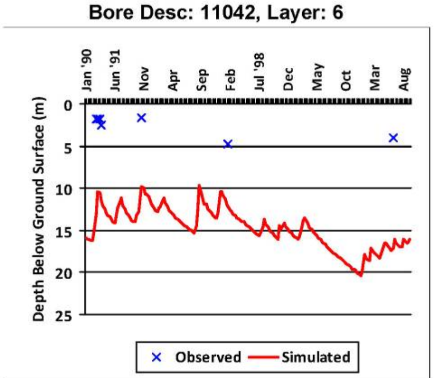
Bore Desc: 11040, Layer: 6



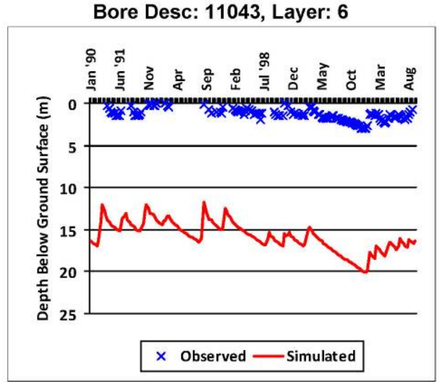
Bore Desc: 11041, Layer: 6



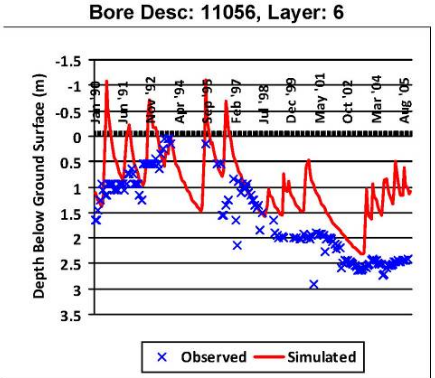
Bore Desc: 11042, Layer: 6



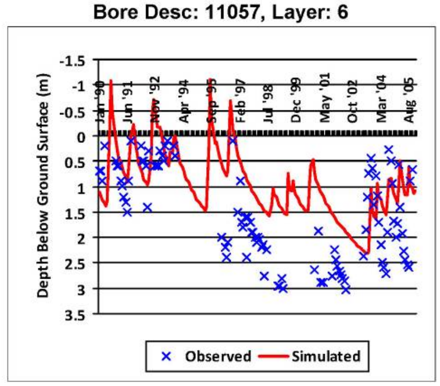
Bore Desc: 11043, Layer: 6



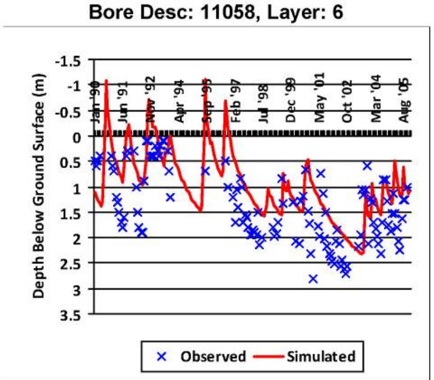
Bore Desc: 11056, Layer: 6



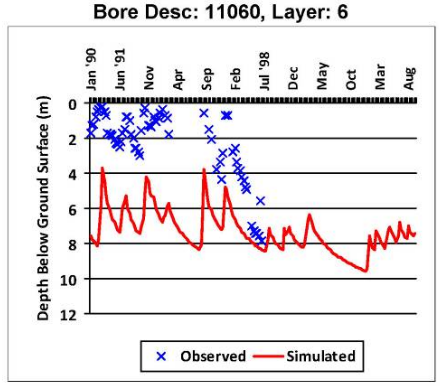
Bore Desc: 11057, Layer: 6



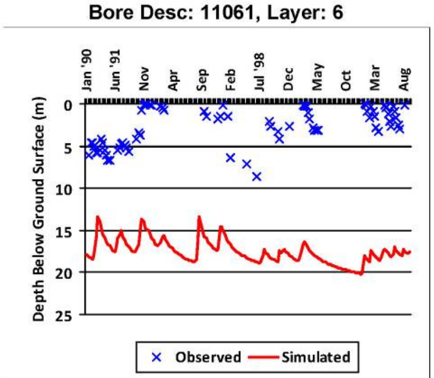
Bore Desc: 11058, Layer: 6



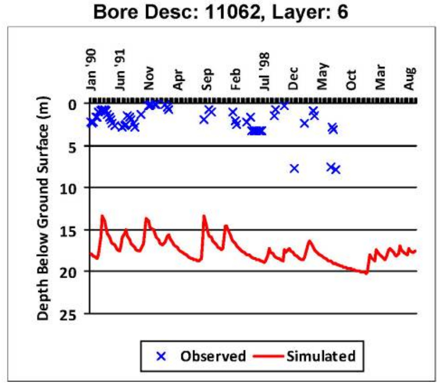
Bore Desc: 11060, Layer: 6



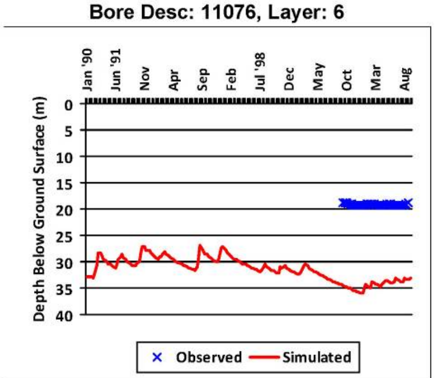
Bore Desc: 11061, Layer: 6



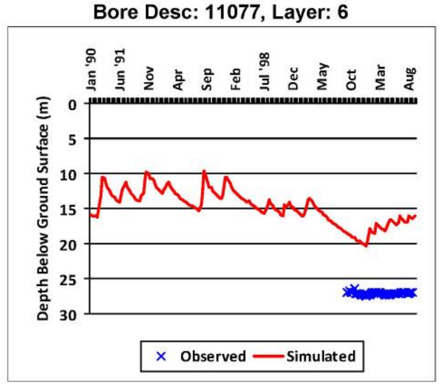
Bore Desc: 11062, Layer: 6



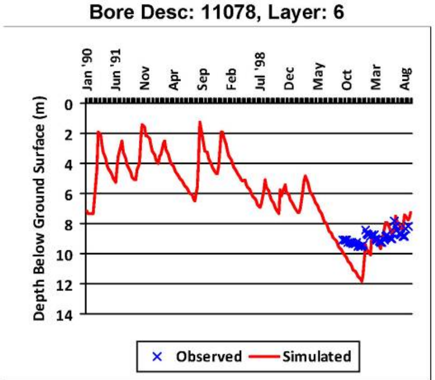
Bore Desc: 11076, Layer: 6



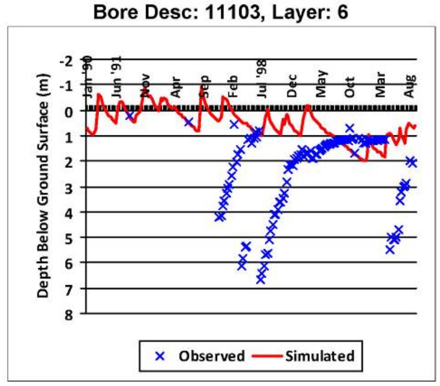
Bore Desc: 11077, Layer: 6



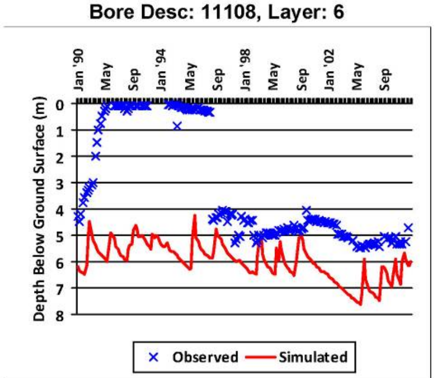
Bore Desc: 11078, Layer: 6



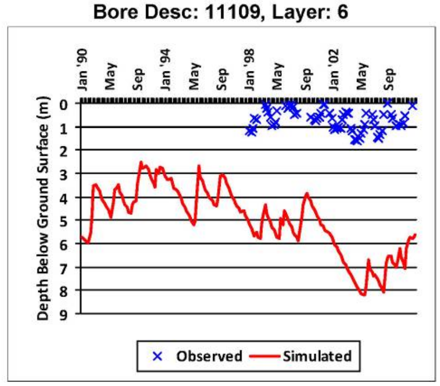
Bore Desc: 11103, Layer: 6



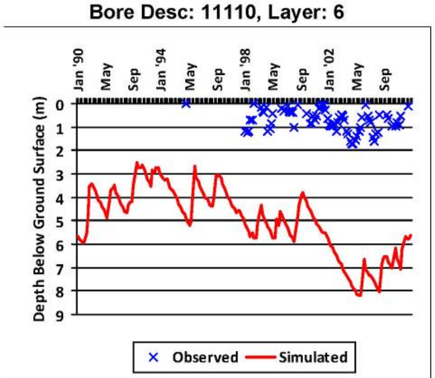
Bore Desc: 11108, Layer: 6



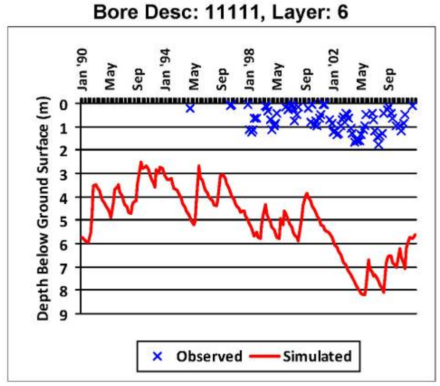
Bore Desc: 11109, Layer: 6



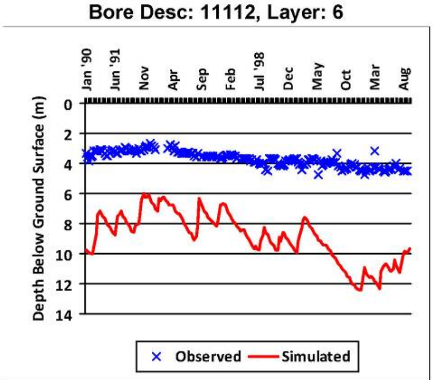
Bore Desc: 11110, Layer: 6



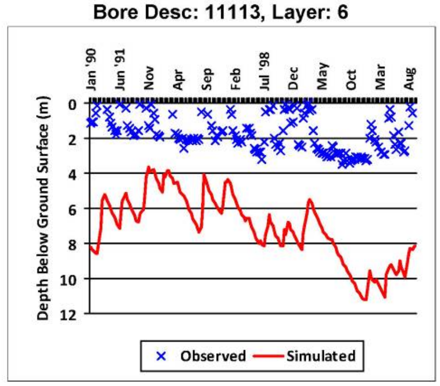
Bore Desc: 11111, Layer: 6



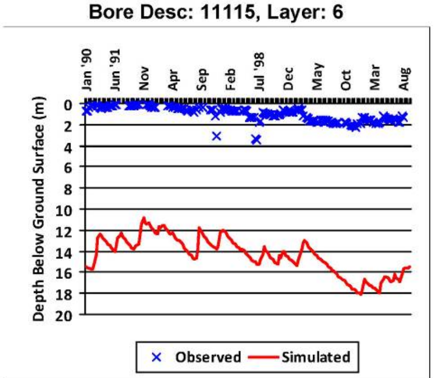
Bore Desc: 11112, Layer: 6



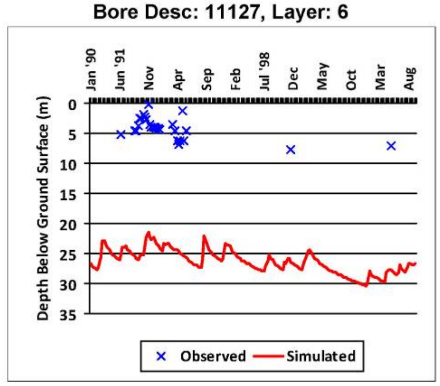
Bore Desc: 11113, Layer: 6



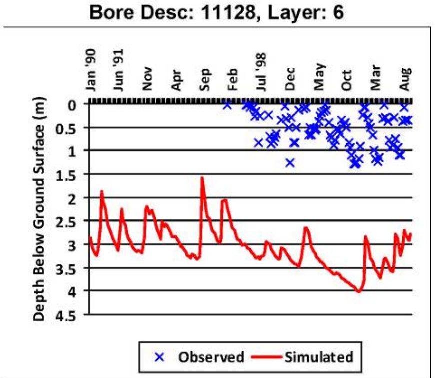
Bore Desc: 11115, Layer: 6



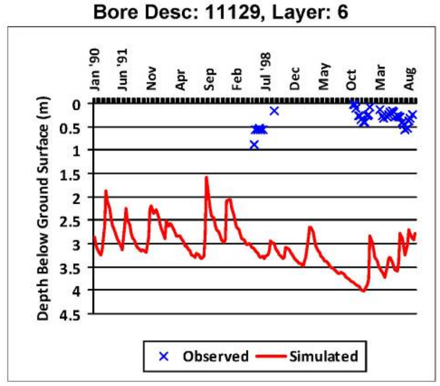
Bore Desc: 11127, Layer: 6



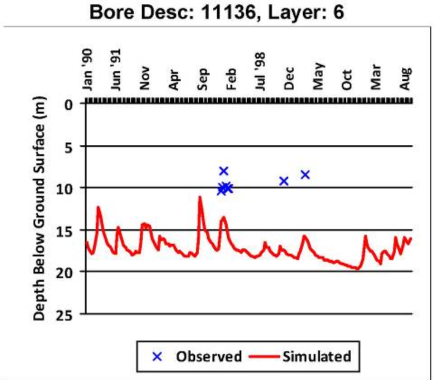
Bore Desc: 11128, Layer: 6



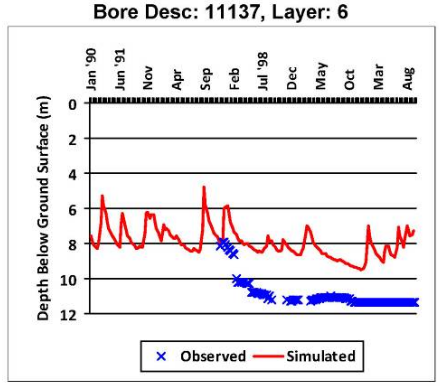
Bore Desc: 11129, Layer: 6



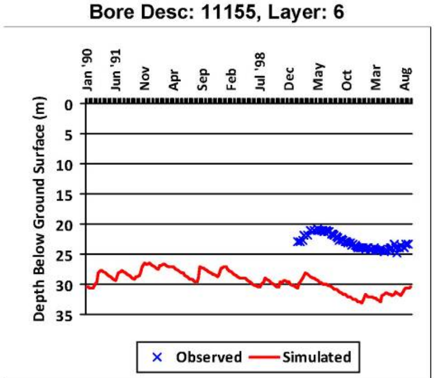
Bore Desc: 11136, Layer: 6



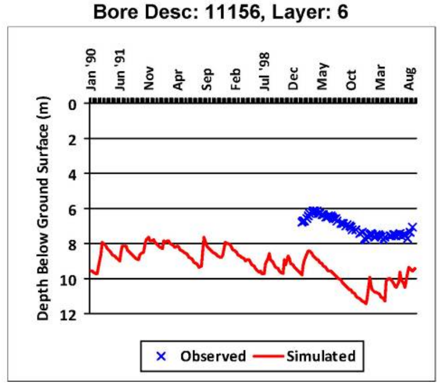
Bore Desc: 11137, Layer: 6



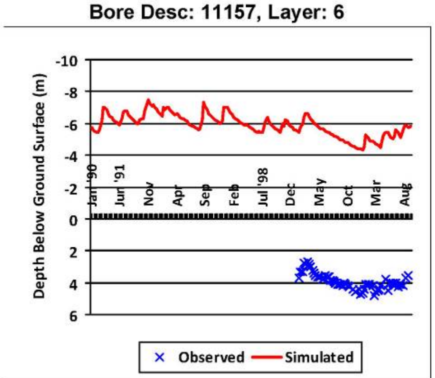
Bore Desc: 11155, Layer: 6



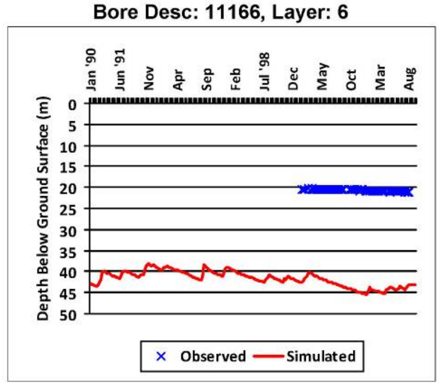
Bore Desc: 11156, Layer: 6



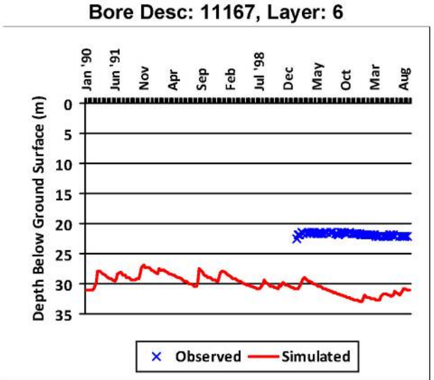
Bore Desc: 11157, Layer: 6



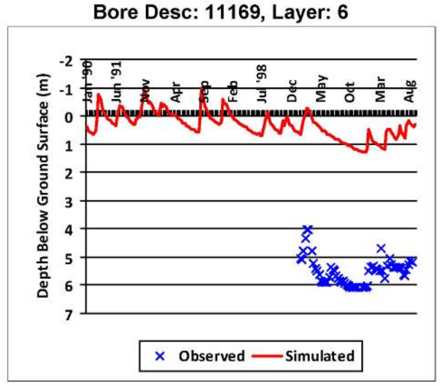
Bore Desc: 11166, Layer: 6



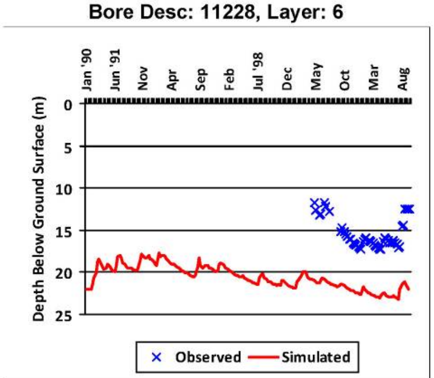
Bore Desc: 11167, Layer: 6



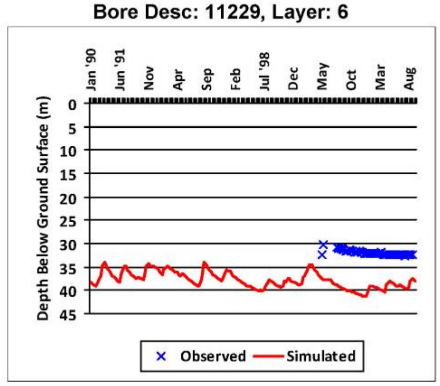
Bore Desc: 11169, Layer: 6



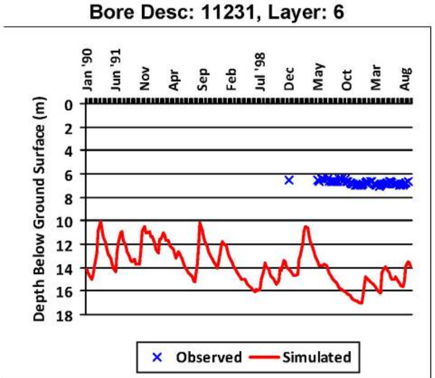
Bore Desc: 11228, Layer: 6



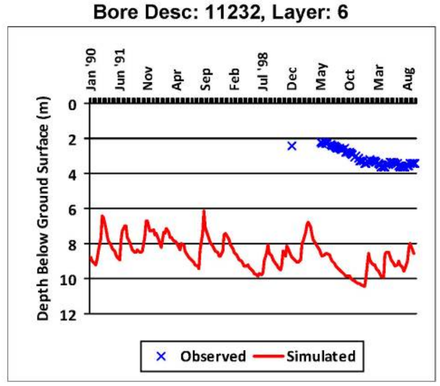
Bore Desc: 11229, Layer: 6



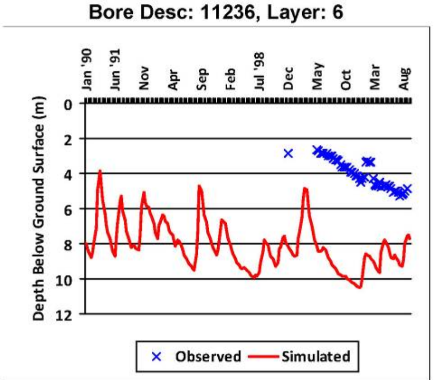
Bore Desc: 11231, Layer: 6



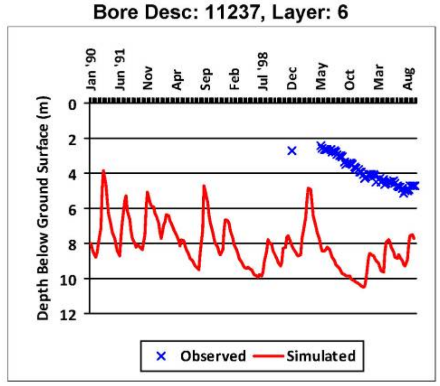
Bore Desc: 11232, Layer: 6



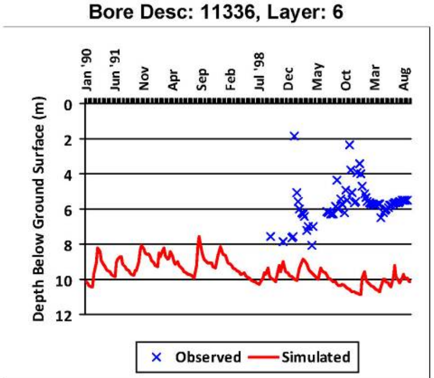
Bore Desc: 11236, Layer: 6



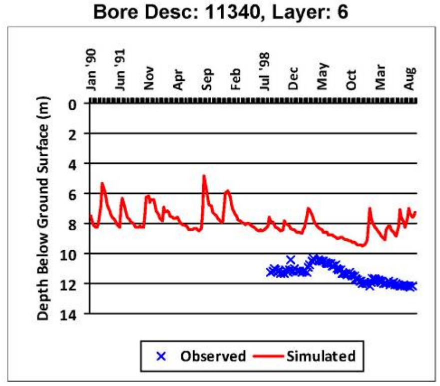
Bore Desc: 11237, Layer: 6



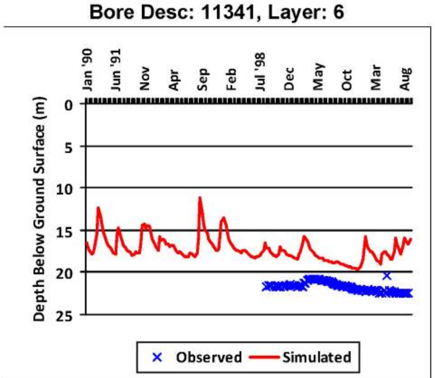
Bore Desc: 11336, Layer: 6



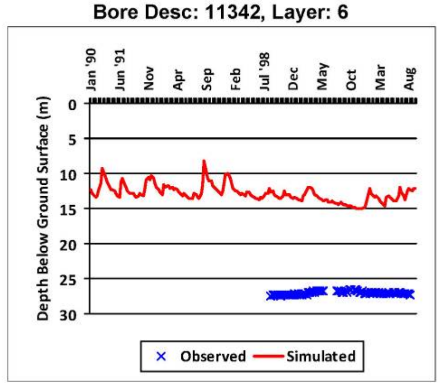
Bore Desc: 11340, Layer: 6



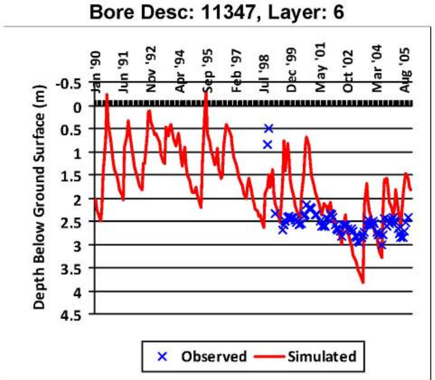
Bore Desc: 11341, Layer: 6



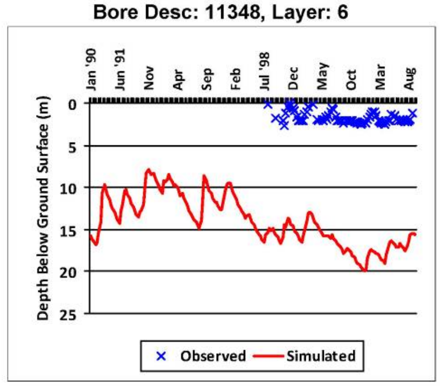
Bore Desc: 11342, Layer: 6



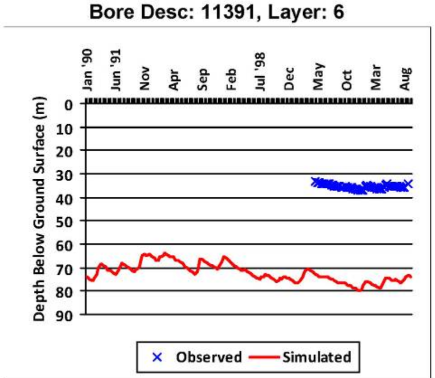
Bore Desc: 11347, Layer: 6



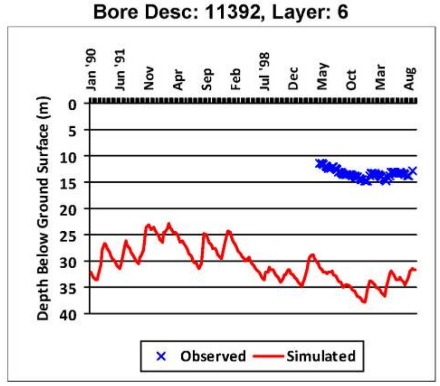
Bore Desc: 11348, Layer: 6



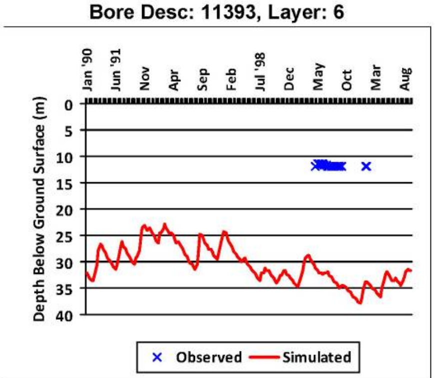
Bore Desc: 11391, Layer: 6



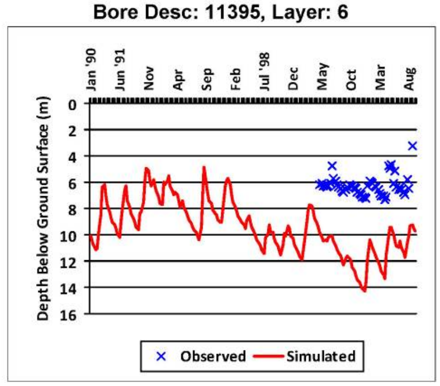
Bore Desc: 11392, Layer: 6



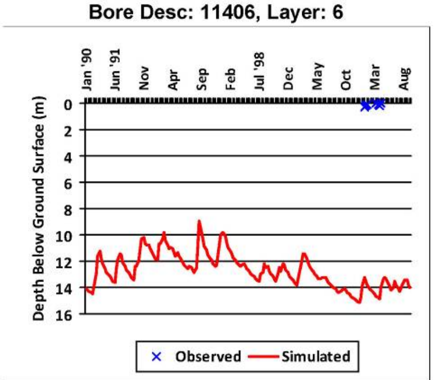
Bore Desc: 11393, Layer: 6



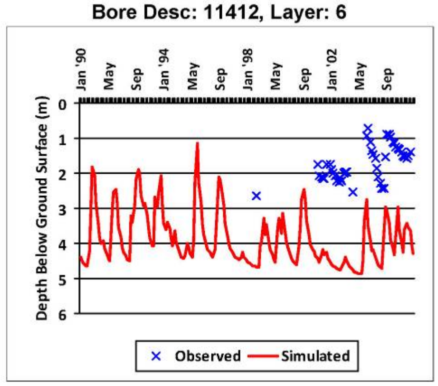
Bore Desc: 11395, Layer: 6



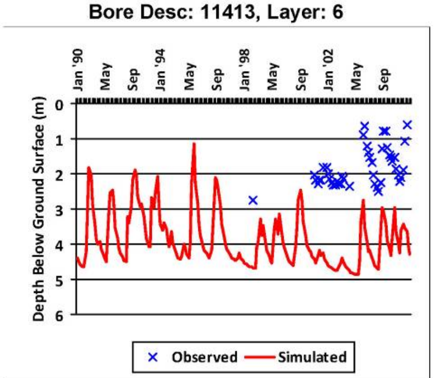
Bore Desc: 11406, Layer: 6



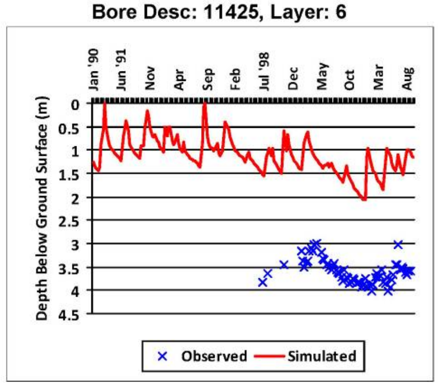
Bore Desc: 11412, Layer: 6



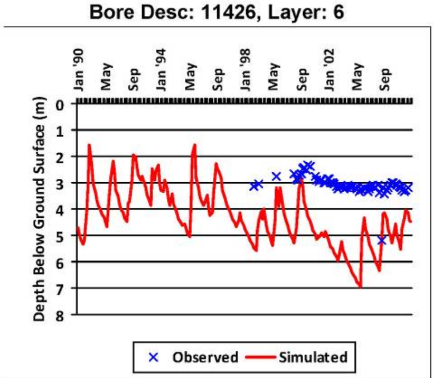
Bore Desc: 11413, Layer: 6



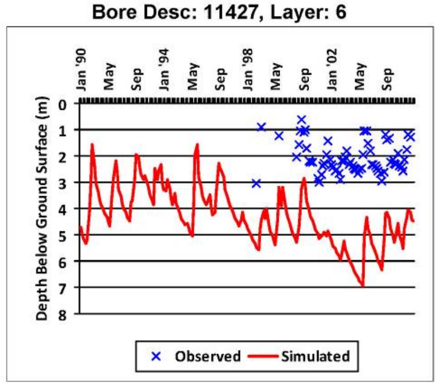
Bore Desc: 11425, Layer: 6



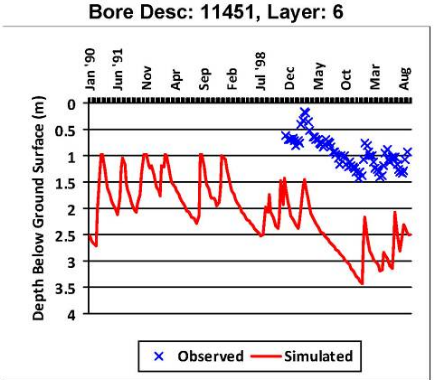
Bore Desc: 11426, Layer: 6



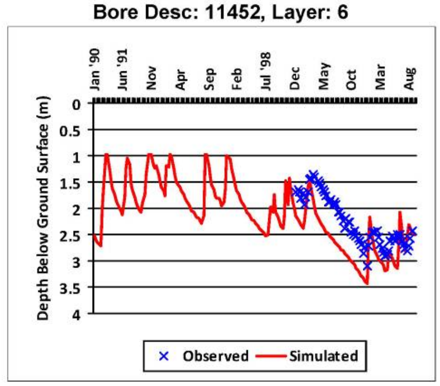
Bore Desc: 11427, Layer: 6



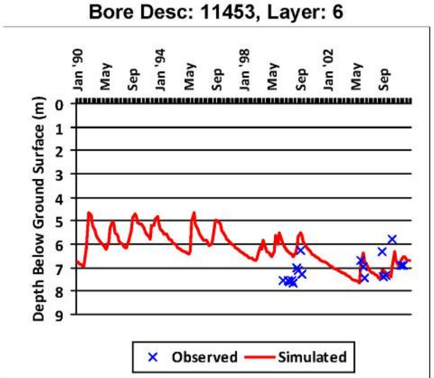
Bore Desc: 11451, Layer: 6



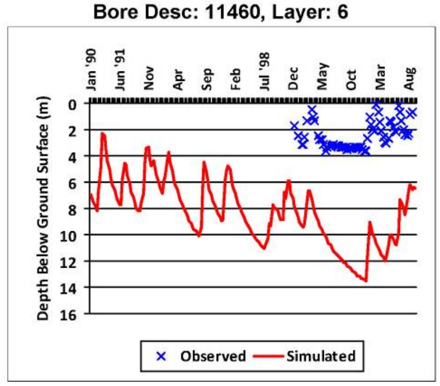
Bore Desc: 11452, Layer: 6



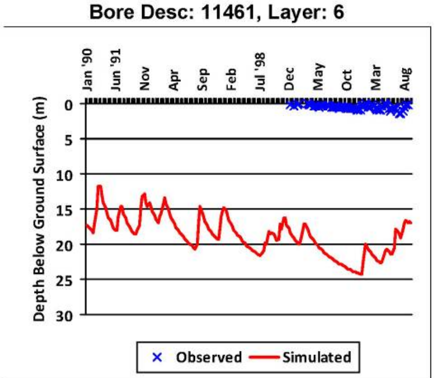
Bore Desc: 11453, Layer: 6



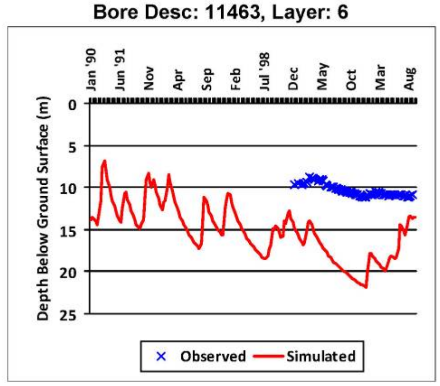
Bore Desc: 11460, Layer: 6

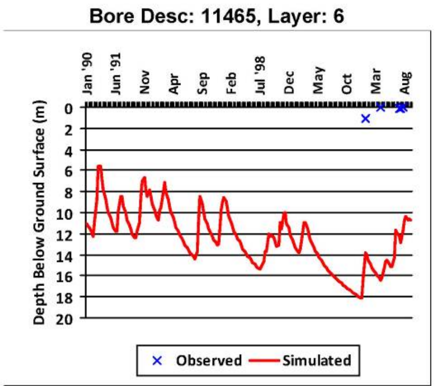


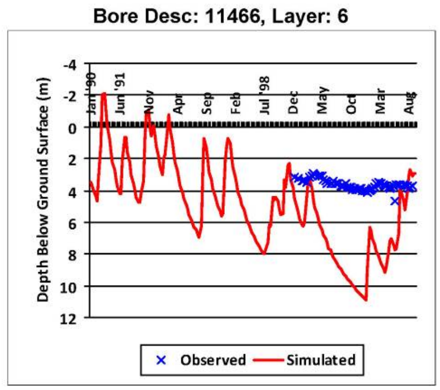
Bore Desc: 11461, Layer: 6

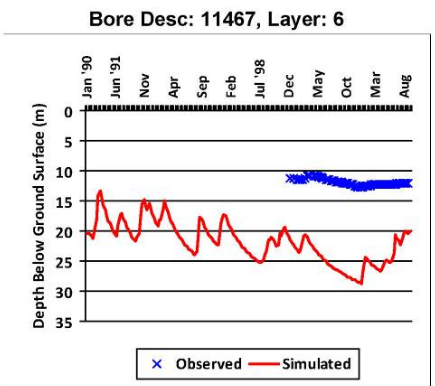


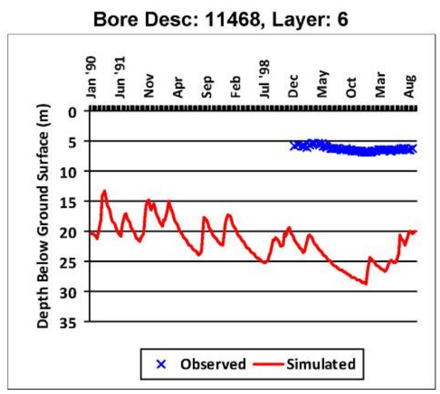
Bore Desc: 11463, Layer: 6

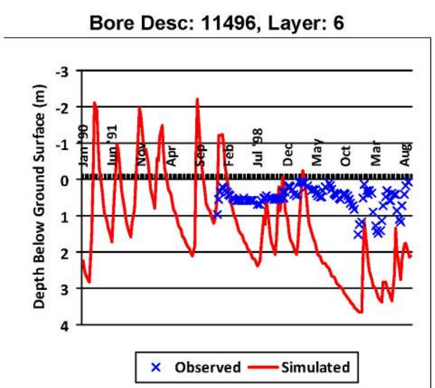


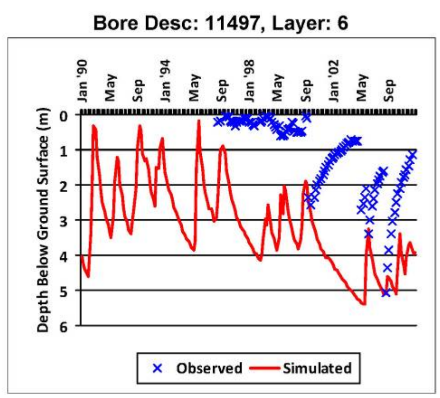

Bore Desc: 11465, Layer: 6
Depth Below Ground Surface (m)
Jan '90
Jun '91
Nov
Apr
Sep
Feb
Jul '98
Dec
May
Oct
Mar
Aug
0
2
4
6
8
10
12
14
16
18
20
Observed
Simulated


Bore Desc: 11466, Layer: 6
Depth Below Ground Surface (m)
Jan '90
Jun '91
Nov
Apr
Sep
Feb
Jul '98
Dec
May
Oct
Mar
Aug
-4
-2
0
2
4
6
8
10
12
Observed
Simulated

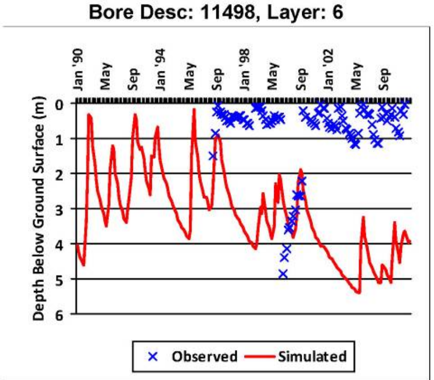

Bore Desc: 11467, Layer: 6
Depth Below Ground Surface (m)
Jan '90
Jun '91
Nov
Apr
Sep
Feb
Jul '98
Dec
May
Oct
Mar
Aug
0
5
10
15
20
25
30
35
Observed
Simulated


Bore Desc: 11468, Layer: 6
Depth Below Ground Surface (m)
Jan '90
Jun '91
Nov
Apr
Sep
Feb
Jul '98
Dec
May
Oct
Mar
Aug
0
5
10
15
20
25
30
35
Observed
Simulated

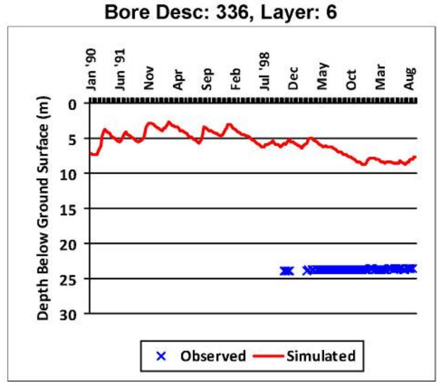

Bore Desc: 11496, Layer: 6
Depth Below Ground Surface (m)
Jan '90
Jun '91
Nov
Apr
Sep
Feb
Jul '98
Dec
May
Oct
Mar
Aug
-3
-2
-1
0
1
2
3
4
Observed
Simulated


Bore Desc: 11497, Layer: 6
Depth Below Ground Surface (m)
Jan '90
May
Sep
Jan '94
May
Sep
Jan '98
May
Sep
Jan '02
May
Sep
0
1
2
3
4
5
6
Observed
Simulated

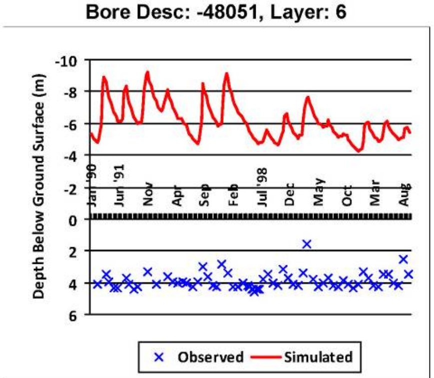
Bore Desc: 11498, Layer: 6



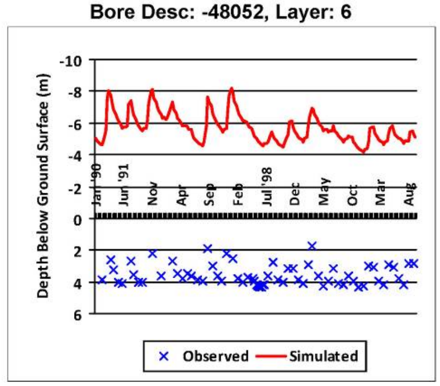
Bore Desc: 336, Layer: 6



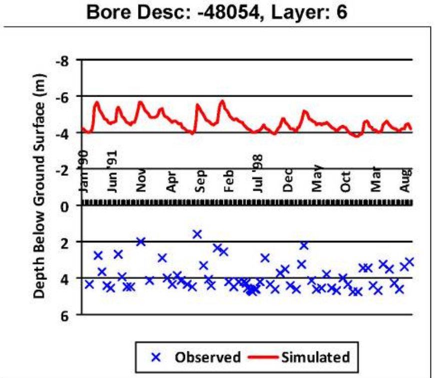
Bore Desc: -48051, Layer: 6



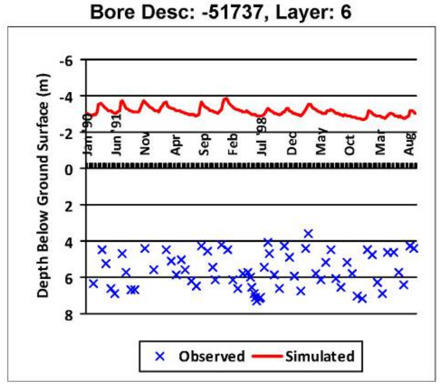
Bore Desc: -48052, Layer: 6



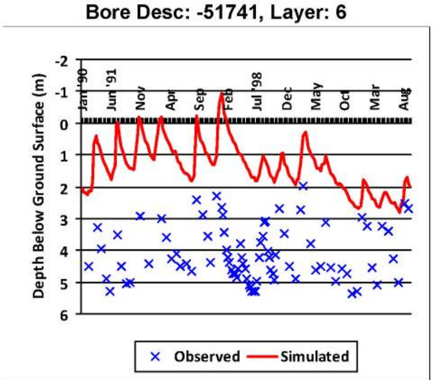
Bore Desc: -48054, Layer: 6



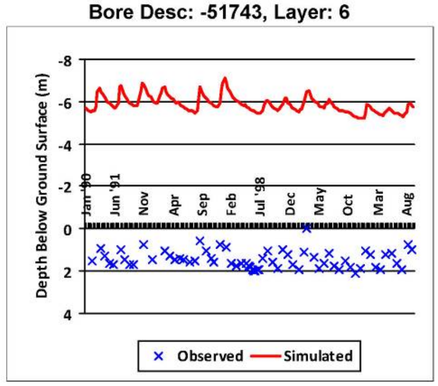
Bore Desc: -51737, Layer: 6



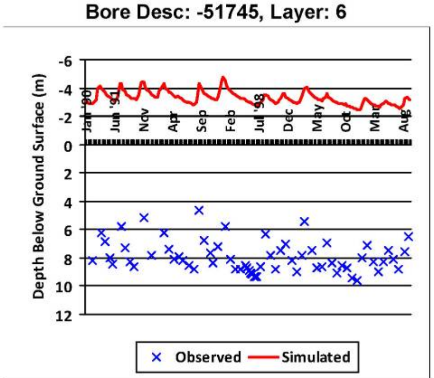
Bore Desc: -51741, Layer: 6



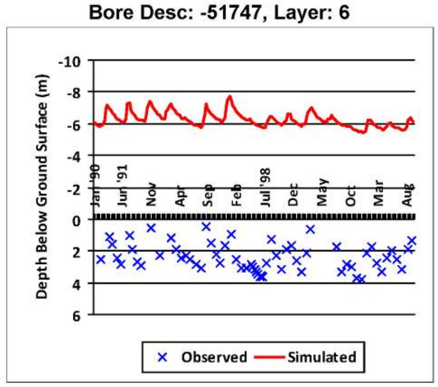
Bore Desc: -51743, Layer: 6



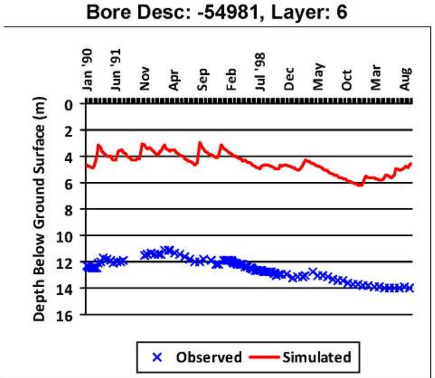
Bore Desc: -51745, Layer: 6



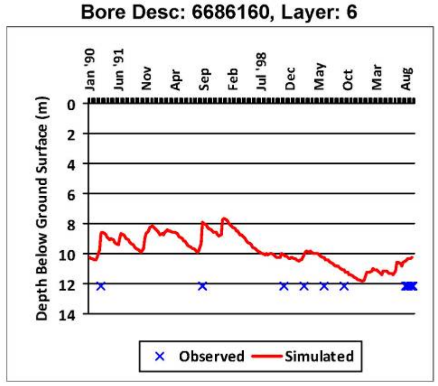
Bore Desc: -51747, Layer: 6



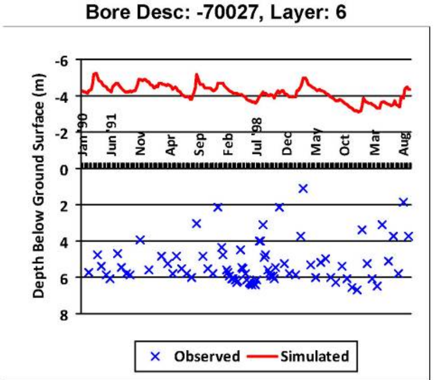
Bore Desc: -54981, Layer: 6



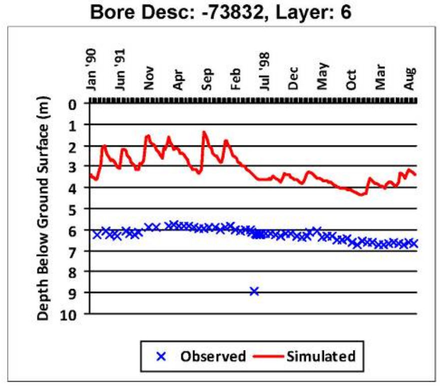
Bore Desc: 6686160, Layer: 6



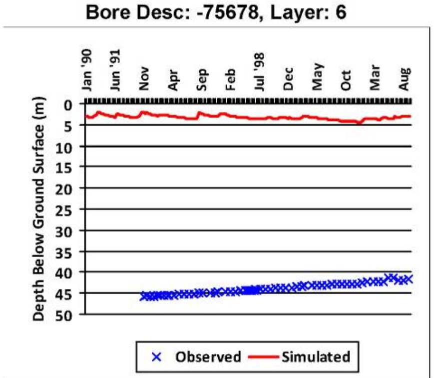
Bore Desc: -70027, Layer: 6



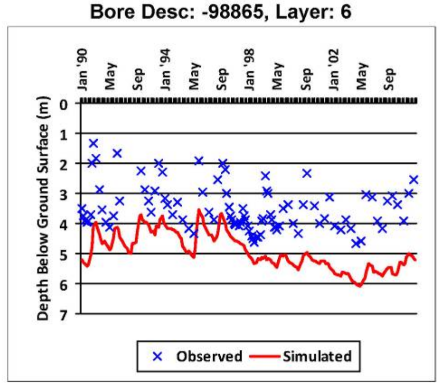
Bore Desc: -73832, Layer: 6



Bore Desc: -75678, Layer: 6



Bore Desc: -98865, Layer: 6



Bore Desc: -99102, Layer: 6