Groundwater–surface water exchange in the South East: 30 years of change

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Department for Environment and Water

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Foreword

The Department for Environment and Water (DEW) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

John Schutz
CHIEF EXECUTIVE
DEPARTMENT FOR ENVIRONMENT AND WATER

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Summary

The widespread declines in groundwater levels across parts of the South East NRM region over the past 30 years have led to changes in the way groundwater interacts with surface water features. This project has assessed the likelihood of gaining conditions for each wetland, drain and watercourse feature for a number of representative time periods. This was done by first developing a series of watertable surfaces using (1) intervals of five-year average groundwater levels from 1985 to the end of 2014, and an additional period from 2015 to the end of 2017, and (2) the autumn and spring seasons of 2017. These watertable surfaces were compared with the minimum surface water levels based on the 2 m LiDAR digital elevation model to classify the likelihood of gaining conditions for each surface water feature (and for each watertable surface created) as either very high, high, moderate, low or very low. This assessment allows changes through time to be assessed on both site-specific and regional scales, to inform a range of future water planning and management decisions.

Environmental consultants, formerly Sinclair Knight Merz Pty Ltd (SKM), employed a similar but temporally-coarser approach by using a 15-year average period for spring and autumn data to derive a classification scheme that describes the likelihood of gaining conditions (SKM, 2009). SKM's approach is subject to greater uncertainty than the shorter time periods used in the current project (i.e. any large changes in groundwater levels over this 15-year period are not resolved unless shorter time periods are used). Nevertheless, there is also considerable uncertainty and potential error within this current assessment due to the reduction in monitoring frequency and number of wells within the observation network over time, which reduces the accuracy of the watertable surface interpolation. Additionally, using yearly averaged groundwater levels masks the seasonal variability that the watertable often exhibits, which is however captured by the spring and autumn 2017 analysis. Thus the results presented here are best used to show the relative changes for site specific features, or summarised at the regional scale, and are conservatively accurate to within ±1 m (i.e. ± one likelihood classification).

Results show that the greatest reduction in the likelihood of gaining condition classifications has occurred along the boundary between the Cross-Border Creek Catchments Drainage Management Unit (DMU) and the DMUs on the low-lying flats (see Figure 1.1), in addition to areas that are now under plantation forest. Many other DMUs have shown a decline in the likelihood of gaining condition classifications after the early-1990s and then a recovery in more recent five-year periods, but few show a full recovery to a 'very high' likelihood of gaining conditions. A number of DMUs have transitioned from being dominated by gaining condition classifications in the earlier five-year periods (i.e. late-1980s to 1990s) to more recently being dominated by losing conditions.

There are areas where there is potential for enhancing recharge using the drainage network, however the salinity of both surface and groundwater sources should first be better described to ensure a benefit to groundwater users. It should be noted that the wetlands that interact with perched watertables are not assessed in detail within this report due to the lack of continuous observation datasets and limitations in spatial data coverage. These wetlands should be investigated separately to the analysis shown in this report, which pertains primarily to features interacting to the regional unconfined aquifer.

It is recommended that the classifications for the likelihood of gaining conditions and their characterisation of wetlands and drain networks be considered for use as a revised baseline in the South East region (i.e. updating the earlier assessment completed by SKM (2009)). The 2015–17 period could be used to represent recent average conditions, while the autumn and spring 2017 classifications could be used to inform the likely seasonality of the interaction between the groundwater and surface water features. These could be incorporated into any future assessments of groundwater dependent ecosystems (GDEs) and their environmental water requirements, within the context of the changes that have occurred in the past 30 years, but using the most up-to-date information.

1 Introduction

The challenges in managing the surface waters of the South East Natural Resources Management Region (SE) have changed substantially since construction of the drainage network began early last century. New considerations include impacts of landuse change, climate variability, the complexities of surface and groundwater interaction, and the increasing interest in both water security and environmental values. These modern challenges, together with reductions in the resources required to address them, require an adjustment in thinking about how surface waters are managed. The location of wetlands, drains and watercourses in addition to selected towns, key landscape-based regions, hydrogeological zones (HZs), groundwater management areas (GMAs) and drainage management units (DMUs) are shown in Figure 1.1.

The SE Natural Resources Management Board and South Eastern Water Conservation and Drainage Board (the Boards) have recognised the need for an overarching strategy to provide a framework for the management of water in numerous drains and wetlands. The Boards have initiated the South East Drainage and Wetland Strategy (the Strategy) in response to this need. The broad aims of the Strategy are to:

- act as the guiding planning framework for management of surface water, drains and wetlands
- reflect community values and aspirations
- optimise the management of surface water to maximise net benefits to water dependent ecosystems, primary production, the regional community, industry and cultural heritage
- provide guidance and direction to the Boards and other SE surface water managers
- enable the measurement of progress toward drainage and wetland management objectives.

A number of technical investigations have been completed and/or scoped to support the development of the Strategy including: (1) an assessment of Environmental Water Requirements (EWRs) for wetlands (Harding, in prep.), (2) a review and analysis of groundwater monitoring infrastructure located at key high-value, groundwater-dependent ecosystem (GDE) sites and (3) related work in the Border Designated Area investigating the relationships between groundwater levels and GDEs (Harding et al., 2018; Cranswick, 2018).

The outcomes of these and other previous studies can be analysed to inform our understanding of correlations between surface water conditions and groundwater level variations at these sites within a broader context. Additional information may be required for development of the Strategy, such as identifying locations where water is best retained in the landscape, context for prioritising wetlands for conservation (where EWRs can be met) and identifying areas suitable for recharge of groundwater. Any locations where these features overlap are likely to be important areas in terms of prioritising infrastructure, action and developing policy to reduce risk.

Critically, there is a need to contextualise the key outcomes of these pieces of work through an appreciation of the variable nature of groundwater–surface water (GW–SW) exchange across the region. This project will facilitate that need by creating a series of spatial products using freely-available groundwater, surface water and ground elevation data. These will include maps showing:

- the likely state of connection between surface water and groundwater features in the spring and autumn of 2017
- how the state of connection has changed over time using spatial analysis of five-year average groundwater level epochs from 1985 to the end of 2014 and 2015–17
- the recharge potential of the drainage network and how this has changed over time.

These large-scale maps can be used as the backdrop for more site-specific investigations and will be compared with recently completed field and other investigations. This new information could then be used for a range of purposes in the development of the Strategy currently being prepared by the Boards. For example these might be:

to develop a new baseline for the likelihood of GDEs (superseding the previous work by SKM, 2009); an improved context for understanding the changes that have occurred along specific drain reaches or wetland hydrological regimes; the identification of significant losing reaches where groundwater recharge is likely to be occurring and could be enhanced; or to inform a risk assessment of the condition of GDEs as a result of various climatic, groundwater and landuse practices.

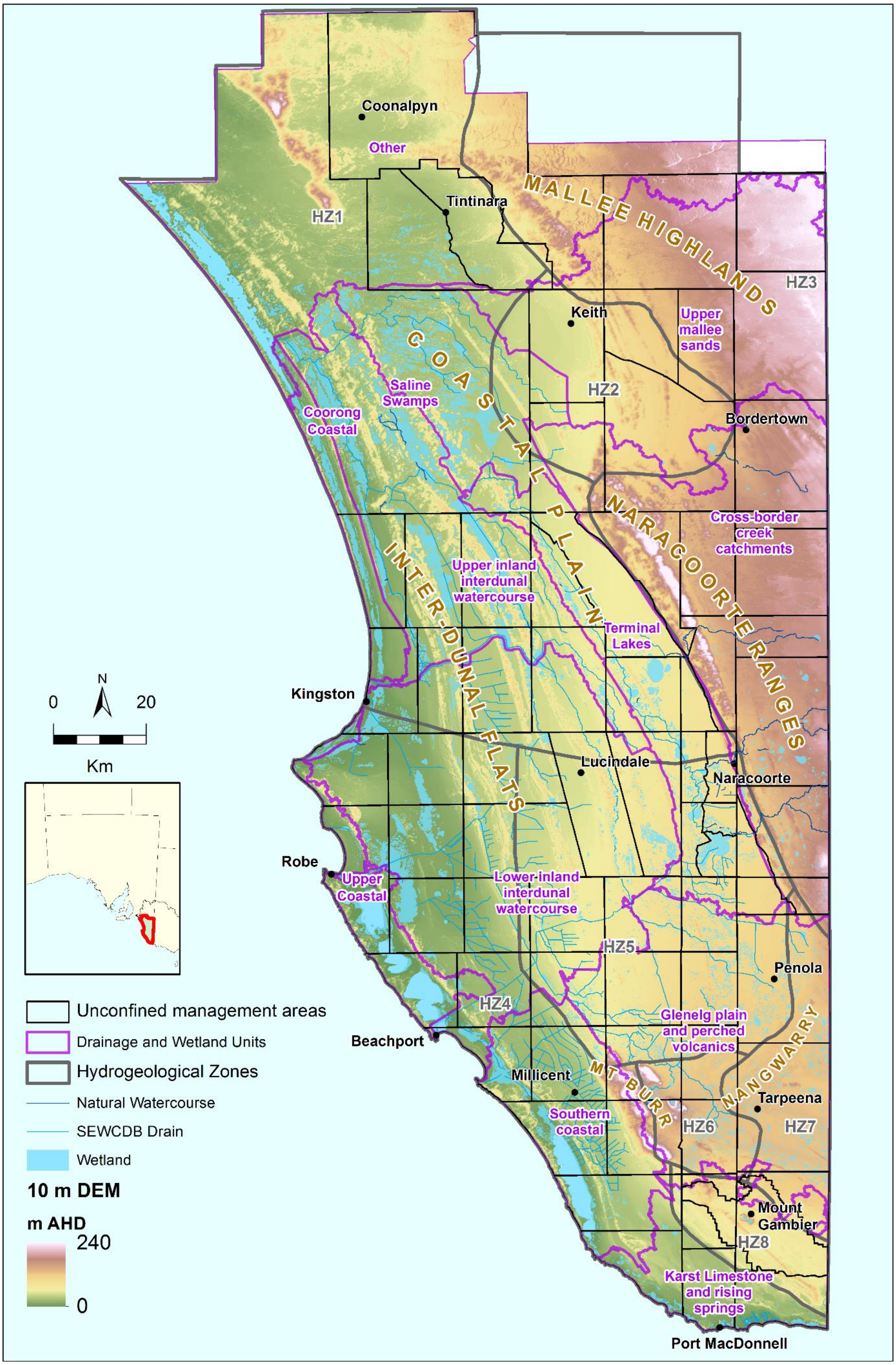

Figure 1.1. Location map of the South East surface water features, management areas and hydrogeological zones

2 Aims and objectives

The overall purpose of this project is to characterise the changes in GW–SW exchange over time in the South East region. This includes establishing a series of spatial products that describe the likelihood of gaining or losing conditions for wetland, watercourse and drain features across the region during specific time periods. These aims will be achieved by:

- retrieving, filtering and analysing groundwater level data from SA Geodata from a range of time periods
- generating watertable surfaces after testing a range of interpolation methods from point data
- spatial analysis comparing the differences between watertable surfaces and surface water features
- developing a classification scheme to assess and report on the relative changes in GW–SW exchange over time.

3 Methodology

3.1 Retrieving groundwater levels from the drillhole database SA Geodata

Time-series groundwater level data were retrieved and collated from South Australia's drillhole database SA Geodata using Microsoft Access® queries. These queries returned observation well data that satisfied the following criteria:

- located in the "South East" NRM region
- group type is observation "OMN"
- standing water level "Is Not Null"
- anomalous and pumping classifications were "N"
- the dry classification was not "Y"
- measured during monitoring "M"
- series type is temporal series "T".

This returned all standing water levels (SWL) in metres below ground surface (m bgs) and reduced standing water level (RSWL) in metres Australian Height Datum(m AHD) (which is approximately equal to mean sea level) as time-series data for multi-year time periods. Data for each time period were then averaged with the standard deviation of SWL values calculated. These data were then combined with aquifer type and approximate water column depth in Microsoft Excel® before being imported into ESRI ArcMap for spatial analysis and data filtering. The time periods assessed are: 1985–89, 1990–94, 1995–99, 2000–04, 2005–09, 2010–14, 2015–17, autumn 2017 and spring 2017.

3.2 Filtering of groundwater level data

To select only groundwater measurements that were representative of the watertable, a series of filters were applied using a query in ArcGIS. The logic used is outlined below:

- water column is <40 m (thereby excluding deep unconfined wells and most confined wells)
- average SWL is >-1 m bgs (i.e. very low-pressure artesian at most)
- standard deviation of SWL is <2 m bgs and not = 0 (i.e. reasonable seasonal variability and not a single water level value which returns a 0 value, except for spring and autumn 2017 datasets)
- exclude SWL data for aquifer codes that may not be representative of the watertable (i.e. Thgr(U2) and deeper).

Then, a visual inspection of individual wells that are within known or interpreted perched systems (i.e. in Mt Burr and Nangwarry areas shown in Figure 1.1), from deeper sub-units of Tertiary Limestone Aquifer (TLA) (i.e. near the pulp/paper mill near Millicent) or as erroneous, were identified and added to an exclusion query. Other wells that were part of detailed small-scale investigations were also removed if they were only present for a short period (i.e. less than approximately five years), provided there were sufficient additional shallow wells nearby. Additional erroneous water levels were identified within each epoch (five-year period) using preliminary inverse distance weighting (IDW) and then Topo to Raster interpolated surfaces. The derived RSWLs (using the Light Detecting and Ranging (LiDAR) digital elevation model (DEM) surface elevations) are compared with the existing RSWLs (i.e. official surveyed elevations using a range of methods over time). Numerous derived RSWLs appeared too high (influenced by vegetation) or too low (influenced by possible inaccuracy of observation well coordinates). After comparison to nearby wells and the regional flow pattern, the updated RSWL for many wells was reverted to the original RSWL.

3.3 Generation of watertable surfaces

Initially, a range of interpolation methods were tested to generate water table surfaces, to determine which method would be optimal. These included variations of IDW, Kriging, Splines, Radial Basis Functions, Natural Neighbour, Local Polynomial, Empirical Bayesian Kriging and Topo to Raster, and a statistical comparison of their outputs relative to observed water levels. Where appropriate the Geostatistical Analyst Tool within ArcGIS was utilised to perform and optimise interpolations. Details of this analysis is documented in Herpich (unpublished) and is not further discussed in this report. Topo to Raster was selected as the most representative of the regional flow patterns from a hydrogeological perspective despite not being the most accurate method (i.e. residuals between observed and interpolated elevations for some other methods were lower). The final parameters and settings for the Topo to Raster interpolation were (where different from default values):

- Output Cell Size -50
- Output Extent – Same as Natural Resources SE
- Margin in cells – 50
- Drainage Enforcement – no enforce
- Primary type of input data – spot
- Maximum number of iterations – 50
- Roughness Penalty – 0.5
- Discretisation error factor – 3
- Vertical standard error – 0.

A coastal boundary was initially included and set at 0 m AHD, however this introduced a low bias on the watertable within approximately 1–2 km of the coast which resulted in erroneous classifications (e.g. Piccaninnie Ponds which is known to be a gaining feature, was calculated as having a low likelihood of gaining conditions). The coastal boundary condition was then abandoned to free the groundwater observations such that they had a greater influence over the interpolated surface. This resulted in more accurate classifications for wetlands that had known GW–SW exchange conditions near the coast, but possibly less accurate elevations near the interface with the coastal boundary (for which there is limited observation well data to compare).

3.4 Spatial analysis of gaining–losing conditions

To estimate the elevation difference between the surface water features and each watertable surface, a number of options were explored. Ultimately, the minimum DEM surface for each drain segment (i.e. between polyline vertices) and each wetland feature polygon was subtracted from the average of the groundwater elevations intersected. This was considered to be the most representative of the likely hydraulic gradient between the surface water and groundwater systems as other combinations either over or under-represented the hydraulic gradient. For example, when the average DEM value was subtracted from the minimum groundwater elevation, a larger difference was calculated (meaning a bias towards losing conditions). Using the average groundwater elevation is considered a conservative approach, with a small bias towards gaining conditions. This approach aims to account for any condition where GDEs may still be supported by groundwater discharge (through the capillary fringe) which provides unsaturated conditions from some depth below the GDE across an area much larger than where the minimum elevation is located.

It is possible that using a percentile-based approach (e.g. the 10^{th} or some other percentile lowest elevation) may have resulted in a more representative assessment of the interaction between groundwater and surface water features, but this method would involve far greater investment in time-intensive spatial analysis. However, this approach could be explored in future regional or site-specific assessments.

There are also a number of limitations to this general approach which include the:

- assumption that the LiDAR DEM being flown in late-2007 was representative of the minimum elevation of surface water features (i.e. either a dry feature or a wet feature that is representative of a historical low water level)
- potential for a gaining bias due to the low elevations of any dug structures within wetlands that were not successfully masked out in this project (i.e. by individual inspection to improve the DEM for this purpose)
- potential for a gaining bias from individual surface water features that are long or have a large area that intersects more groundwater elevation cells (i.e. in some cases where groundwater gradients were steep, the length/size of surface water features needed to be manually reduced – but this was not done in great detail due to processing constraints)
- drains existed when LiDAR was acquired.

Initial results of GW–SW exchange analyses identified that dams constructed within wetlands impact classification and the minimum elevation of wetlands. In order for a more representative minimum elevation, the feature type of dams were selected from the DEW corporate waterbodies layer, which was then used to erase the area from the wetlands layer.

3.5 Uncertainty of watertable surfaces and likelihood classifications

There are a number of sources of potential error related to the elevations used and their combination which adds uncertainty to this analysis. These are primarily related to the accuracy of 2 m LiDAR DEM and groundwater level measurements. The vertical elevation accuracy of the DEM is ±0.5 m, despite a standard deviation of 0.052 m for 200 test points (Location SA, 2016). This presumably accounts for errors introduced by vegetation cover, the density of flight paths and other potentially changing features in the landscape (i.e. water levels). The potential error for groundwater level measurements is considered to be smaller, perhaps up to ±0.2 m, which accounts for inaccuracies in the measured distance between top of casing and ground surface and each depth to groundwater measurement.

As outlined in Herpich (unpublished) there are also potentially larger errors in the surfaces derived from the Topo to Raster interpolation and all other interpolation methods, in addition to those discussed in the previous sections. These occur mostly in the areas between groundwater observation points and are a result of the:

- sparsity of the observation network in some areas, particularly where the spatial density of the network has reduced over time
- spatial variability in hydraulic properties of the aquifer which may result in groundwater flow that is not reflective of the interpolation assumptions between data points
- inability of the observation well network to describe small or regional scale variations due to groundwater extraction (i.e. drawdown), plantation forest or other landuse changes which influence the groundwater system and watertable surface.

The errors in surface and observation well reference elevations are very likely to be similar in magnitude as both surface and groundwater elevations were estimated based on the same LiDAR DEM (in most cases). Measurement error of depth to water readings in combination with the measurement error of the difference between ground elevation and reference elevation are considered to be small but not negligible. Error due to the interpolation method and deficiency of the observation network to represent small scale variations (i.e. drawdown due to groundwater extraction) in the watertable surface is considered to be the largest source of uncertainty. For the purposes of this study, a conservative estimate of total error in the classification of gaining or losing conditions is ±1 m.

3.6 Development of the classification scheme

To develop a classification scheme for the likelihood of gaining conditions, a number of wetland and drain monitoring sites with more detailed level measurements were assessed. The primary analysis was an extension of Harding *et al.* (2018) who used Water Observations from Space (WOfS) to reconstruct historical wetland hydrographs in combination with nearby groundwater observations (given the general lack of historical wetland monitoring records). The average yearly difference between the groundwater and surface water levels over time were compared to the description of wetland hydro-periods and their relationship with the groundwater observations (Harding *et al.*, 2018). This allowed a relative classification scheme to be derived based on a combination of the hydraulics (i.e. elevation difference in water levels) and descriptions of the hydrological regime of the wetlands. This scheme was then applied to a number of drain monitoring sites that also had nearby groundwater observation wells, in combination with the DEM. The results of this analysis is presented in Sect. 4.2.

4 Results and discussion

4.1 Data summary and spatial analysis results

4.1.1 Groundwater datasets

A summary of the number of observation wells used to create the watertable surfaces is shown in Table 4.1. There were a large number of wells removed based on an assessment targeting the shallow unconfined observation wells that were representative of the regional aquifer (i.e. not perched, deep or confined). The number of wells available also decreases overall from the late-1980s to present, as the observation network has been reduced. The implication of this reduction is that more uncertainty is introduced into the surfaces where the spatial distribution of wells become sparser. In total, and across all time periods there were 735 observation wells that were removed and 1870 wells used.

Table 4.1. Number of wells used for interpolation of watertable surfaces

Epoch	Total number of wells	Number of wells used after filtering
1985–94	1787	1345
1985–89	1157	829
1990–94	1477	1108
1995–99	1508	1095
2000–04	1282	904
2005–09	1250	849
2010–14	1291	919
2015–17	1083	714
Spring	906	668
Autumn	932	679

The calculation of the average standard deviation of the water level data is shown across the region (Figure 4.2) and can be evaluated in relation to the hydrogeological zones (Figure 1.1) that were derived by Harrington and Currie (2008). Standard deviation can be used as a proxy for seasonal variation (i.e. higher standard deviations reflect larger seasonal variations or in some cases a large decline or rise in water levels, while lower standard deviations represent small seasonal variations or in some cases limited data points). Increasing seasonal variation could, for example, indicate years of greater recharge following above-average rainfall, or alternatively greater seasonal drawdown due to extraction. Table 4.2 and Figure 4.1 show the changes over time for each hydrogeological zone. Generally decreasing seasonal variation is seen in HZ2, HZ3 and HZ7 which could be due to the growth in the areas dominated by plantation forestry and/or reduced recharge. HZ1 and HZ4 are mostly stable which is likely reflective of more stable rainfall patterns within in these zones and/or less impact from groundwater extraction and plantation forestry. HZ5, HZ6 and HZ8 show greater variation and this may be due to greater changes in the rainfall patterns between each epoch and/or changes in both landuse and extraction.

Table 4.2. Mean standard deviation of groundwater level by hydrogeological zone and epoch

Zone	1985–89	1985–94	1990–94	1995–99	2000–04	2005–09	2010–14	2015–17	Mean
HZ1	0.39	0.35	0.32	0.33	0.30	0.33	0.32	0.28	0.33
HZ2	0.43	0.44	0.41	0.48	0.39	0.51	0.34	0.27	0.41
HZ3	0.22	0.27	0.17	0.16	0.15	0.21	0.14	0.12	0.18
HZ4	0.40	0.40	0.45	0.40	0.46	0.41	0.41	0.41	0.42
HZ5	0.71	0.65	0.64	0.50	0.68	0.58	0.49	0.65	0.61
HZ6	0.51	0.47	0.48	0.55	0.50	0.67	0.54	0.55	0.53
HZ7	0.37	0.41	0.40	0.36	0.26	0.30	0.19	0.24	0.32
HZ8	0.17	0.20	0.13	0.28	0.17	0.32	0.21	0.13	0.20
Mean	0.40	0.40	0.37	0.38	0.36	0.41	0.33	0.33	0.37

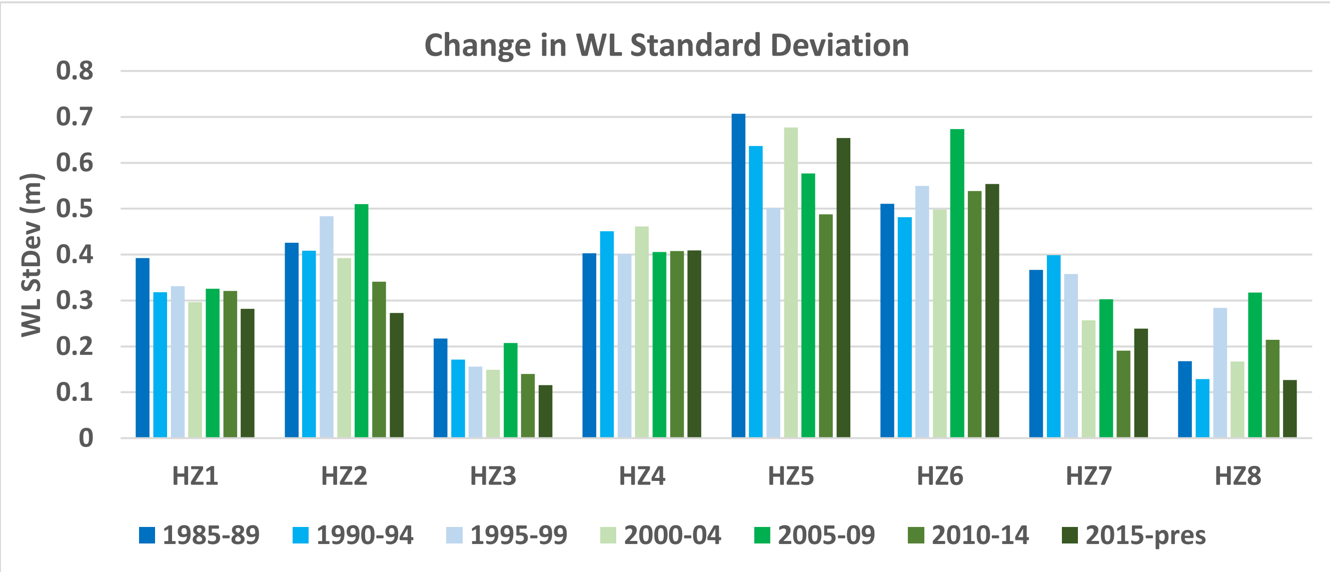

Figure 4.1. Change in mean groundwater level standard deviation for each hydrogeological zone over time

4.1.2 Regional watertable surfaces and net changes

Regional watertable surfaces have been created for each of the following five-year epochs: (1) starting from 1985 and finishing at the end of 2014, (2) a period from 2015–17 and (3) two additional surfaces created for the autumn and spring of 2017. At the regional scale, these surfaces all show the same general groundwater flow patterns (Appendix A). Over the past 30 years, groundwater level declines have been observed across the study area (Figure 4.3), and there are distinct hot-spot areas of greater drawdown (i.e. large declines within the Stirling, Wirrega and Willallooka GMAs of the Tatiara Prescribed Wells Area (PWA), within the Coles, Short, and Zones 1A–5A of the Lower Limestone Coast PWA). There are also some areas where the watertable appears to have has risen (i.e. north of Coonalpyn and south of Millicent) but these are most likely due to the differences in the spatial coverage of groundwater data between the two time periods. There are also areas where the watertable shows only small changes over the time period analysed. These areas are found in some parts of the Naracoorte Ranges (southern HZ3) and extend up towards Bordertown in the transition between the coastal plain (HZ1/2/4/5) and Mallee highlands (northern HZ3) where enhanced recharge following land clearance has caused rising watertables (see also Figure 1.1). However these rises are masked by the recent declines due to a combination of climate variability and groundwater extraction since the mid-1990s. The implications of such changes with respect to GW–SW exchange are presented in the following sections.

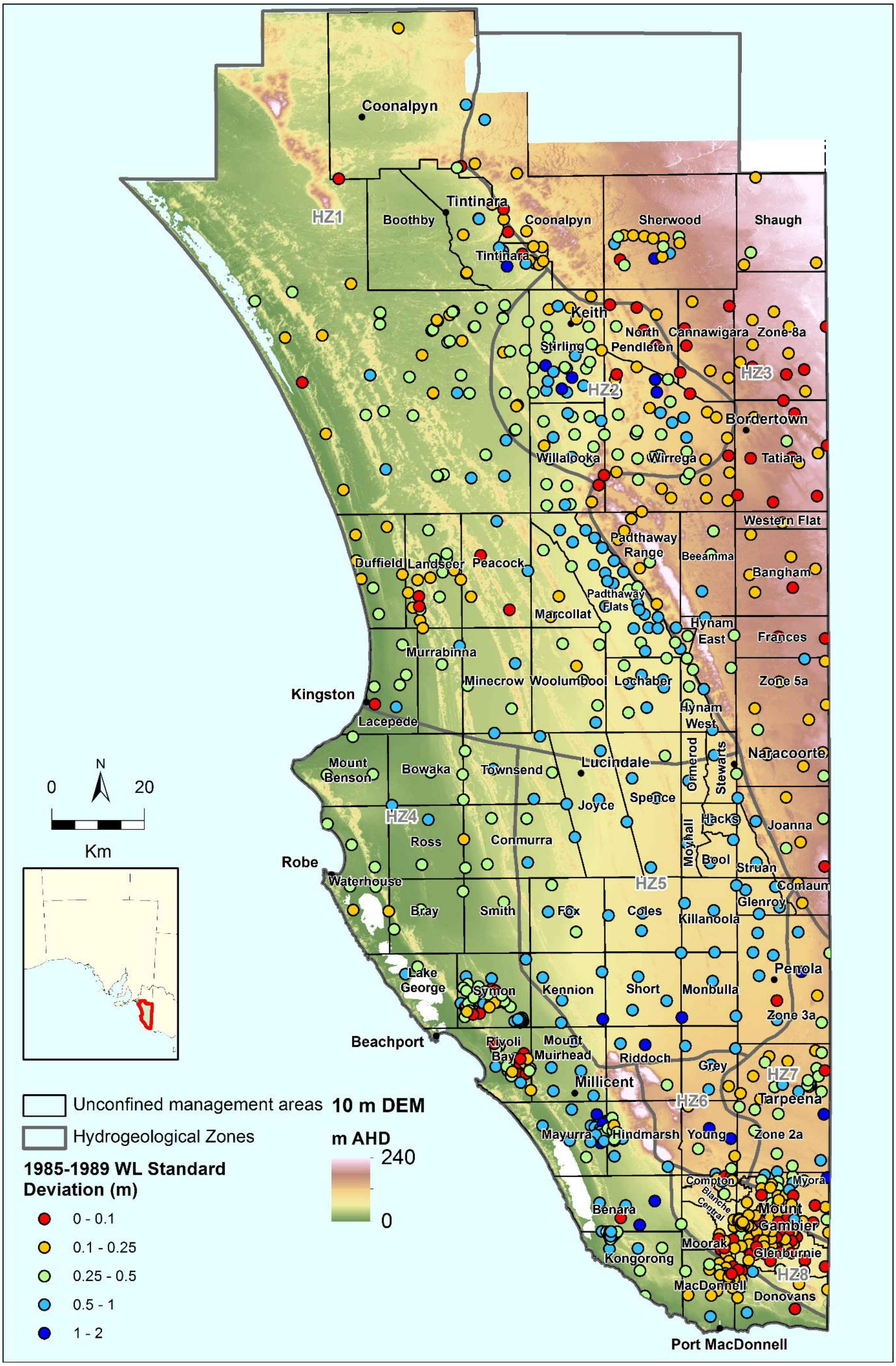

Figure 4.2. Average standard deviation of groundwater levels in the 1985–89 period

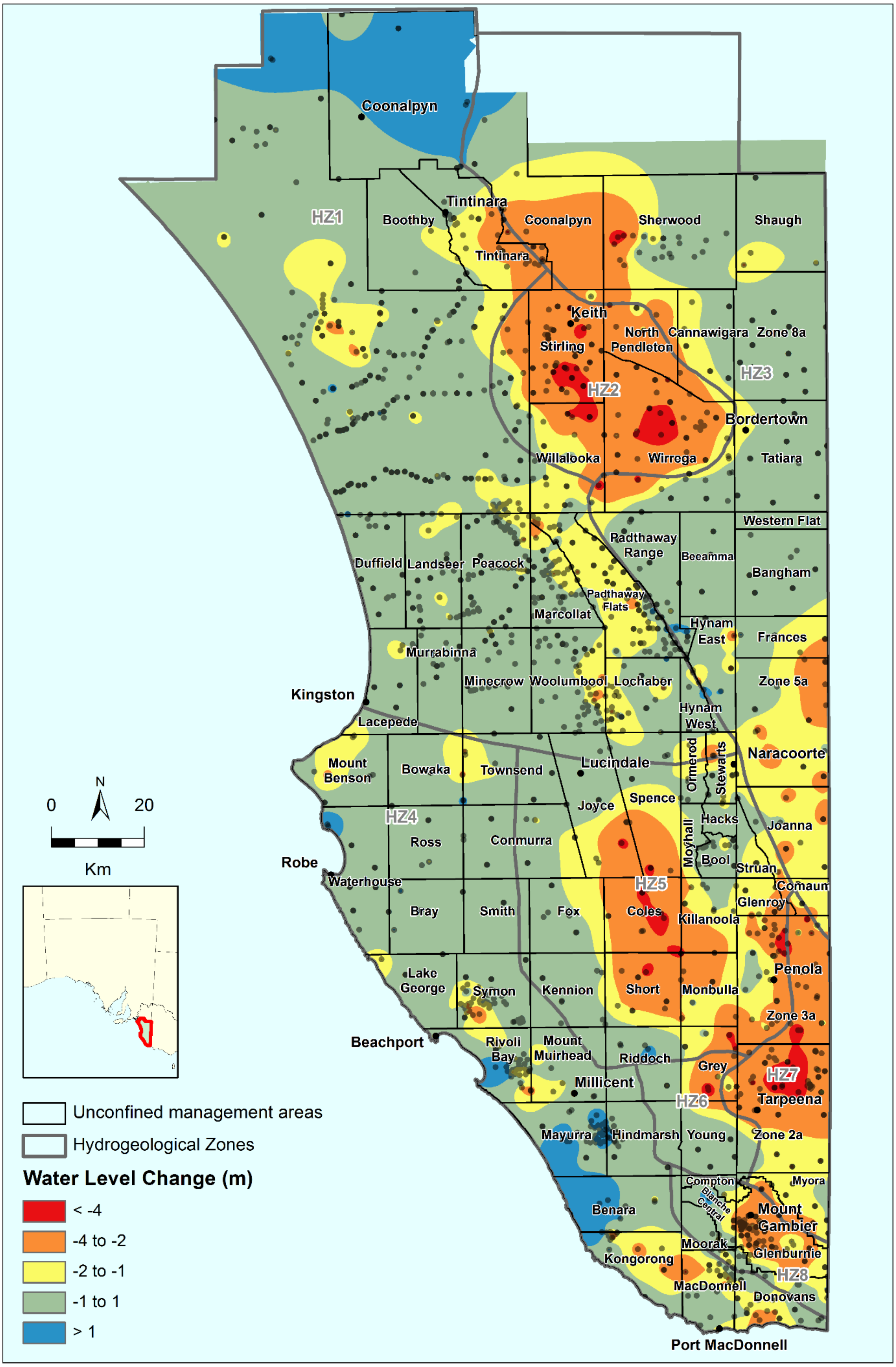

Figure 4.3. Average change in groundwater level between the 1985–94 and the 2015–17 average periods

4.1.3 Perched groundwater systems

Perched aquifers were identified in the Mt Burr and Nangwarry areas (i.e. HZ6&7, see also Figure 1.1) from a number of observation wells. Unfortunately, the spatial distribution of these wells is not sufficient to create accurate or extensive perched watertable surfaces.

Simple comparisons between the perched watertable and the minimum wetland bed elevation for the Mt Burr area are shown in Figure 4.4. Groundwater levels in blue are located in the vicinity of the perched wetlands represented by the blue line. These data suggest that the perched groundwater is only occasionally higher than the wetland bed and is likely to support phreatophitic vegetation rather than an aquatic ecosystem directly. In contrast, the groundwater levels in grey (RID013) show shallow groundwater that is seasonally above the bed of the wetland (grey line) and so the perched aquifer is likely to support the water regime of the wetland (i.e. seasonal discharge into the wetland feature to support the duration of wet periods). Unfortunately, data collection from many of the perched groundwater observation wells ceased in the late 1990s. Further analysis of some of these and other GDE sites can be found in Harding (2018), including detailed datasets recently downloaded from water level loggers from more recently instrumented monitoring sites.

Observation wells monitoring the perched aquifer in the Nangwarry area have limited data records and are no longer monitored (NAN016, NAN017 and NAN034). It is possible that the perched watertables exist seasonally in this area; however, much of the rainfall and potential recharge would now be intercepted by plantation forests. Other wells have been identified as likely representative of perched watertables and these include: GRY033, YOU23, RID13, HIN40, HIN45, HIN78, HIN106, HIN108, HIN109, HIN110 and HIN111.

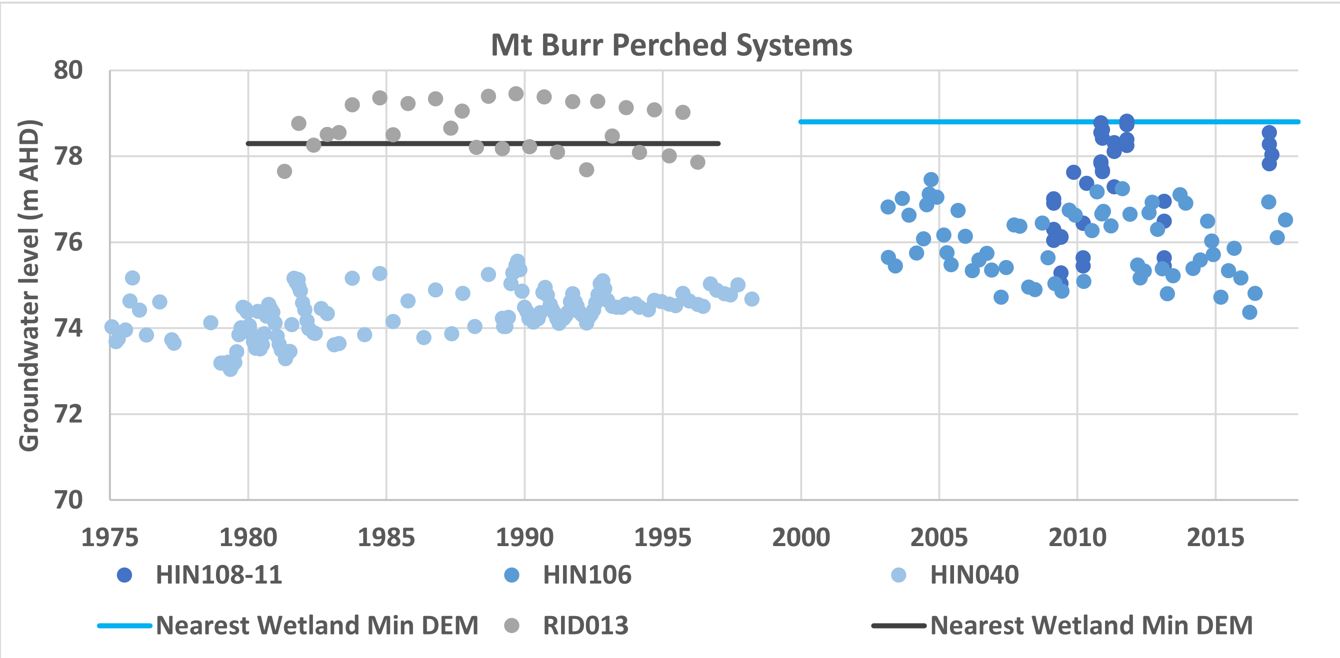

Figure 4.4. Hydrographs for the perched aquifer near Mt Burr

4.2 Ground-truthing

To develop a classification scheme for the likelihood of gaining, losing and variably gaining/losing conditions, surface water levels have been compared with groundwater levels at a number of locations. Eight drain monitoring sites and twelve GDE wetland sites (after Harding *et al*., 2018) have been paired with nearby groundwater observations wells, each having sufficient time-series data and appropriately shallow screen depth to allow for a robust assessment. The location of these sites is shown in Figure 4.5, while their details are summarised in Table 4.3 – including a preliminary classification prior to detailed analysis. There may be other suitable comparison sites but this analysis was considered sufficient to establish indicative GW–SW exchange relationships. Example hydrograph comparisons, water level difference and classifications are presented in the following two sections.

There are also a number of sources of error which may cause offsets to these data including the resolution of water observations from space (WOfS) cells (25 m) being used in combination with the 2 m LiDAR DEM and other errors discussed in Harding *et al*. (2018) and those discussed herein (Sect. 3.5). Upon further analysis by Harding and Herpich (2017) for Englands Swamp, the WOfS data appears to have an offset of +0.2 m compared with the measured surface water levels at this site, which is within the error of the classifications defined in this study.

Table 4.3. Details of paired surface water and groundwater monitoring locations for water level comparisons

GDE wetland or drain site	Data source	Obswells	Preliminary classification	Hydrogeo-logical zone
Taylors Swamp	WOfS	JOA005, JOA027	Variable–losing	HZ3
Deadmans Swamp	WOfS	JOA005, JOA027	Gaining–losing	HZ3
Sawpit Swamp	WOfS	PEN027, PEN105	Gaining–losing	HZ7
Coinville Swamp	WOfS	PEN027, PEN105	Gaining–variable	HZ7
McKinnon Swamp	WOfS	PEN011	Variable–losing	HZ7
Dip Swamp	WOfS	MIN015	Gaining–losing	HZ7
South Bool 1	WOfS	JOA008, JOA026	Gaining–variable	HZ5
South Bool 2	WOfS	JOA008, JOA026	Gaining–variable	HZ5
Glenrise 1	WOfS	PEN003	Variable	HZ5
Glenrise 2	WOfS	PEN003	Variable	HZ5
Coomooroo Swamp	WOfS	MON014, MON038	Variable	HZ5
Kearney Lake	WOfS	YOU028	Variable	HZ6
Bakers Range Watercourse (D/S Well and Bridge)	A2391007	MSN006, MCN001	Losing	HZ1
Blackford Drain (Amtd 4.0km)	A2390506	LAC006	Gaining–variable	HZ1
Drain L (U/S Princes Highway)	A2390510	CNM007	Gaining–variable	HZ4
Drain L (Boomaroo Park Amtd 7.3km)	A2390505	WAT009	Variable–losing	HZ4
Drain M (D/S Callendale Regulator)	A2390514	CLS004	Gaining–losing	HZ5
Drain M (Woakwine Amtd 5.1km)	A2390512	SYM013	Gaining–variable	HZ4
Reedy Ck - Mt Hope Drain (7.2 km NE South End)	A2390513	RIV008	Gaining	HZ4
Drain 48 (200m U/S Lake Bonney Rd Bdge)	A2390533	MAY048	Gaining	HZ4

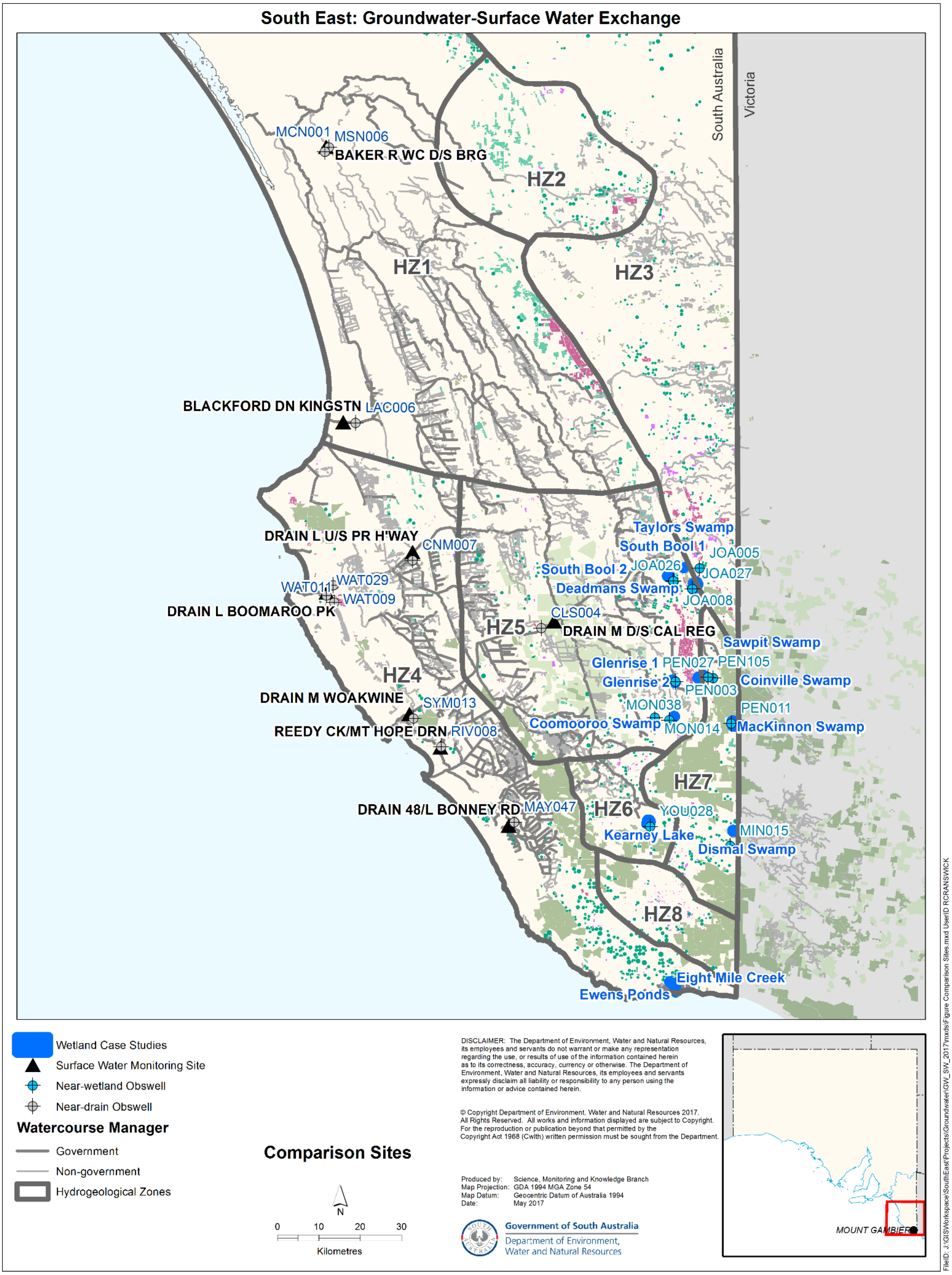

Figure 4.5. Location of surface water monitoring and GDE wetland sites paired with groundwater observation wells

4.2.1 GDE wetland investigation sites

The GDE wetland sites are located across a range of hydrogeological zones including those located on the low-lying flats and elevated areas. It is expected that these represent a range of GW–SW exchange conditions that have changed over time. Two examples are shown below for Kearney Lake and Dip Swamp while all comparisons are shown in Appendix B. The Kearney Lake example shows the seasonality of gaining and losing conditions with periods of consistently losing conditions in the late-1990s and late-2000s (Figure 4.6). Dip Swamp shows a change from gaining to variable in the mid-1990s to losing conditions after 2005 (Fig. 4.7).

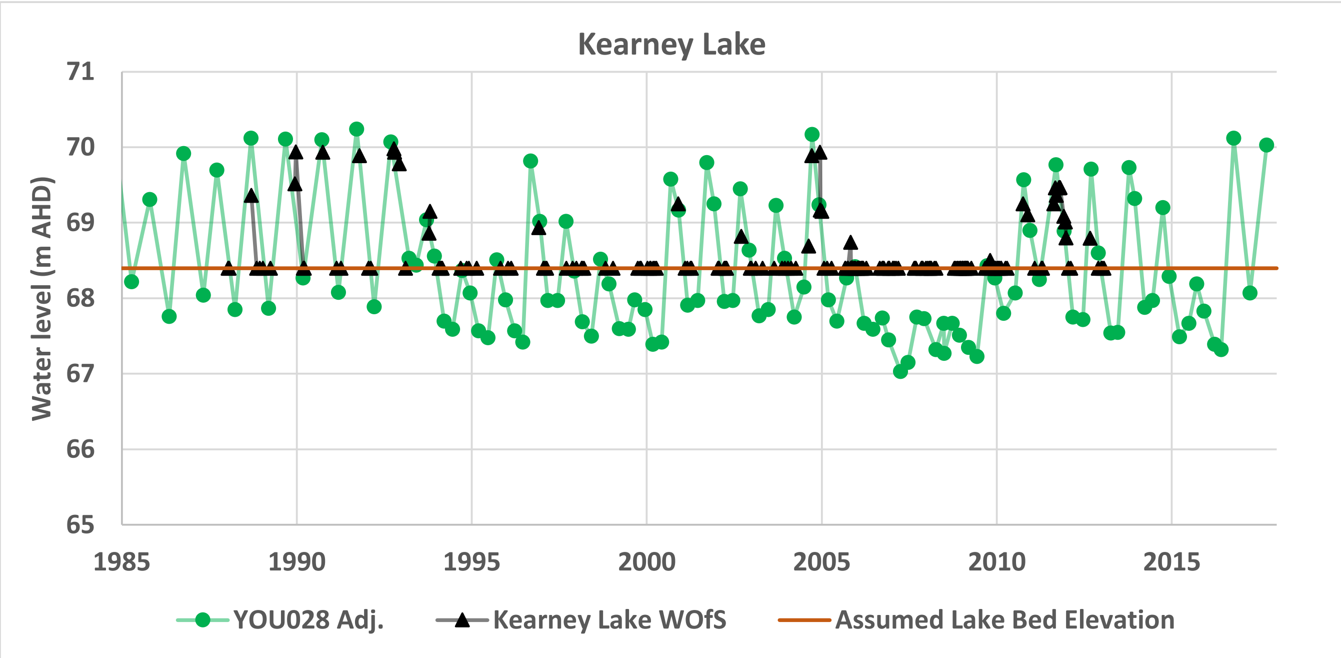

Figure 4.6. Hydrographs for Kearney Lake with observation well YOU028

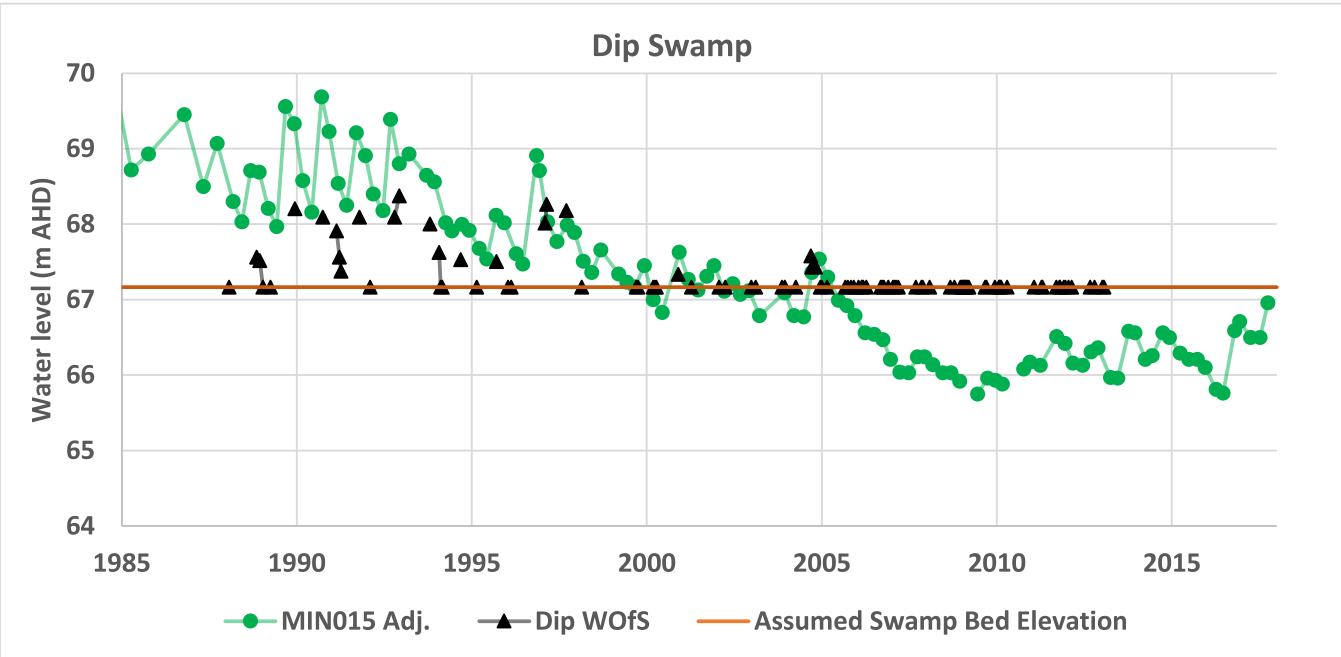

Figure 4.7. Hydrographs for Dip Swamp with observation well MIN015

To classify the type of GW–SW exchange occurring over time, the average WOfS-derived elevations have been subtracted from the average groundwater level for each year to determine the elevation difference. During periods when the wetland features are dry, the minimum bed elevation is subtracted from the groundwater elevation and indicates the potential for losing conditions (i.e. if the wetland receives surface water runoff it has the potential to be lost to the groundwater system as the groundwater level is below the bed elevation). The elevation differences are seen to change over time from more positive to more negative values which corresponds to the declines in the elevation of both groundwater and WOfS-derived water levels (Figure 4.8).

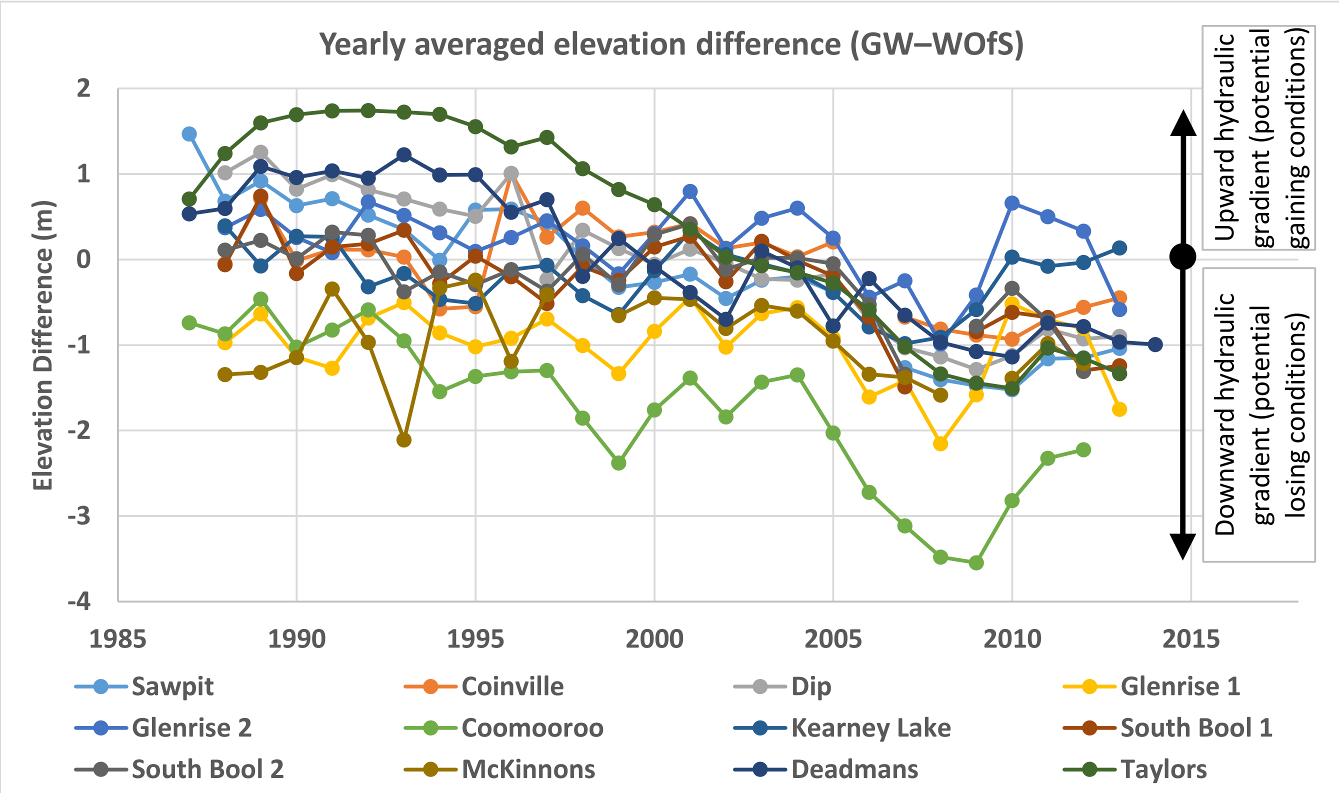

Figure 4.8. Elevation difference between groundwater and wetland WOfS levels

The development of the likelihood classifications for gaining conditions are based on the elevation differences shown in Figure 4.8, in combination with the descriptions of wetland hydrological regimes of Harding *et al.* (2018). The elevation difference represents the potential for upward or downward flow between the surface water and groundwater systems. For example, a 'very high' likelihood of gaining conditions are defined as average groundwater level greater than 1 m above the minimum wetland elevation (Table 4.4). This incorporates the potential error of the difference calculation and accounts for some degree of groundwater discharge through evapotranspiration. A 'high' likelihood of gaining conditions is assigned to surface water features where the difference between groundwater and surface water elevations is 0–1 m. A 'moderate' likelihood of gaining conditions is defined as a difference of -1–0 m and describes GW–SW exchange that could be either gaining and losing, depending on seasonal conditions. This includes periods where the wetland may be dry (i.e. no surface expression of groundwater) but still receiving groundwater discharge through evapotranspiration that contributes to the presence of damp conditions supporting aquatic ecosystems. Losing conditions are 'high' likelihood and 'very high' likelihood when the difference between the wetland bed and groundwater level is between -1 and -2 m and greater than -2 m (i.e. more negative), respectively. This represents the condition where the groundwater system is beginning to transition away from directly discharging into the aquatic ecosystem (i.e. less influence on the surface water expression in the wetland), but is likely to still support phreatophitic vegetation. A disconnected losing classification has not been considered for these wetlands as the hydraulic properties of the wetland sediments or shallow aquifer would be required for such classification (Brunner *et al.*, 2009) and are not currently available. The classification thresholds are intended to account for the propagation of error resulting from the calculation of representative vertical hydraulic gradients from the LiDAR DEM and interpolated groundwater surface. It should be noted that the potential error of this analysis is considered to be ± one likelihood classification.

Table 4.4. Likelihood classifications for gaining conditions, wetland type, drain condition, losing conditions

Mean elevation difference (GW–SW)	Gaining (i.e. groundwater discharge)	Likely wetland type	Likely drain condition	Losing (i.e. potential groundwater recharge)
> 1	Very high	Permanent	Permanent flow	Very low
1 to 0	High	Permanent to seasonal	Permanent to seasonal flow	Low
0 to -1	Moderate	Frequently seasonal	Frequently flowing	Moderate
-1 to -2	Low	Occasionally seasonal	Occasionally flowing	High
< -2	Very low	Unlikely	Unlikely	Very high

The results of the analyses for the 12 GDE wetlands are shown as yearly averages (Figure 4.9). From the mid-1990s until the mid-2000s, there is decrease in the number of wetlands classified as 'very high' and 'high' likelihood of gaining conditions, while the number of wetlands classified as 'moderate' likelihood shows an increase. From 2005 to 2008 (i.e. towards the end of the drought), there is an increase in the number of wetlands classified as 'low' likelihood of gaining conditions. After 2008, the number wetlands classified as 'moderate' and 'high' likelihood increase. These results are consistent with the changes in hydro-periods described by Harding *et al.* (2018) where a number of wetlands along the boundary between the Naracoorte Ranges and the interdunal flats (Figure 1.1) were shown to transition from a state of permanent inundation to consistently dry conditions, while others on the inter-dunal flats showed reductions in depth and duration of inundation followed by partial hydrological recovery after the mid-2000s in response increased rainfall. At the time of analysis WOfS data was not available for the most recent 4 years as indicated by the 'N/A' classification.

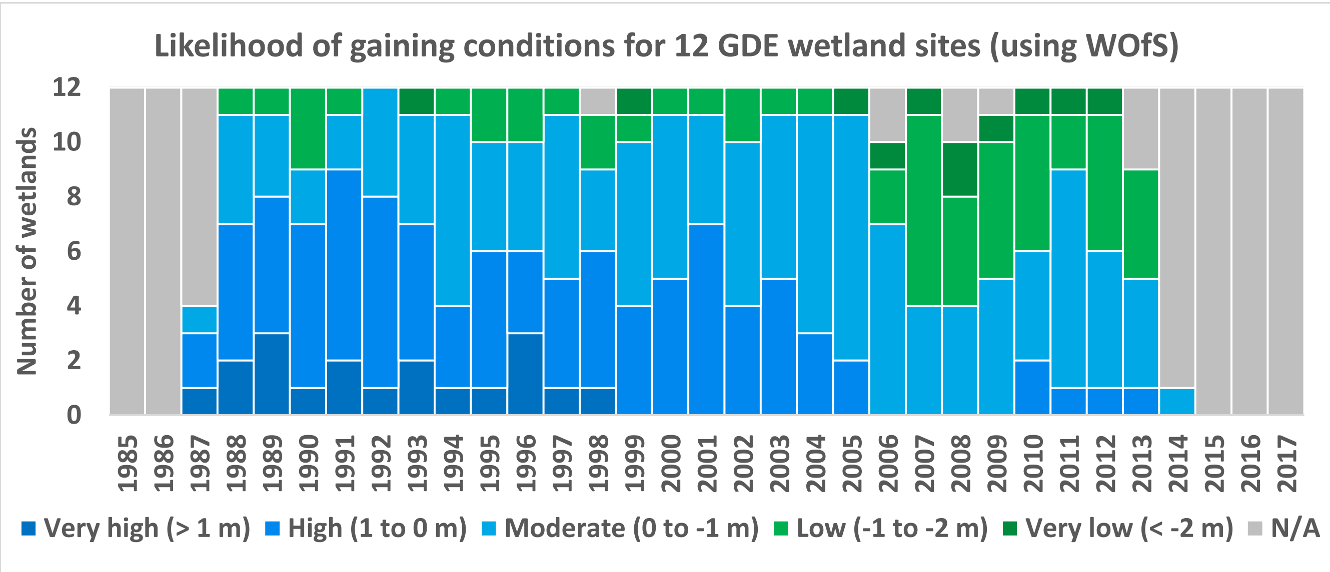

Figure 4.9. Change in likely GW–SW exchange over time for 12 GDE wetlands using WOfS and groundwater level differences (m) with classification five thresholds

4.2.2 Drain monitoring comparison sites

Drain monitoring sites are generally situated on the low-lying parts of the landscape (i.e. inter-dunal flats – see Figure 1.1) where groundwater level trends have tended to be more stable (Figure 4.3). As shown in Figure 4.10, there are only a few monitoring comparison sites that show significant change in the nature of GW–SW exchange including: Drain L (Boomaroo Park 7.3 km), Drain M (D/S Callendale Regulator) and Bakers Range Watercourse which also show consistent negative elevation differences (implying the potential for losing conditions). These changes are seen to occur after around 2005 and may be related to landuse changes in that area. The remaining five comparison sites show consistently positive differences (i.e. likely gaining conditions)) as might be expected for drains constructed with the intention of lowering the watertable (Figure 4.10).

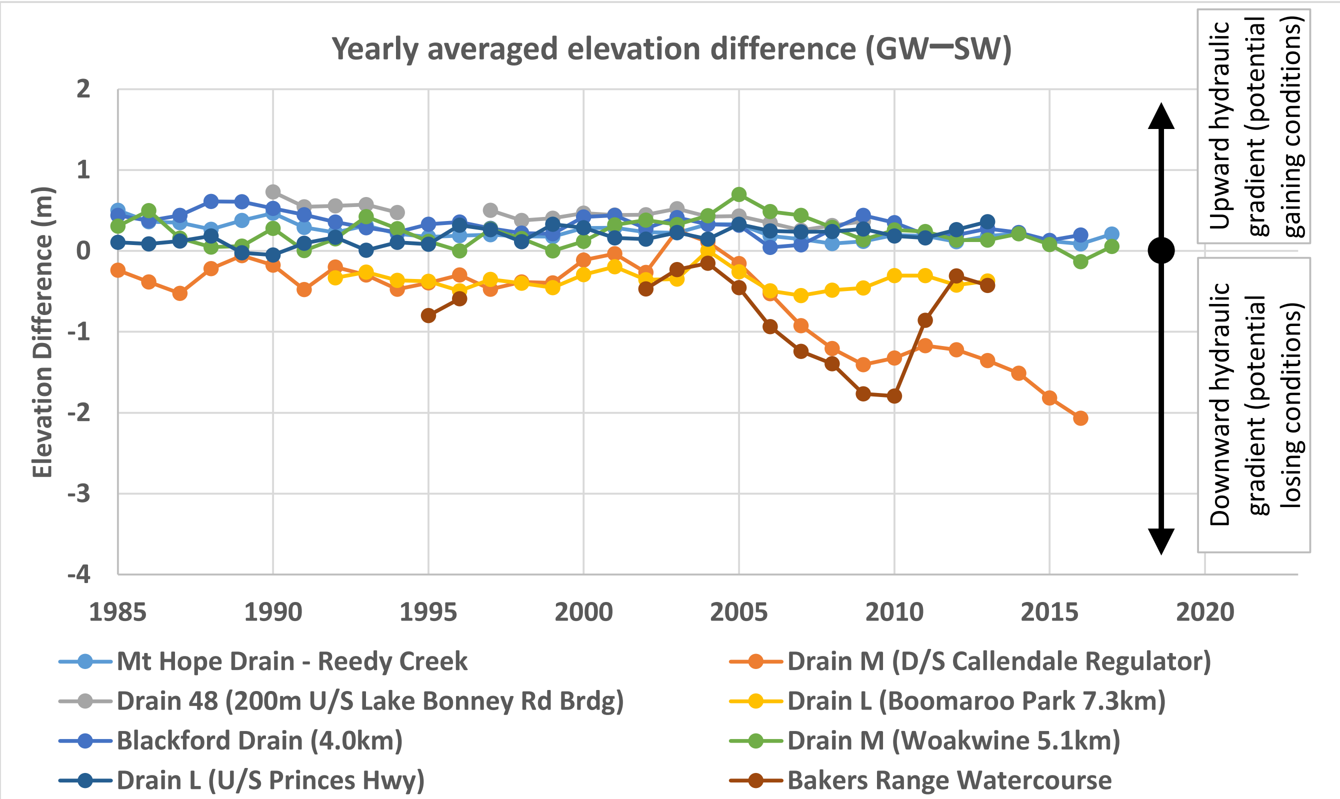

Figure 4.10. Elevation difference between groundwater and drain water levels

Comparisons for all sites are shown in Appendix C, while an example of relatively consistent differences is shown for the Mount Hope Drain at Reedy Creek (A2390513, Figure 4.11). Here, the pattern of seasonality in the groundwater variation is similar to that of the drain water levels, although water levels are offset and groundwater is consistently higher. This suggests gaining conditions are persistent in this location. Drain M, which is located downstream of the Callendale Regulator (A2390514, Figure 4.12), shows a change in the GW–SW exchange over time due to declining groundwater levels after 2005. This drain is likely to be gaining or variable (i.e. most likely gaining in winter and losing in summer) until the mid-2000s, and since then has become losing.

GW–SW exchange classifications have been applied to these drains according to the thresholds derived for wetland GDEs. These are shown as yearly averages in Figure 4.13. Overall the exchange is more stable over time for drains compared to wetlands, although there are two drain sites which show a change after 2006 from 'moderate' likelihood to 'low' likelihood of gaining conditions. Incomplete data records for a number of sites limits the analysis after 2009 for Drain 48 and after 2013 for three and then five additional sites in 2017 (i.e. represented by grey bars which are not assessed, "N/A"). It is therefore difficult to derive any clear results for these sites using the currently available datasets as no clear trends are evident.

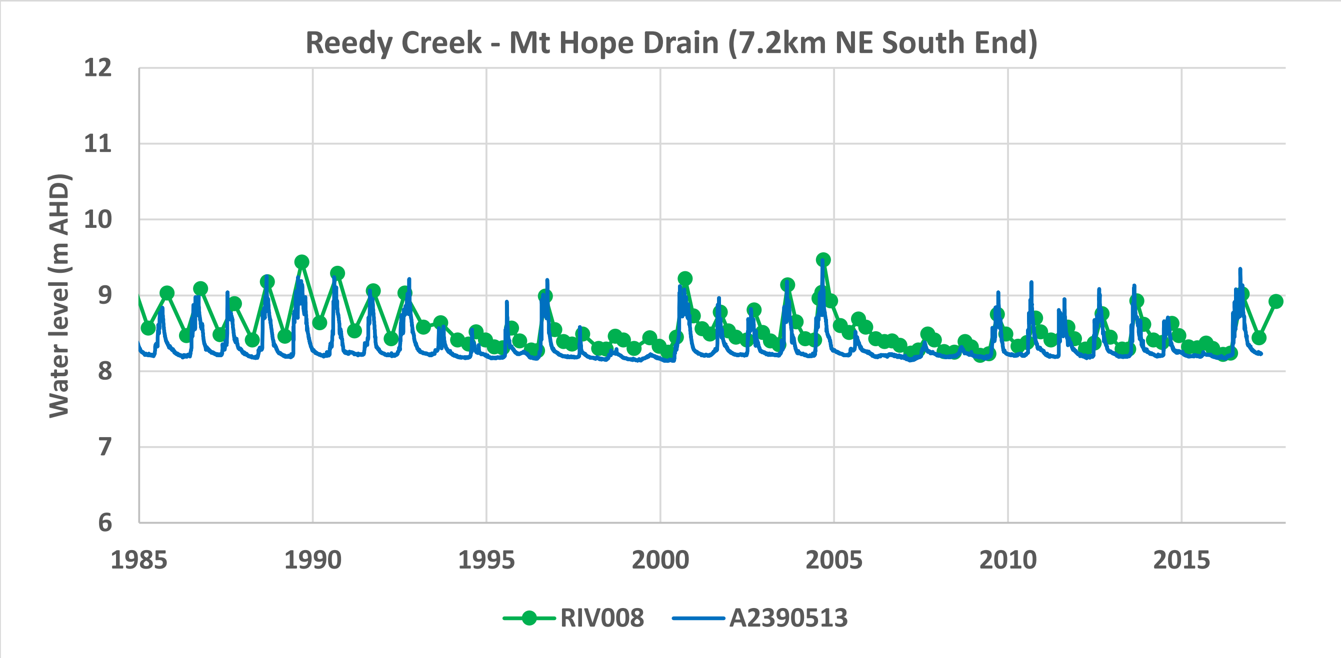

Figure 4.11. Hydrographs for Mount Hope Drain (A2390513) with observation well RIV008 (using old ref. elev.)

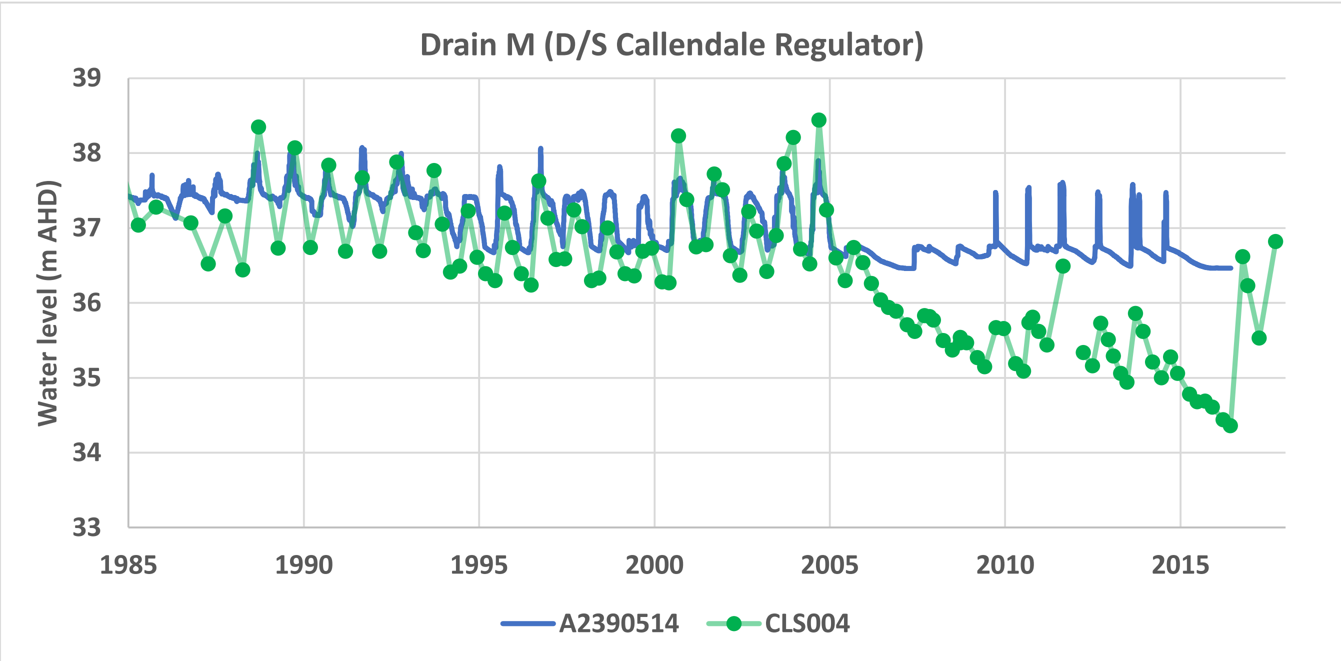

Figure 4.12. Hydrographs for Drain M (A2390514, adjusted) with observation well CLS004

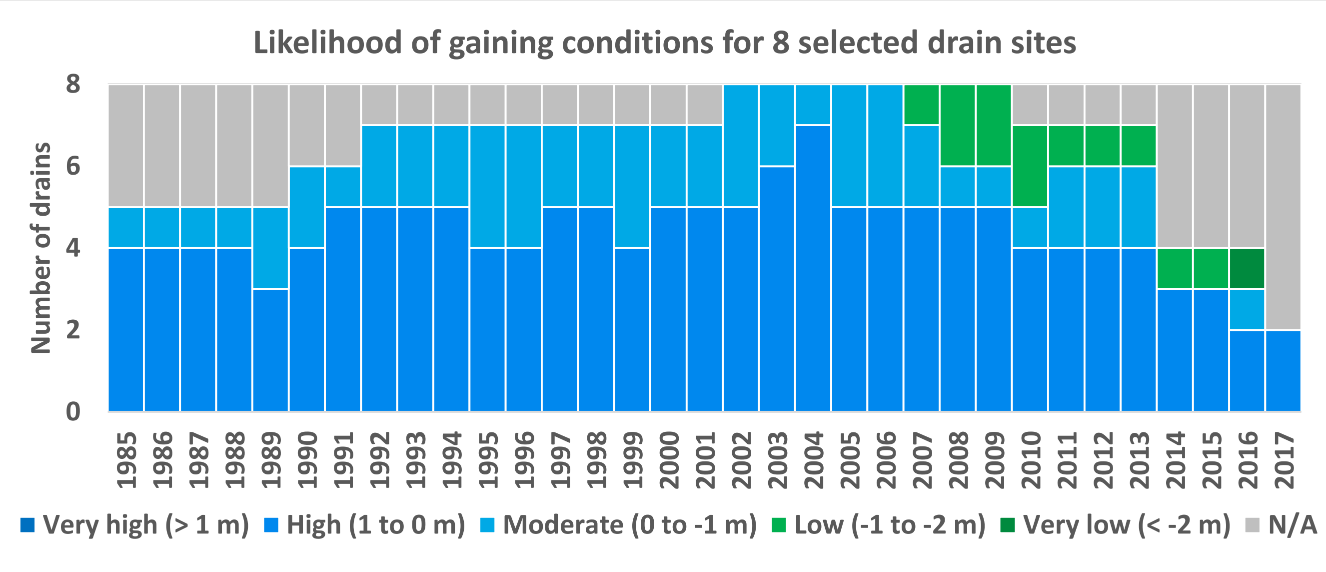

Figure 4.13. Change in GW–SW exchange classification over time for eight drain sites using adjusted drain level and groundwater level differences (m) with classification thresholds

4.3 Regional summary

The classification scheme for likelihood of gaining conditions was applied to each wetland, drain and watercourse feature within the South East region using analysis of the DEM and watertable surfaces for each time period. These data are presented over time as the count and total area of each likelihood classification for each time period for wetlands (Figure 4.14 and Figure 4.15, respectively) and for drain segment count and total length for drains (Figure 4.16 and Figure 4.17, respectively). Maps of the likelihood classification for all surface water features are more effective for showing the spatial distribution of the results (e.g. the 2015–17 epoch in Figure 4.18 and all time periods in Appendix D). There are a number of critical features of this analysis:

- the autumn and spring watertable surfaces for 2017 represent respectively the minimum and maximum water levels for that year; taking the average of these two surfaces would be the most robust approach if comparing with watertables from other epochs, and
- the majority of the wetlands classified as 'very low' likelihood of gaining conditions are found in (1) the southern part of the Cross-Border Creeks Catchments, Glenelg Plain and Perched Volcanics DMUs – these largely represent perched wetlands that are not connected with the regional aquifer (only limited assessment of the changes to these features is reported in Section 4.1.3, while more detail for some of these systems can be found in Harding, 2018).

There are clearly changes over time in the number (Figure 4.14) and area (Figure 4.15) of wetlands in each likelihood category. In the 1985–89 epoch, the decline in wetlands classified 'very high' likelihood of gaining reaches a minimum during 2005–09 and then shows some stabilisation. The yearly maximum water levels in the spring of 2017 suggest that many wetlands are still very likely to receive groundwater discharge despite the regional declines in groundwater levels that have occurred since the mid-1990s. These trends largely correspond with changes in rainfall recharge across the region; however, a number of exceptions are discussed for specific DMUs in the following section. The number and area of wetlands classified as 'high' likelihood of gaining shows a more subdued pattern of decline and recovery, while wetlands classified 'moderate' likelihood decline in number but increase in area. This is most likely due to larger wetlands changing from 'very high' or 'high' to 'moderate' likelihood while others smaller wetlands change to 'low' or 'very low'. The changes in area are considered to be more indicative of changes relevant for interpretation (as opposed to the changes in number) despite the very high classification being dominated by a relatively small number of large coastal wetlands.

The changes over time in the number of drain segments (Figure 4.16) and drain length (Figure 4.17) within each likelihood classification are similar, because each segment has a similar length (i.e. more similar than the number of wetlands and their corresponding areas). The changes in likelihood of gaining conditions measured as length of drain is considered to be more indicative of changes relevant for interpretation and is the metric used in this study. The length of drains classified as both 'very high' and 'high' likelihood of showing gaining conditions are seen to decrease from the 1985–89 epoch, reaching a minimum during 2005–09, after which the data show some stabilisation. This is balanced by an increase in the length of drains classified as 'moderate', 'low' and 'very low' likelihood of gaining , while the length of drains classified as 'high' likelihood is stable after an increase between the 1985–89 and 1995–99 epochs. The larger length of drains classified as 'very high' likelihood of gaining conditions in spring 2017 reflects the seasonality of a considerable length of the drain network which is most active during periods of high water levels (i.e. compared with the lower autumn or average groundwater levels).

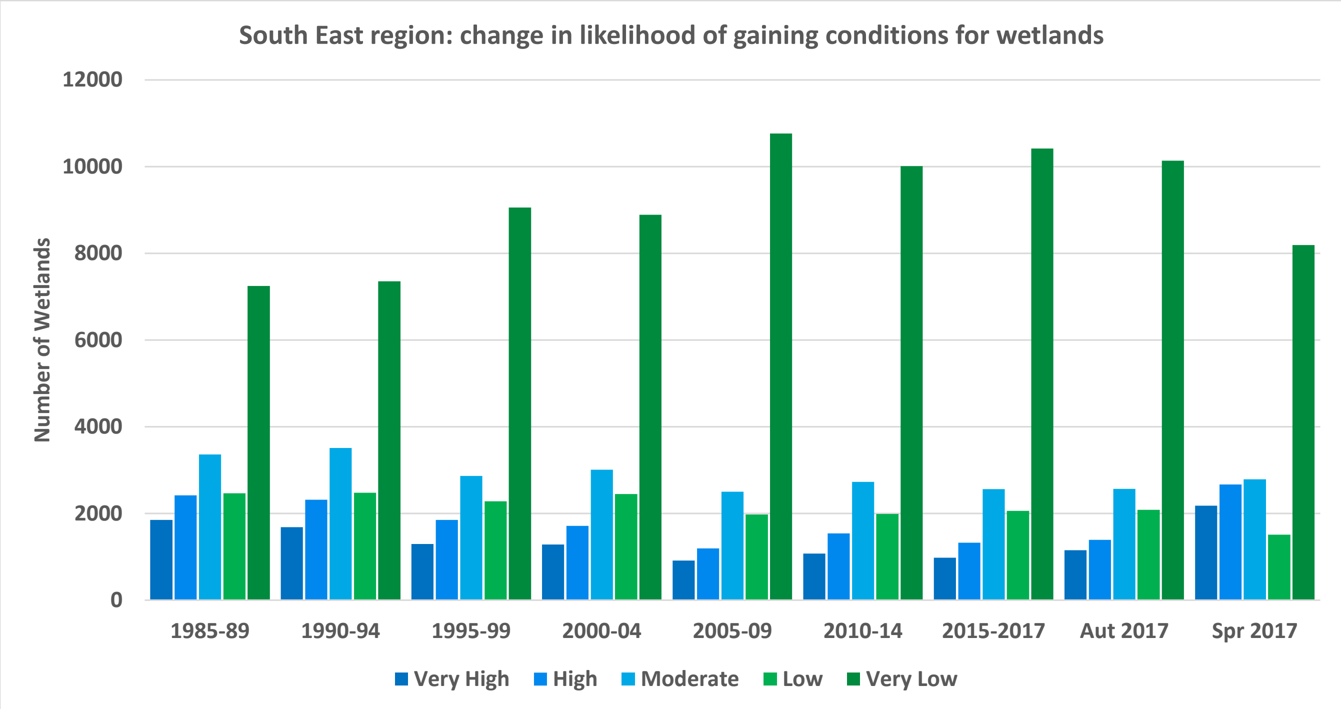

Figure 4.14. Change in likelihood of gaining conditions for wetlands and water courses over time (count)

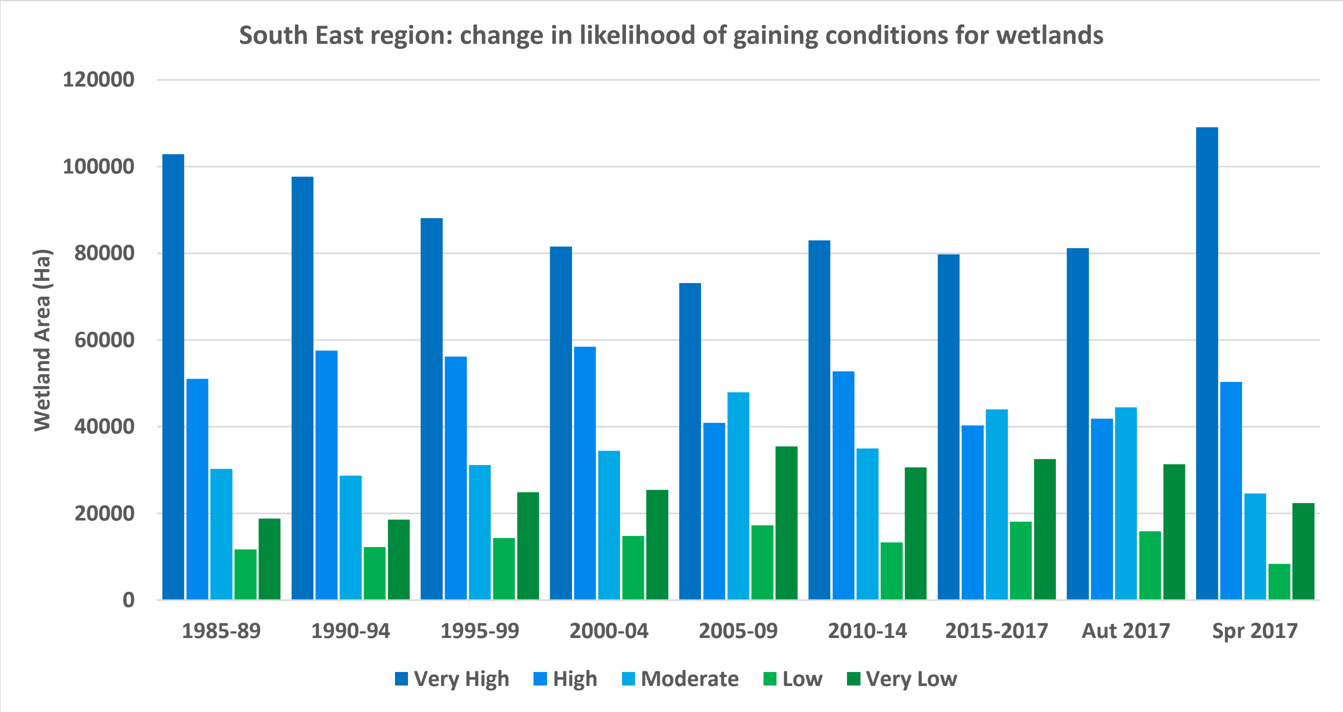

Figure 4.15. Change in likelihood of gaining conditions for wetlands and watercourses over time by area (Ha)

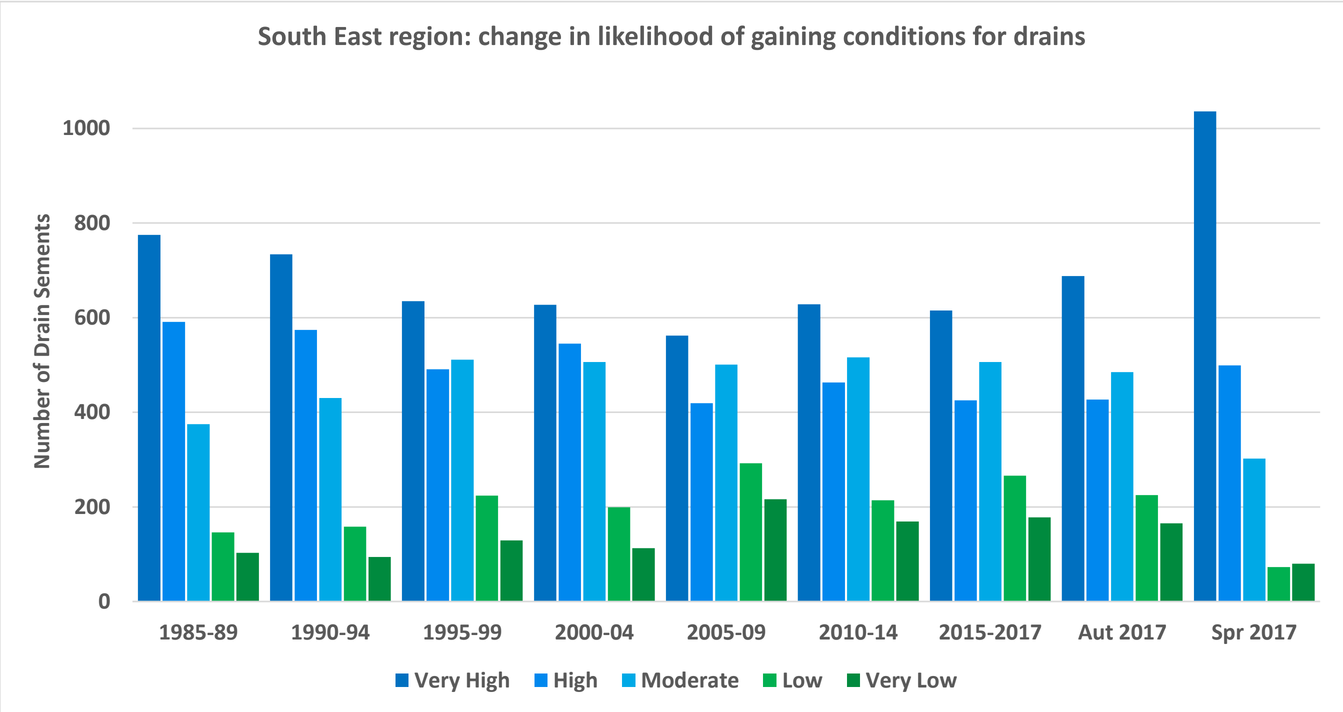

Figure 4.16. Change in likelihood of gaining conditions for drains over time (number of segments)

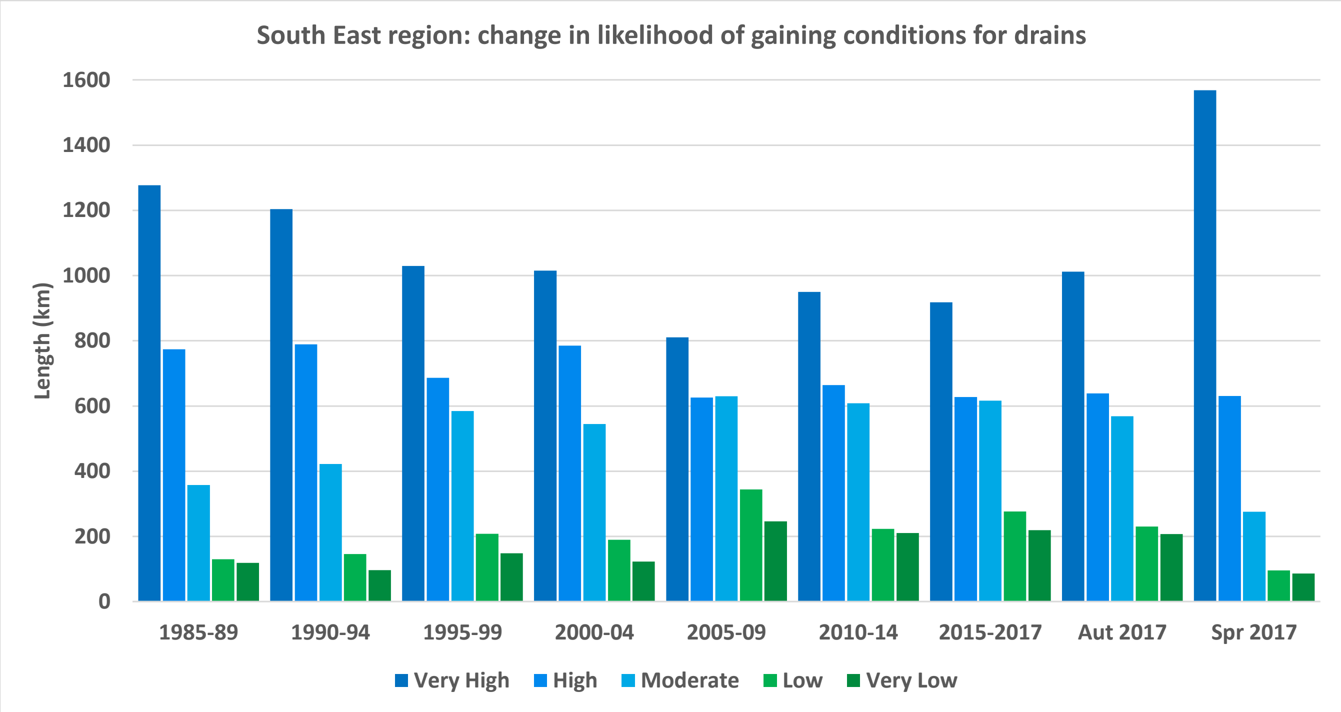

Figure 4.17. Change in likelihood of gaining conditions for drains over time by length (km)

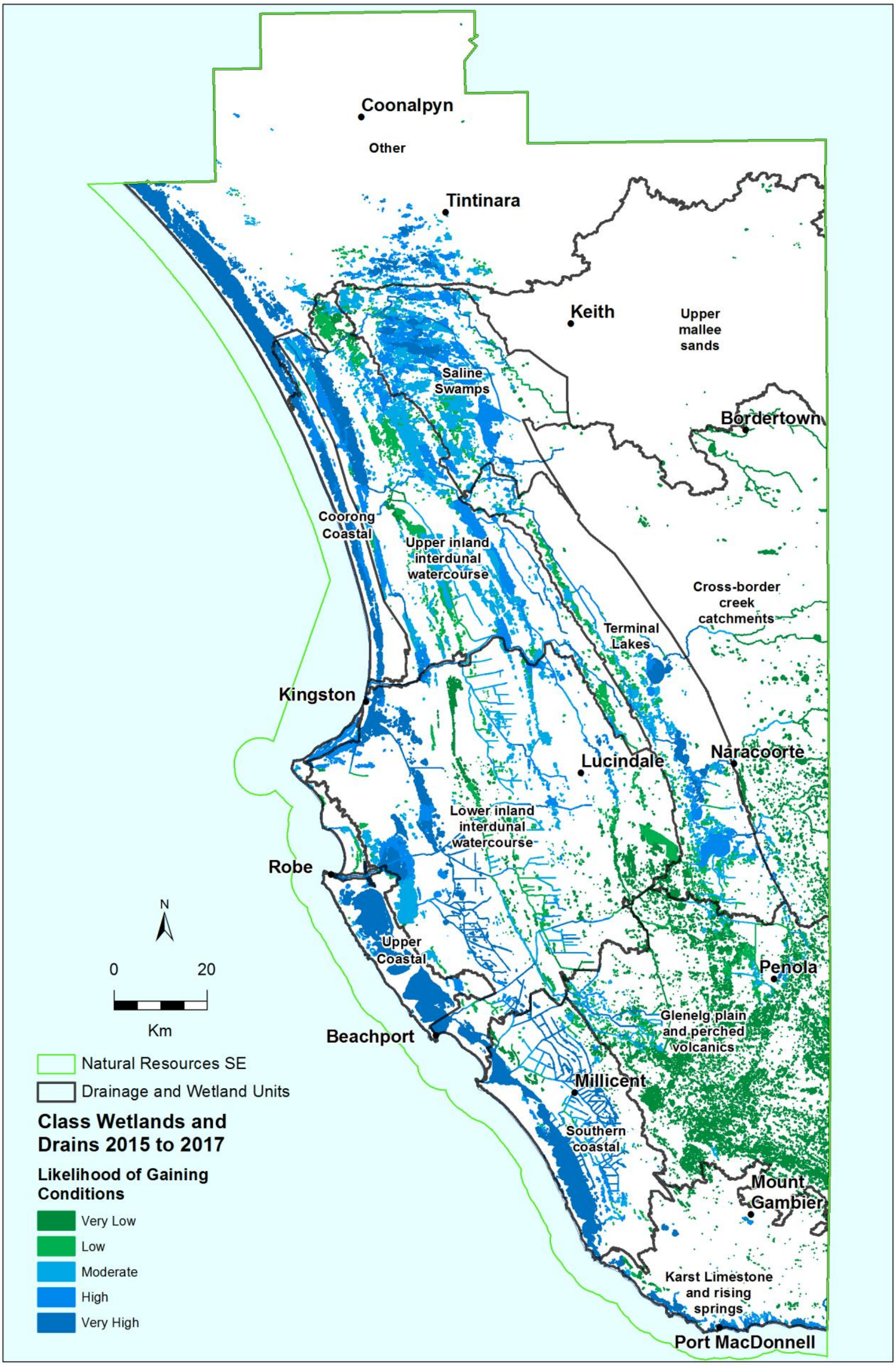

Figure 4.18. Likelihood of gaining conditions for wetlands, drains and watercourses for the 2015–17 epoch

4.4 Drain management unit summaries

4.4.1 Overview

The boundaries of each DMU have been derived using a two-part process. Boundaries were initially derived through a project which incorporated drainage flow schematics, management options, wetlands and catchment boundaries (Wood & Way, 2011). These boundaries were further revised by the South East Water Conservation Drainage Board in 2018 to assist with development of the South East Wetlands Drainage Strategy (Figure 4.21). For each of these DMUs, the change over time of 'very high', 'high' and 'moderate' likelihood of gaining conditions is shown for wetlands (Fig. 4.19) and for drains (Fig. 4.20). The largest reduction in the area of wetlands likely to experience gaining conditions are the Upper and Lower Interdunal Watercourse, Glenelg Plain and Perched Volcanics, Saline Swamps and the Terminal Lakes DMUs. Changes in the other DMUs are less pronounced and relatively stable (e.g. Coorong Coastal, Karst and Limestone Springs, Other and Upper Coastal DMUs). There is a slight reduction and then recovery of gaining condition classifications for the number of wetlands in some DMUs but this variation is not as clear when measured by area. Changes over time for the length of gaining drains shows similar patterns to the changes in gaining wetland area for each DMU. A selection of DMUs are described with respect to their changes over time in the following section which allows a more detailed description of individual classifications.

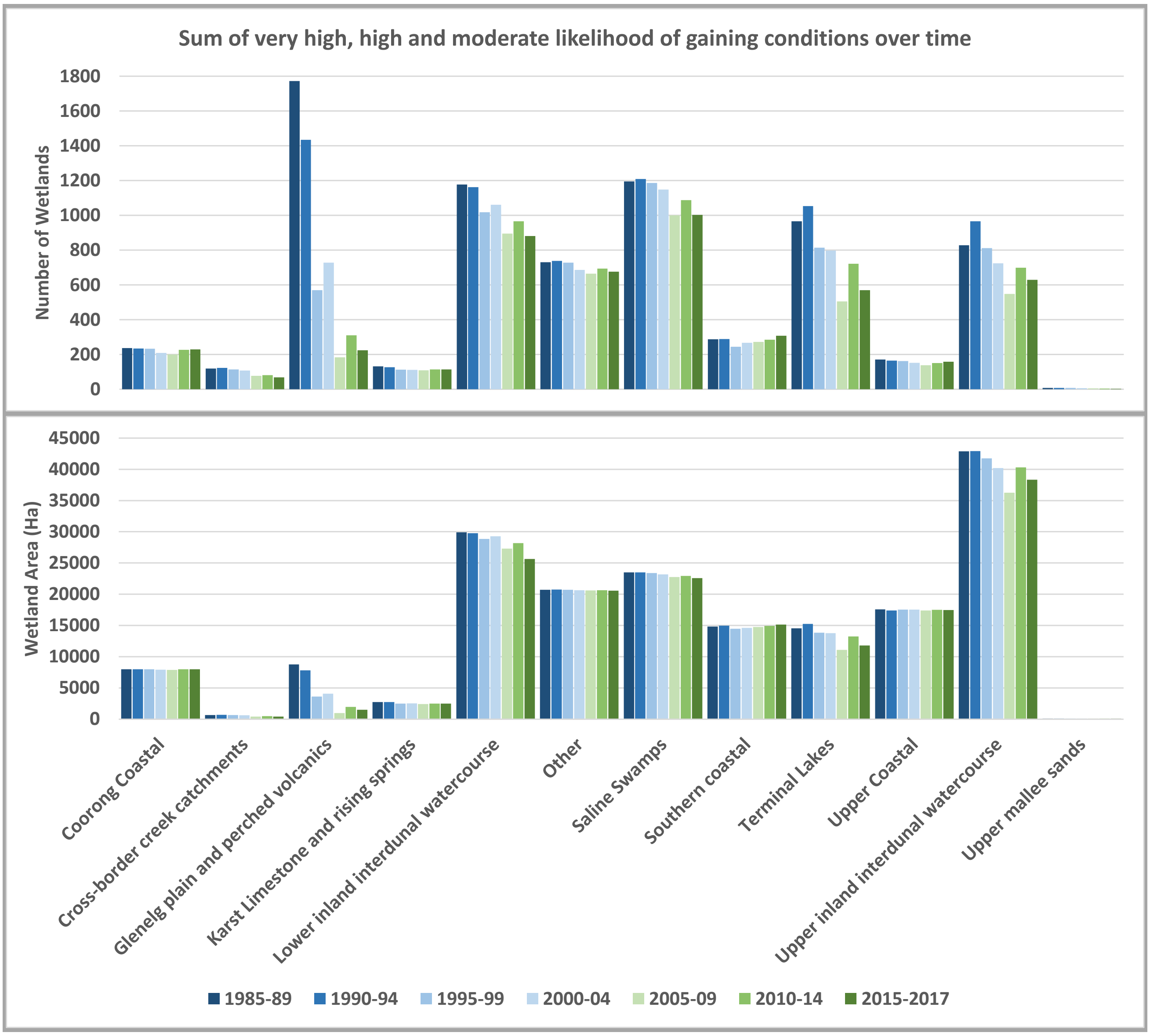

Figure 4.19. Change in likelihood of gaining wetland conditions for all DMUs over time

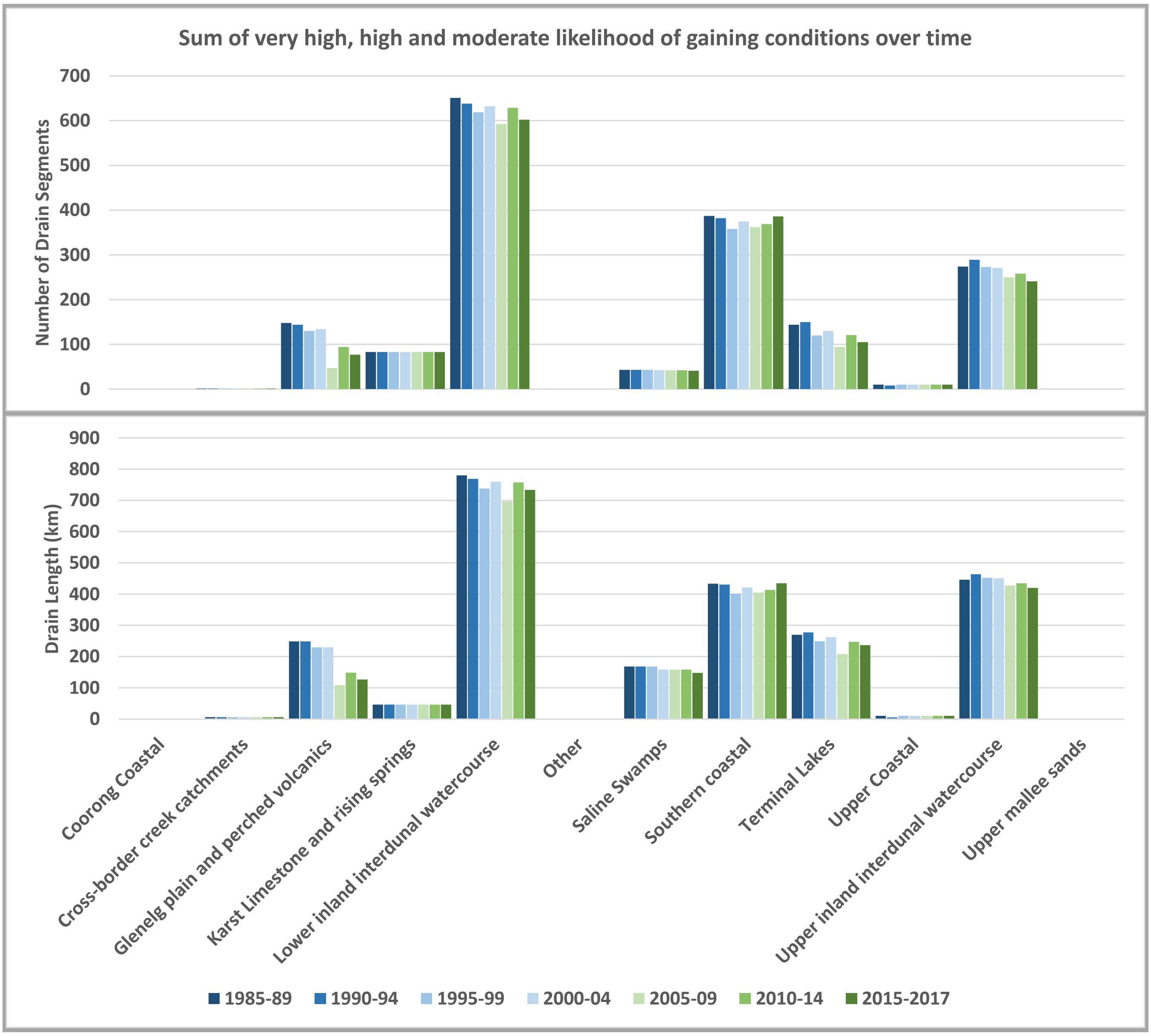

Figure 4.20. Change in likelihood of gaining drain conditions for all DMUs over time

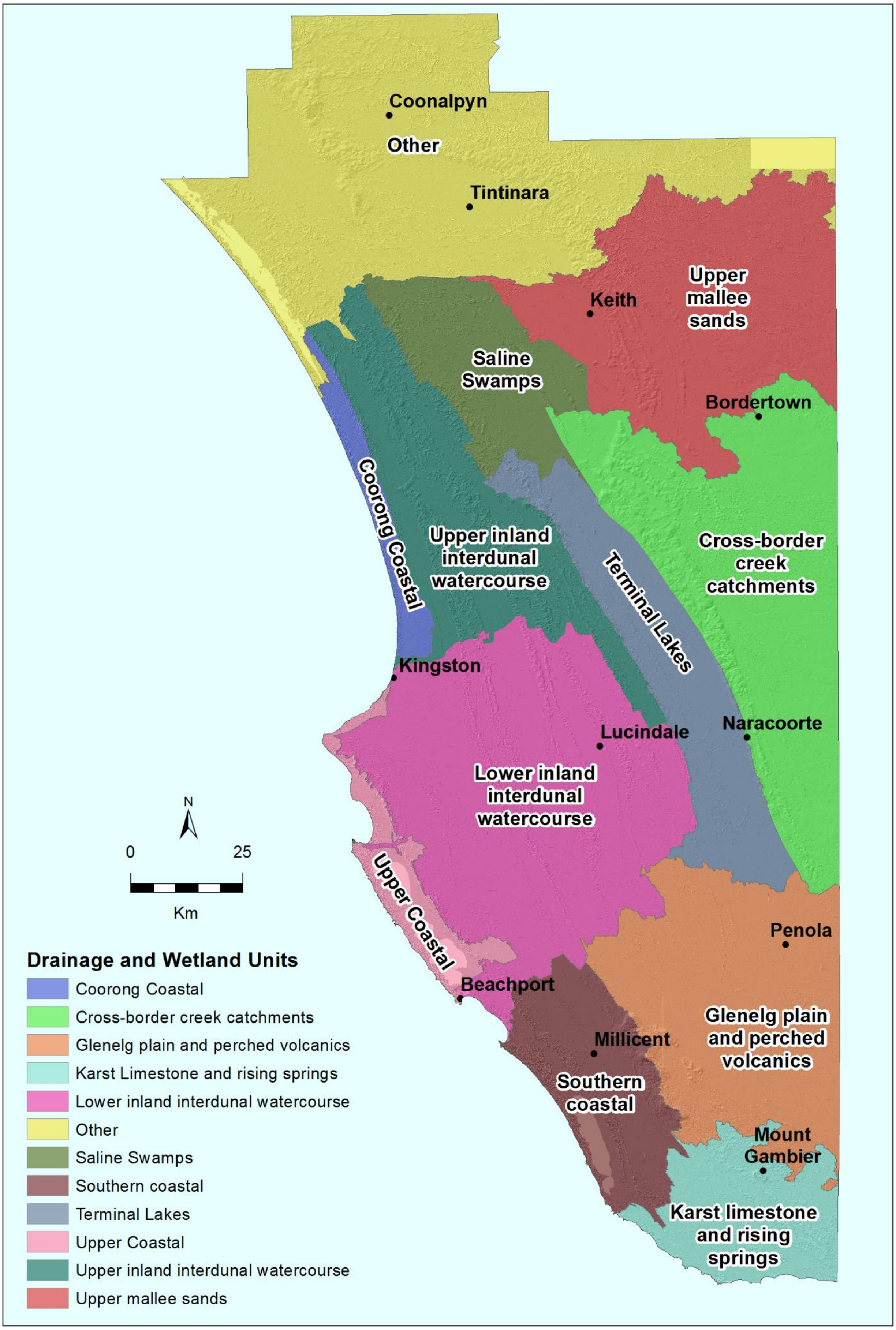

Figure 4.21. Locations of drainage management units

4.4.2 DMU 30-year summary examples

A selection of the DMUs are highlighted below to demonstrate the likely range of changes in GW–SW exchange, while a complete record of all DMU results are presented in Appendix E.

Wetlands in the Coorong Coastal DMU that show a reduction in 'very high' likelihood of gaining conditions reach a minimum in the 2005–09 epoch before showing a recovery (Figure 4.22). Also, the area of wetlands classified as 'high' and 'moderate' likelihood of gaining conditions increased and then decreased over the same epochs. This reflects the trend of low rainfall from the mid-1990s until the mid-2000s and is consistent with falling groundwater levels that are observed over this period.

The Upper Inland Interdunal Watercourse DMU also shows a reduction in the area of wetlands classified as 'very high' likelihood of gaining conditions (Figure 4.23). While the area of wetlands in this DMU is dominated by 'high' and 'moderate' likelihood, the area classified as 'moderate' and 'low' likelihood increase from the early-1990s, reaching a maximum in the 2005–09 epoch, as would be expected during the low rainfall years followed by a series of years that recorded above-average rainfall.

Figure 4.24 shows the likelihood of gaining conditions for the Cross-Border Creek Catchment wetlands. The area of wetlands showing 'very low' likelihood of gaining conditions dominates this DMU but has been removed from the figure so that the more subtle changes to wetlands with a higher likelihood of gaining conditions can be more clearly shown. Here the area of wetlands classified as 'very high' and 'high' likelihood decreases from the late-1980s until present, while the area of wetlands classified as 'moderate' increases. It appears that in this area the likelihood of gaining wetlands changes from 'very high' and 'high' likelihood in the past to 'moderate' likelihood in more recent years, with no sign of recovery. This regional result is supported by the more detailed assessment of Harding et al. (2018) for specific wetlands found along the western boundary of HZ3 (which shares a very similar area to the Cross-Border Creek Catchment DMU).

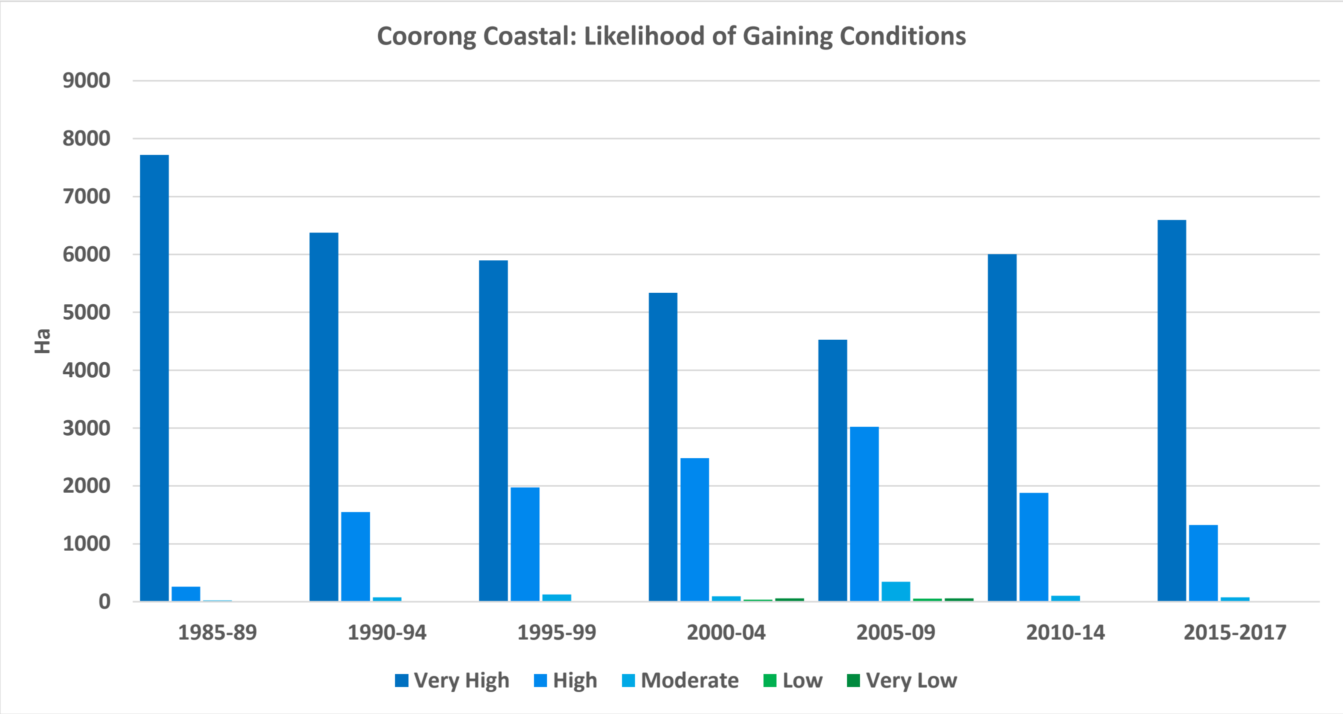

Figure 4.22. Change in GW–SW exchange classification for wetlands in the Coorong Coastal DMU

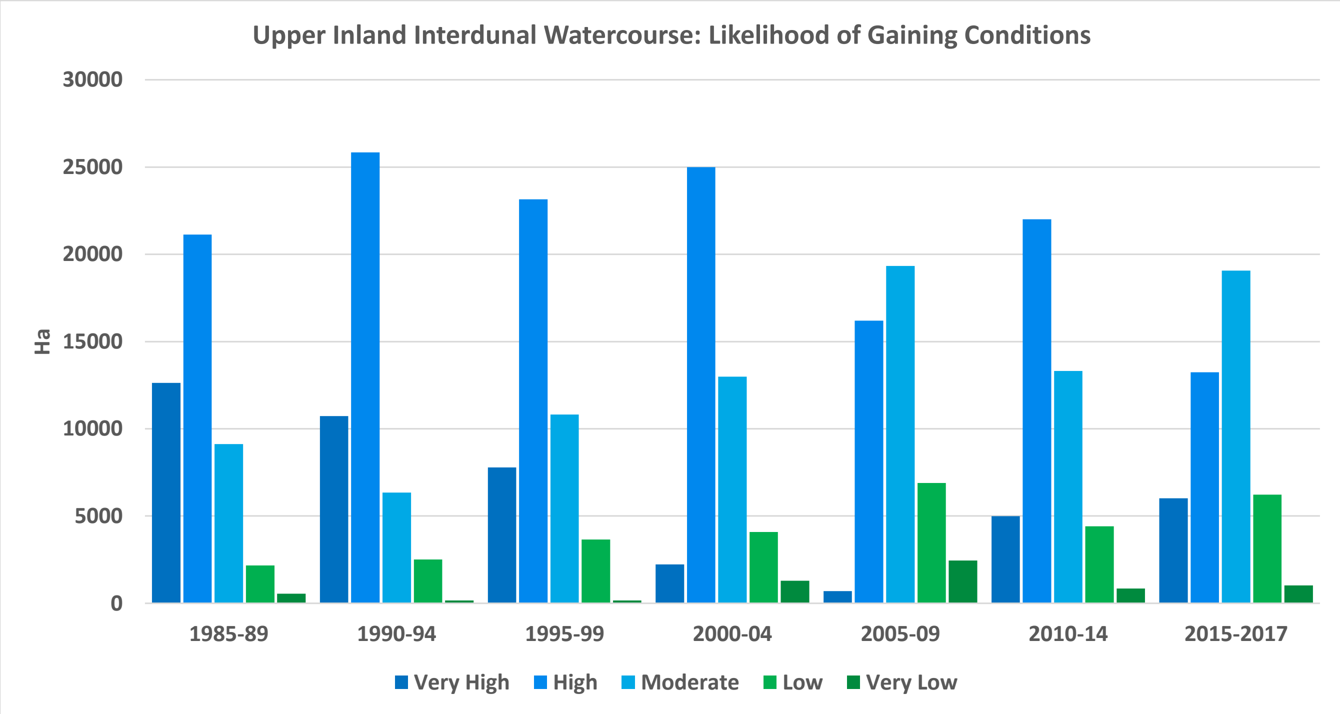

Figure 4.23. Change in GW–SW exchange classification for wetlands in the Upper Inland Interdunal Watercourse DMU

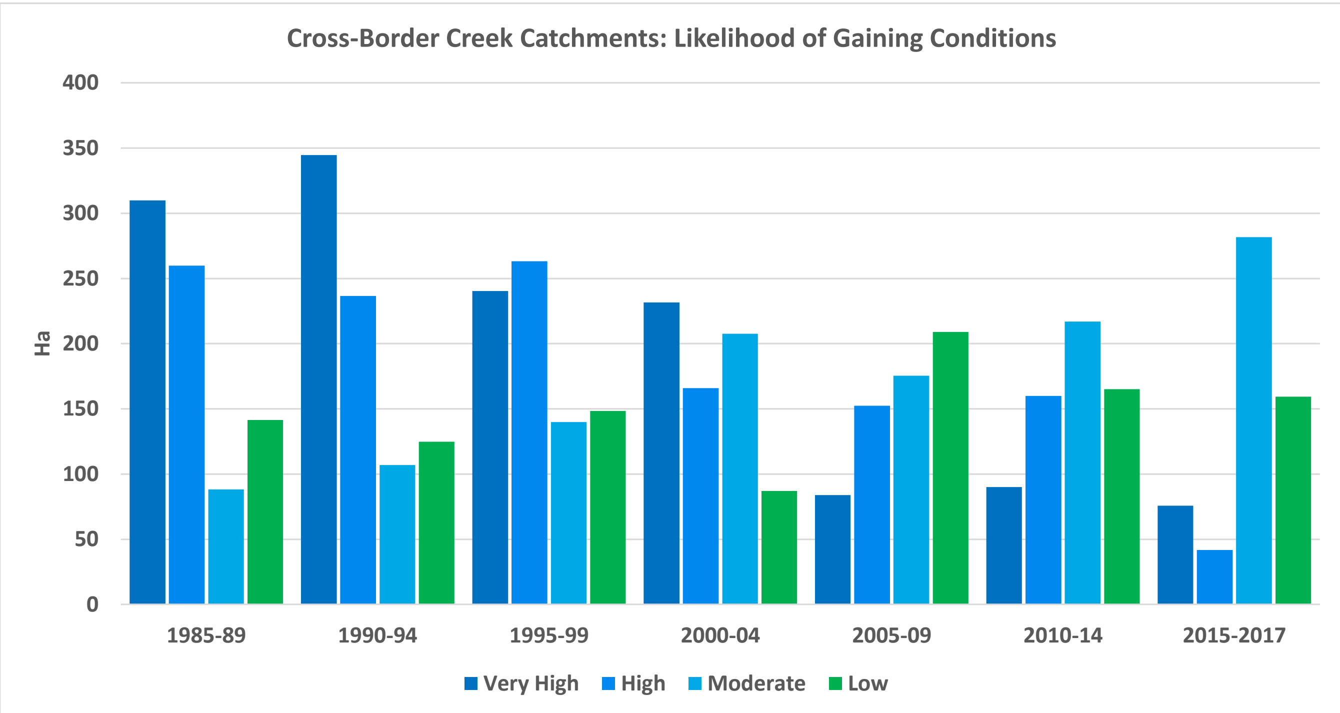

Figure 4.24. Change in GW–SW exchange classification for wetlands in the Cross-Border Creek Catchments DMU (excluding very low classification)

The likelihood of gaining conditions for drains in the Glenelg Plain and Perched Volcanics over time is shown in Figure 4.25. In this DMU, the length of drain gradually transitions from being dominated by 'very high' and 'high' likelihood of gaining during the two earliest epochs towards 'low' and 'very low' likelihood over the three most-recent epochs.

The length of drains within the Karst Limestone and Rising Springs DMU show a change from being dominated by 'very high' likelihood of gaining in the 1985–89 epoch to a mixture of 'very high', 'high' and 'moderate' likelihood of gaining (Figure 4.26). The surface water features in this DMU are still likely to be gaining but the vertical hydraulic gradient towards these features has reduced over time. This trend is similar to the changes in groundwater discharge flowing out to Eight Mile Creek (Cranswick, 2018).

The length of drains within the Terminal Lakes DMU show a steady transition from 'very high' likelihood of gaining conditions in the 1985–89 epoch to being dominated by 'high' and 'moderate' likelihood during the most recent epochs (Figure 4.27). There are also considerable drain lengths that since the early-1990s experience 'low' to 'very low' likelihoods of gaining conditions.

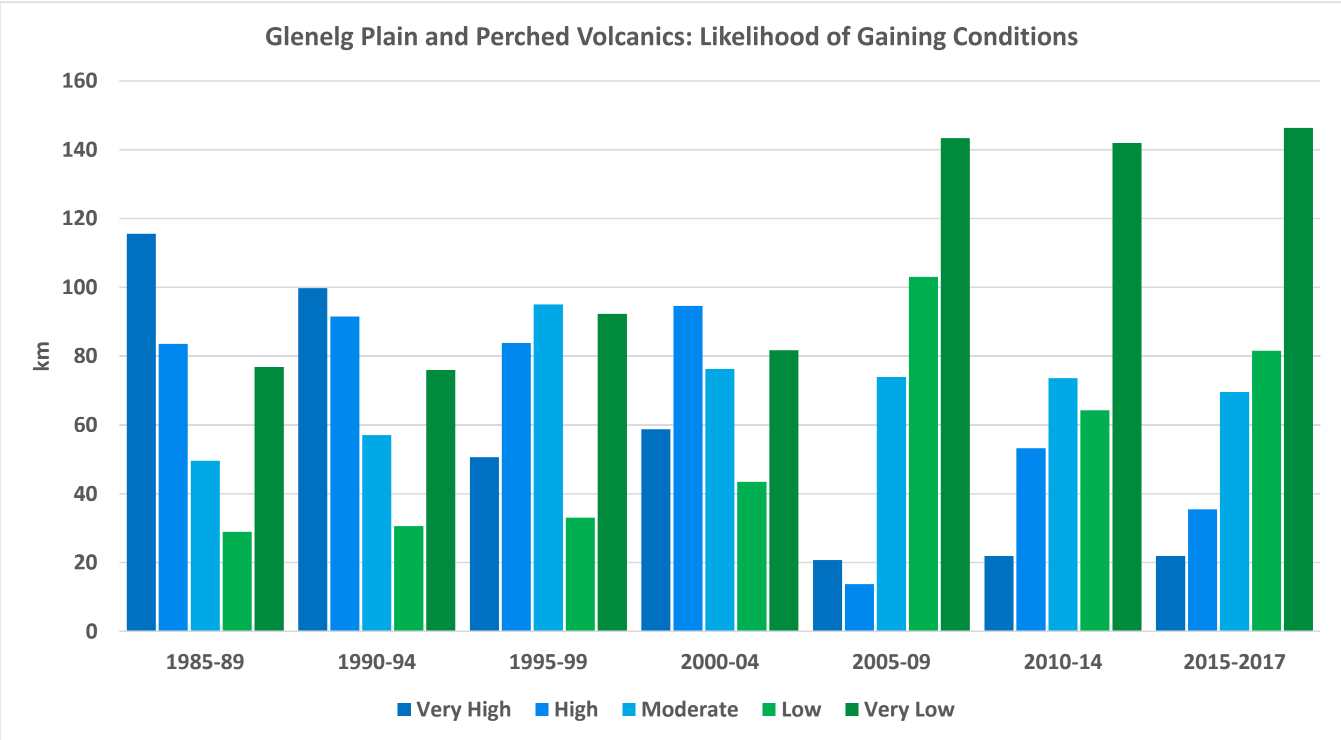

Figure 4.25. Change in GW–SW exchange classification for drains in the Glenelg Plain and Perched Volcanics DMU

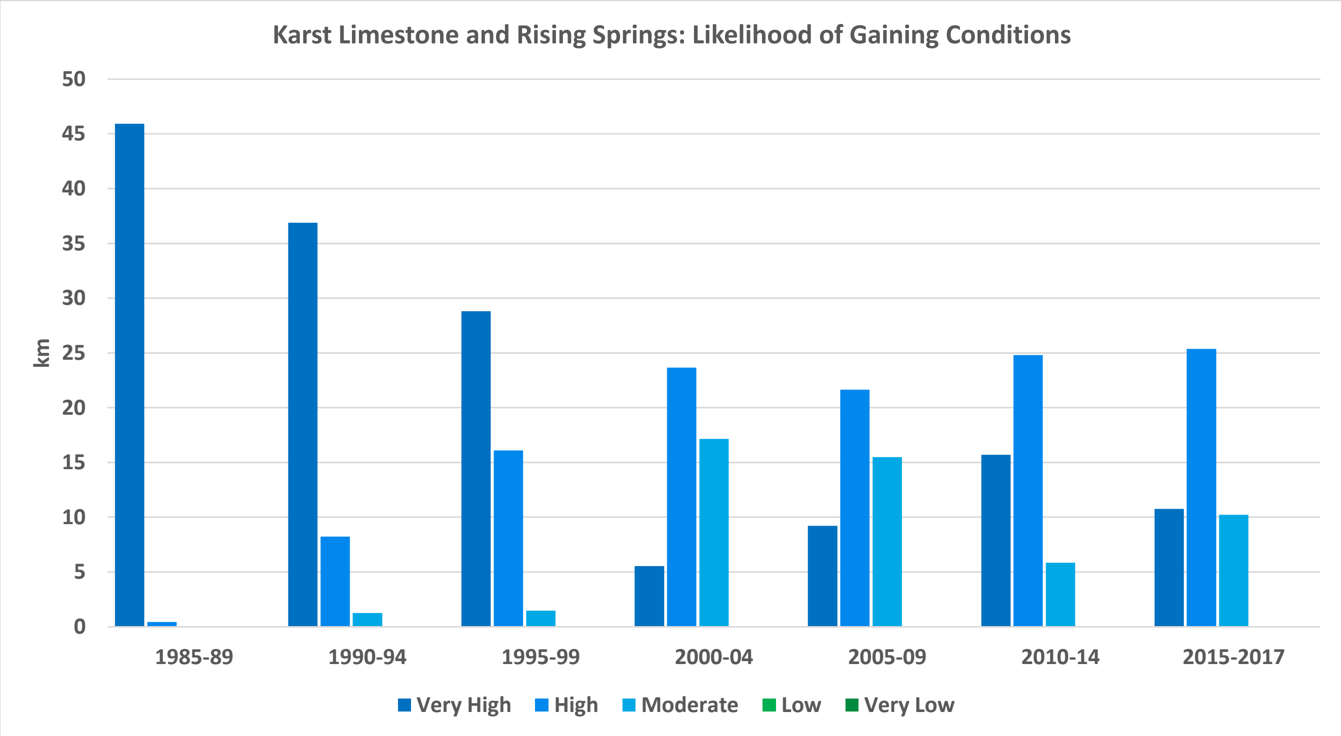

Figure 4.26. Change in GW–SW exchange classification for drains in the Karst Limestone and Rising Springs DMU

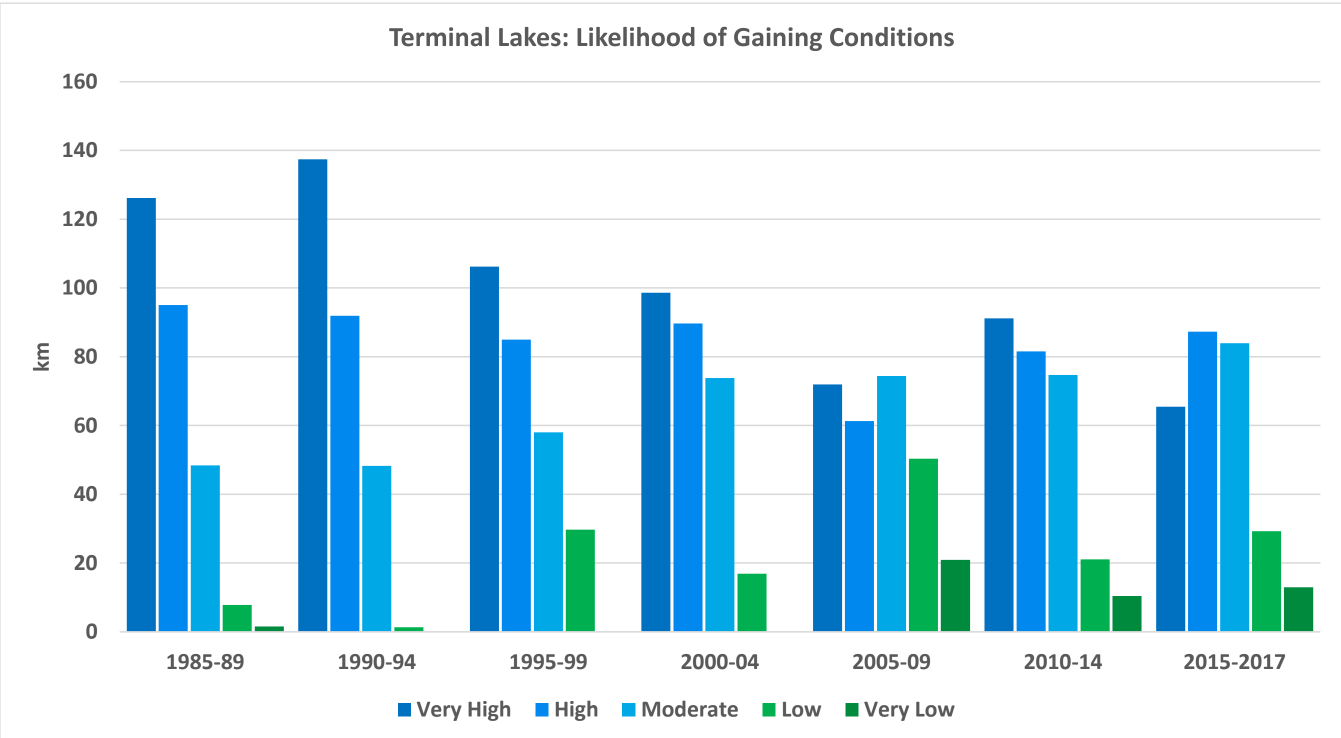

Figure 4.27. Change in GW–SW exchange classification for drains in the Terminal Lakes DMU

4.4.3 DMU autumn and spring 2017 comparison examples

While all of the results are presented in Appendix F, two DMUs are displayed in Figure 4.28 and Figure 4.29 to illustrate the range of seasonal variability of the GW–SW exchange occurring in 2017, between autumn and spring.

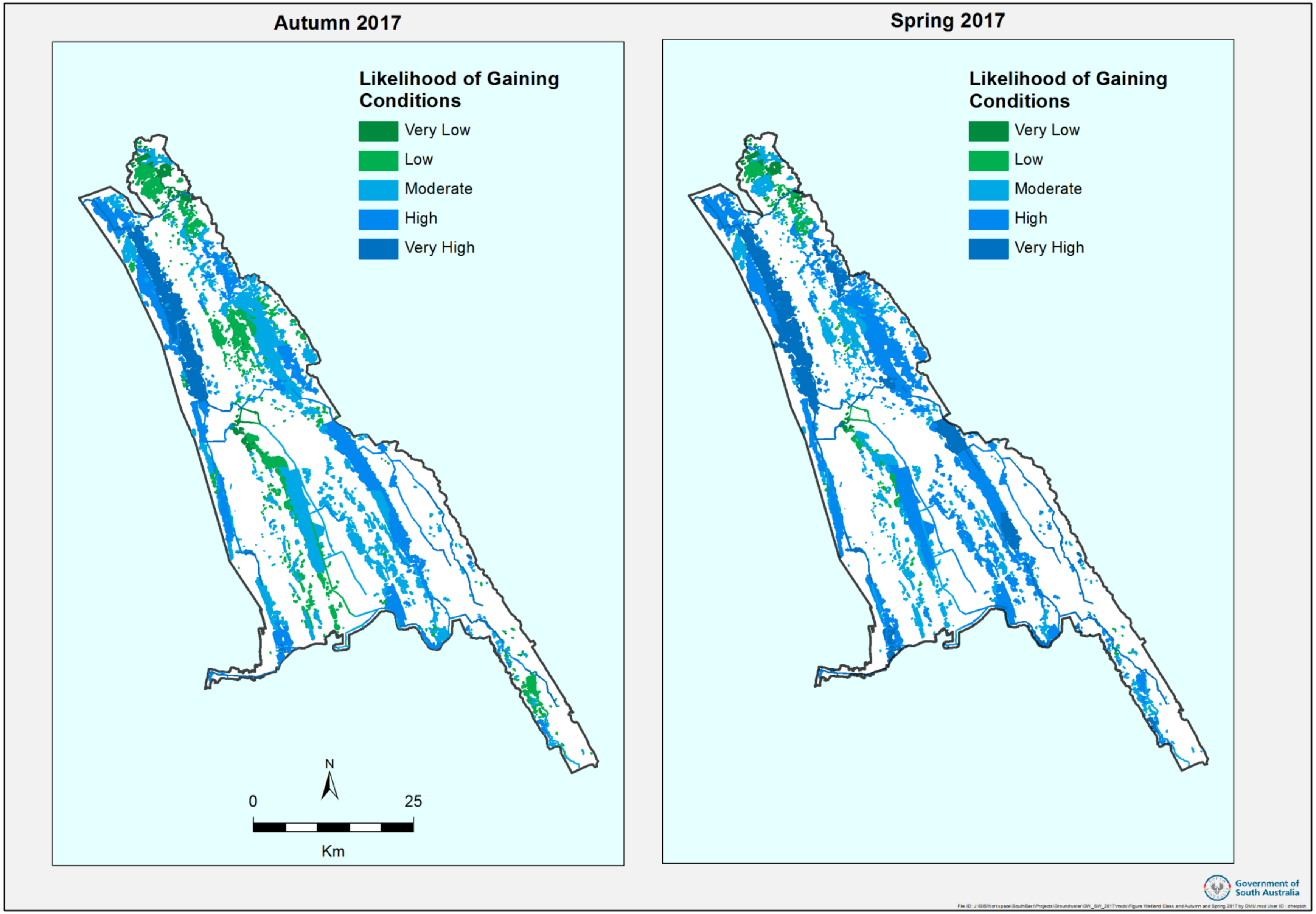

Figure 4.28. Autumn and spring 2017 GW–SW exchange classification in the Upper Interdunal Watercourses DMU

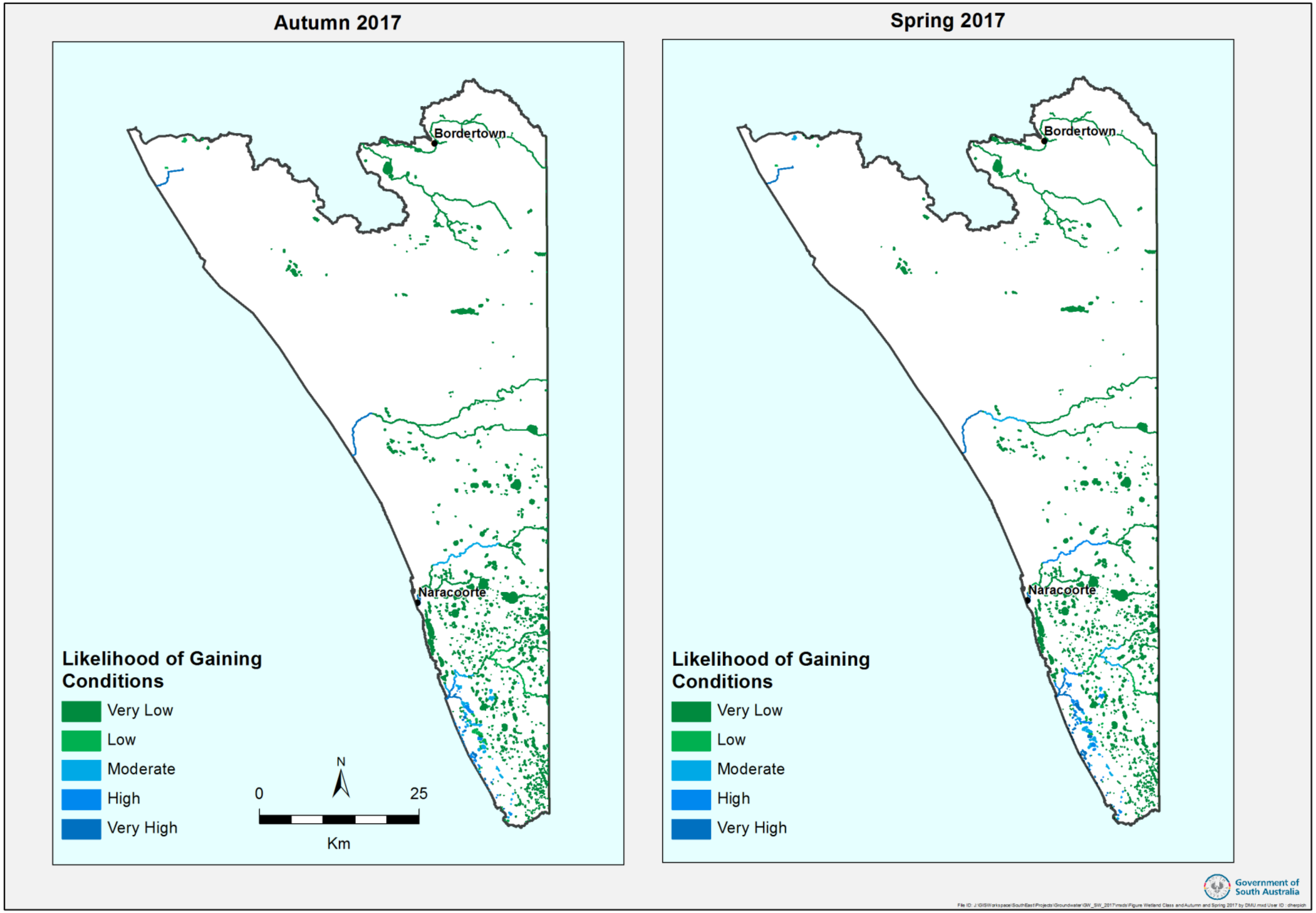

Figure 4.29. Autumn and spring 2017 GW–SW exchange classification in the Cross-Border Creek Catchments DMU

4.5 Site specific examples

To assess the changes over time for site specific areas, detailed spatial analyses using these datasets in ArcMap would be appropriate in a relative sense only, noting that they should not be used to estimate groundwater discharge fluxes or quantitative EWRs for specific wetlands. To give an example of the relative comparisons that are possible, an east–west band capturing Bool Lagoon, Deadmans Swamp and other wetlands towards the Victorian border (Figure 4.30) has been mapped to show the likelihood of gaining conditions for four time periods. There are clear changes over time for wetland features between Taylors and Deadmans Swamps whose likelihood of gaining conditions after the 1995–99 epoch change from 'very high' and 'high', to 'moderate' and 'low'. The area just to the west of Little Bool Lagoon shows wetlands classified as 'very high' and 'high' likelihood of gaining that become 'low' likelihood in the 2005–09 epoch before returning to 'very high' and 'high' likelihood in the most recent epoch. Spatial analysis such as this could include all epochs to give more detailed evaluation of likelihood of losing or gaining conditions for specific wetlands. But, similar to the assessments made by SKM (2009), these should be used with some caution due to the uncertainty inherent in the source data and the resulting wetland classification.

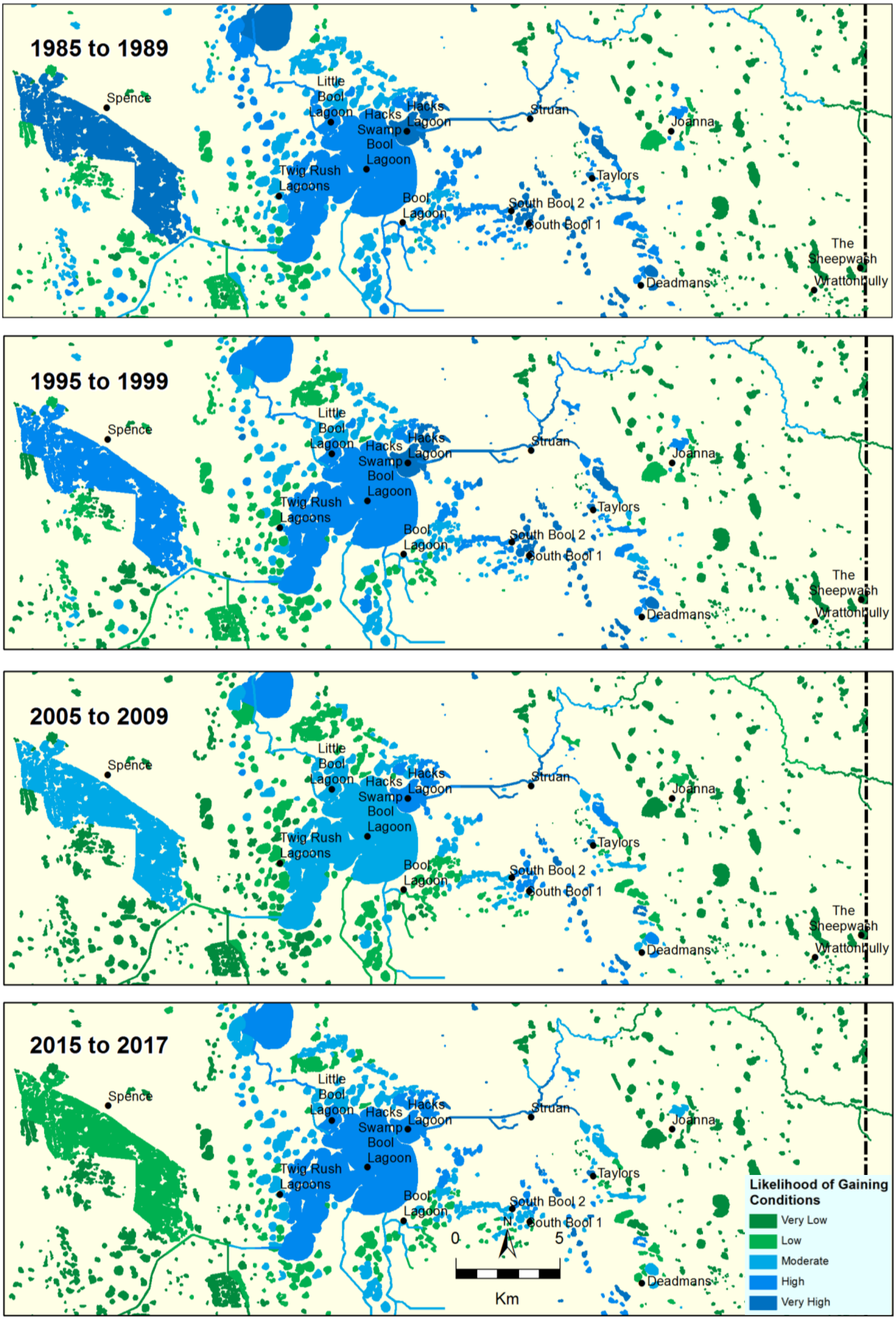

Figure 4.30. Change in GW–SW exchange classification from west of Bool Lagoon to the Border

4.6 Potential for enhancing groundwater recharge

Consistent groundwater recharge is likely to occur from surface water features (if they contain standing or flowing water) where 'low' and 'very low' likelihood of gaining conditions have been identified (i.e. the average groundwater level is >1 m below the feature). Recharge rates could potentially be increased if the residence time of water within these wetlands or drain features can be increased. Additional infrastructure may be needed to implement this as a groundwater management strategy across specific reaches. Importantly however, a detailed assessment of the groundwater salinity distribution and the temporal variability of salinity in the surface water feature would be an important step in establishing whether or not this would be of any particular benefit to groundwater users. Surface water salinity is known to vary depending on how much of the flow is derived from surface runoff and how much is from groundwater discharge. Groundwater salinity within the shallow unconfined aquifer is spatially variable but generally low (i.e. <1500 mg/L) in the areas to the southeast of Kingston and in the Cross-Border Creek Catchments DMU area (DFW, 2012).

The most recent epoch in the analyses of the likelihood of gaining conditions is shown in Figure 4.18. There are areas in the Coles and Short GMAs where drains now have the potential to be losing (i.e. outflow from Bool Lagoon – see Figure 4.30), sections of the Lower Interdunal Watercourses, the Glenelg Plains and Perched Volcanics and the Cross-Border Creek Catchments DMUs. Perhaps the greatest potential for enhanced recharge is in the Cross-Border Creek Catchments DMU where, historically, drainage bores have been used for this purpose for many years. This is likely to have had an influence, however, on reducing the total flow in these creeks before they reach the wetland features on the inter-dunal flats. If planned strategically (i.e. during times of high flows) there may be some benefit in enhanced recharge along these creeks.

Recharge volumes from drains are dependent on the saturated area of the drain, the specific yield and hydraulic conductivity of the drain and underlying sediments, and the hydraulic gradient between the drain water level and the underlying and adjacent watertable. Commonly, these parameters are highly spatially variable and interact dynamically as flow rates through a particular drain reach change. The recharge volumes can be accurately quantified over relatively short reaches when intensively monitored (e.g. Noorduijn *et al*., 2014) or more broadly between gauging stations where they exist along relevant reaches. Estimates of potential recharge volumes have not been included in this study but—based on the work of Noorduijn *et al.* (2014) on the Western Reflows Floodway—recharge rates are likely to range between 0–20 kL/day/km along a reach that is 20 m wide. This is a very low recharge rate compared with the flow rate occurring through the drain at the time of the Noorduijn *et al.* (2014) investigation (~170 ML/day) and is a result of the low hydraulic conductivity of the underlying sediments at this site. Other locations, particularly those that include more sandy sediments or karst features have the potential to lose water at significantly greater rates. For example, the majority of all flow in Tatiara Creek recharges the aquifer through runaway holes (Wood, 2016).

4.7 Implications of climate change

Charles and Fu (2015) have summarized the statistically downscaled climate projections for selected South Australian weather stations in each Natural Resources Management region. These projections were calibrated to rainfall station data with the regional-scale climate forcing simulated by selected global climate models (GCMs) (CSIRO & BoM, 2015). The projected changes of decreasing rainfall and increasing potential evapotranspiration for the South East NRM region are reported as 20-year averages centred around 2030, 2050 and 2070, and compared with the 1986–2005 historical period. The mean annual percent change values based on the intermediate emissions scenario (RCP4.5) and the high emissions scenario (RCP8.5) from the six better-performing GCMs are shown in Table 4.5 and Figure 4.31 (after Charles & Fu, 2015). The largest percentage decreases in average rainfall are seen in spring followed by summer and autumn, with relatively small increases or little change projected for the winter season on average. By 2050, average annual rainfall is projected to decrease by 5.4% in RCP4.5 and 6.6% in RCP8.5, compared with the 1986–2005 baseline.

Table 4.5. South East NRM downscaled projected changes in seasonal rainfall 20-year averages (as a percentage of the 1986–2005 average) from the six better performing GCMs (after Charles & Fu, 2015)

20-year middle	Intermediate emissions RCP4.5				
	Annual	*Summer*	*Autumn*	*Winter*	*Spring*
1995	0	0	0	0	0
2030	-3.5	-7.5	-1.8	4.8	-16
2050	-5.4	-3.6	-3.4	0.7	-17.5
2070	-7.4	-5.5	-5.8	0.3	-21.8
2090	-6.5	-5.6	-5.4	3	-22.8
20-year middle	**High emissions RCP8.5**				
	Annual	*Summer*	*Autumn*	*Winter*	*Spring*
1995	0	0	0	0	0
2030	-4.4	-0.4	-3.3	0.4	-14.4
2050	-6.6	-6.8	-3.4	3.2	-24.2
2070	-11.9	-14	-9.2	-0.7	-30.9
2090	-15.9	-18.3	-12.8	-1.3	-40.3

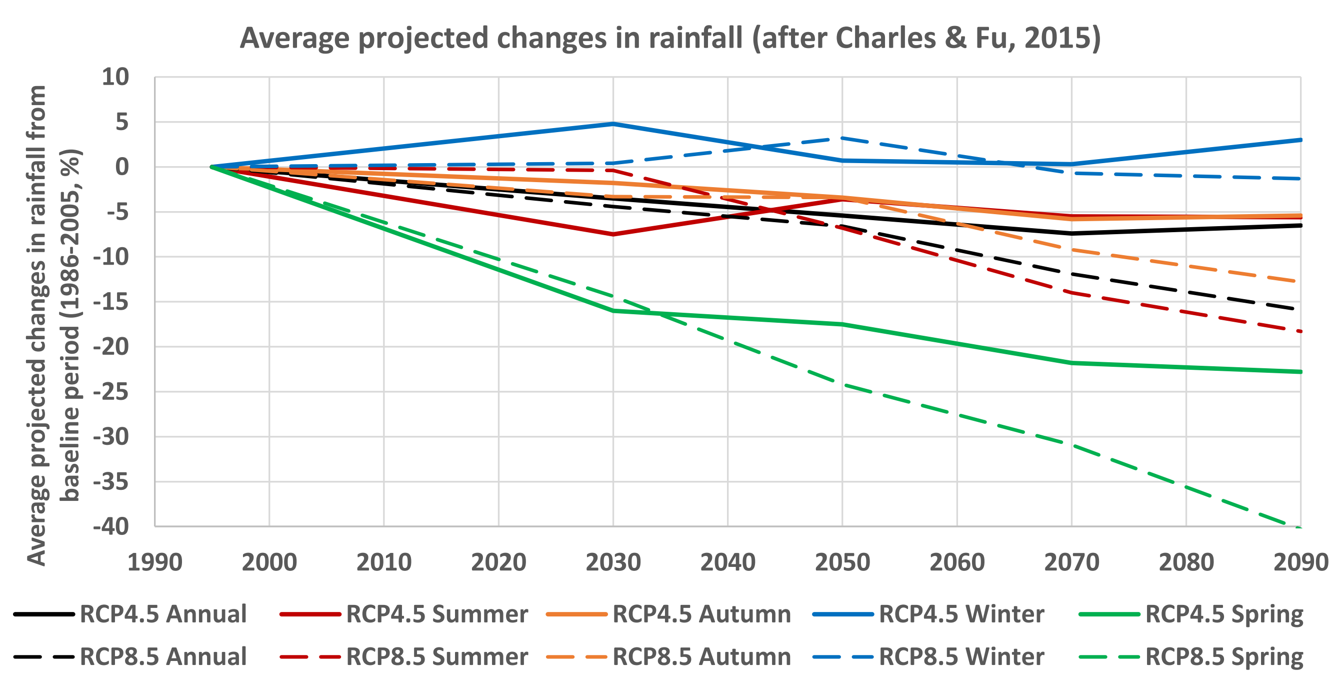

Figure 4.31. South East NRM downscaled projected changes in seasonal rainfall 20-year averages (as a percentage of the 1986–2005 average) from the six better performing GCMs (after Charles & Fu, 2014)

The possible implications of these projected changes in rainfall on groundwater recharge and shallow groundwater levels in the South East have been investigated as part of a number of recent studies. To estimate the likely future groundwater level changes, simple hydrograph regression analyses were performed by Costar *et al.* (2016) and in more detail for a smaller part of the SE by Cranswick (2018). These studies show that in areas which have shown groundwater level declines due to both rainfall variability and groundwater extraction (including plantation forestry), falling water levels are likely to continue, assuming that the land use practices and rates of groundwater extraction are similar to those of the recent past. These studies also show that there are large areas where shallow groundwater level changes are driven primarily by rainfall variability and, due to the projected decline in rainfall, groundwater levels are likely to decline in the future. These studies assume that groundwater level changes are directly proportional to deviation from mean rainfall and, if required, incorporate an additional trend parameter to help match observed groundwater level trends. This linear-regression approach is appropriate as a first-pass assessment, whereas more-detailed recharge studies are required to account for more complex hydrological processes.

For example, groundwater recharge occurs differently across the region depending on the unique combinations of landuse, soil type, rainfall intensity and duration, potential evapotranspiration, irrigation practices and a number of other factors. More detailed studies on the relationship between rainfall and recharge have attempted to quantify this relationship using what is known as a recharge elasticity factor. In an Australian wide study by McCallum *et al.* (2010), the average recharge elasticity factor was 2, meaning for example that a 5% reduction in average rainfall is likely to result in a 10% reduction in average recharge. In the Mount Lofty Ranges, recharge elasticity factors were on average 4.3 (Green *et al.*, 2011) and 2.5 (Alcoe *et al.*, 2014), for the Clare Valley and Cox Creek catchments, respectively.

A GIS-linked version of the one-dimensional soil water and chemical fate and transport model LEACHM (Leaching Estimation and Chemistry Model) (Hutson, 2003) was developed by Morgan *et al.* (2017) for estimating recharge rates in the Upper South East. The authors also investigated the possible influence of climate change on recharge in the Tatiara PWA, using two climate scenarios with three climate data sets used, which were compared with the historical average. Future projections of rainfall for the selected RCP4.5 GCM were 7.8, 5.1 and 4.4 % lower for the 10^{th}, 50^{th} and 90^{th} percentile rainfall datasets, respectively. For the selected RCP8.5 GCM, future rainfall projections were 10.8, 8.2 and 5.2 % lower for the 10^{th}, 50^{th} and 90^{th} percentile rainfall datasets, respectively. These declines are consistent with results of Charles and Fu (2015) that suggest a drying climate over the next 30 years.

The impact of this reduced rainfall on shallow groundwater recharge was calculated by comparing the average historical recharge rates (1985–2006 baseline period) with the average of projected recharge rates. For the RCP4.5 GCM, recharge is estimated to decrease by 16% and 19% for the 10^{th} and 50^{th} percentile rainfall datasets, respectively, and increase by 7% for the 90^{th} percentile rainfall dataset. For the RCP8.5 GCM, recharge is estimated to decrease by 15% and 12% for the 10^{th} and 50^{th} percentile rainfall datasets, respectively, and increase by 1% for the 90^{th} percentile rainfall dataset. Using median rainfall datasets, this suggests that the percent reduction in recharge will be greater than the percent reduction in rainfall by a factor of 1.5–3.7 (i.e. a recharge elasticity factor of 1.5–3.7) over the next 30 years.

Future decreases in rates of groundwater recharge and falling groundwater levels are likely to result in persistent changes to the GW–SW exchange in the South East. The extent of gaining drain reaches will most likely decrease, while the permanence and/or seasonality of individual wetlands is also likely to decline.

4.8 Comparison with previous investigations

4.8.1 Evaluation of approaches to modelling GW–SW exchange around drains in the South East

Harrington *et al.* (2012) use a combination of flow gauging, salinity and Radon-222 (an environmental tracer that can be used to identify groundwater input to surface water features) measurements to describe the GW–SW exchange of selected drain reaches during field campaigns in 2010 and 2011. Qualitative descriptions were given for all drain reaches with uncertainty due to the likely small-scale variation in groundwater salinity and Radon-222 activity which also introduce large errors, amongst other sources of error, into the quantitative assessment. Where salinity of the drain was similar to that of the regional groundwater, the interaction could not be determined but this was supplemented with the interpretation of Radon-222 data which often suggested gaining conditions. The qualitative descriptions represent two snapshots in time (Figures 14 (a) & (b) of Harrington *et al.*, 2012) which were shown to be similar between the two sampling rounds.

When considering both snapshots together, there is general agreement with the analysis completed in this report for the 2010–14 time period. Exceptions include the lower sections of Drain M, Blackford Drain, Mt Hope Drain and a section of Wilmot Drain, which during one or both sampling rounds showed no evidence of gaining conditions in Harrington *et al*. (2012) but were classified as having a 'very high' and 'high' likelihood of gaining conditions in this study. These differences are likely to be due to the temporal variability of the GW–SW exchange (as indicated by the differences in field data between sampling rounds by Harrington *et al*., 2012) in combination with the averaging of groundwater levels across a five-year period which could not be expected to reflect the interaction at the time of sampling in Harrington *et al.* (2012). The field data is expected to be a better representation of the GW–SW exchange at the time of sampling but cannot be applied without significant uncertainty, to different drain reaches or periods of time (i.e. other seasons or years).

4.8.2 Classification of GW–SW exchange for wetlands in the South East

SKM (2009) applied a similar methodology to the current study (creating watertable surfaces and calculating the difference in elevation between the watertable and an intersection with the DEM) with the aim of classifying: potential GW–SW exchange, likelihood of wetland connection with the unconfined aquifer, and groundwater flow regime. This was based on the 15-year average spring and autumn groundwater levels, measured between 1990–2005. This assessment has been used to classify the baseline condition and likelihood of GDEs in the South East since 2009, but results of this study contain considerable uncertainty. The main limitation of SKM's (2009) study is that the watertable surfaces were created using a 15-year average, over a time period where there were groundwater level declines of up to 3 m occurring across some parts of the region. This was somewhat compensated for by using the minimum groundwater level (which perhaps introduces a conservative gaining bias) and deriving the wetland classification scheme through comparison between autumn and spring surfaces (i.e. SKM's Table 8). There could be no assessment of the changes over time using the SKM (2009) assessment which the authors stated as one of the limitations to their scope of works.

To compare the SKM (2009) assessment of wetland GDE dependency we have used the autumn and spring 2017 classifications in a similar way to SKM's Table 8, as shown in Table 4.6 below. There are a number of combinations which are non-intuitive in the bottom-left corner of the table (and would represent a condition where autumn groundwater levels were higher than spring water levels) and if found, can be discounted as erroneous and labelled "*n/a*". The remaining combinations can be used to classify the likely seasonality of groundwater discharge towards wetland and drain features. Four generalised groupings have been defined to include: 'permanent", "seasonal", 'occasional' and 'unlikely' in terms of the likely seasonality of receiving groundwater discharge.

Table 4.6. Likely seasonality of groundwater discharge classification scheme using autumn and spring 2017 watertable surfaces

Spring 2017 mean elevation difference (GW–SW, m)	**Autumn 2017 mean elevation difference (GW–SW, m)**				
	> 1	*1 to 0*	*0 to -1*	*-1 to -2*	*< -2*
> 1	Permanent	Permanent	Permanent	Seasonal	Seasonal
1 to 0	*n/a*	Permanent	Seasonal	Seasonal	Seasonal
0 to -1	*n/a*	*n/a*	Seasonal	Occasional	Occasional
-1 to -2	*n/a*	*n/a*	*n/a*	Occasional	Unlikely
< -2	*n/a*	*n/a*	*n/a*	*n/a*	Unlikely

The number of wetlands for each combination are shown in Table 4.7. The three combinations in the top-right corner for wetlands suggest that autumn groundwater levels are >2 m below spring levels. This may occur in exceptional circumstances (i.e. groundwater surface influenced by point recharge) or where groundwater extraction is having a large influence on the groundwater surface and may warrant more detailed investigation. The category with the largest number of combinations (9465 counts) is located in the bottom-right and represents the numerous perched wetlands that are primarily found in the Glenelg Plain and Perched Volcanics DMU. Other classifications are distributed relatively evenly between the other three categories with 'permanent', 'seasonal' and 'occasional' classifications for 2656, 2816 and 2298 wetlands, respectively. The spatial distribution of these is shown in Figure 4.32.

Table 4.7. Likely seasonality of groundwater discharge into wetlands using autumn and spring 2017 watertable surfaces

Spring 2017 mean elevation difference (GW–SW, m)	Autumn 2017 mean elevation difference (GW–SW, m)				
	> 1	*1 to 0*	*0 to -1*	*-1 to -2*	*< -2*
> 1	1132	835	158	*14*	*4*
1 to 0	*2*	531	1696	379	*38*
0 to -1	*0*	*4*	685	1476	610
-1 to -2	*0*	*0*	*1*	212	1298
< -2	*0*	*0*	*0*	*1*	8167

The number of drain segments for each category are summarised in Table 4.8 and shown spatially in Figure 4.33. The majority of these are likely to be receiving permanent groundwater discharge (1143 segments) while there are a large number of drains that receive seasonal (543), occasional (209) and also are unlikely to receive groundwater discharge (139). The 348 drain segments with occasional and unlikely classifications represent reaches where the drains were likely to be consistently losing water (if they were flowing) to the groundwater system in 2017.

Table 4.8. Likely seasonality of groundwater discharge into drains using autumn and spring 2017 watertable surfaces

Spring 2017 mean elevation difference (GW–SW, m)	Autumn 2017 mean elevation difference (GW–SW, m)				
	> 1	*1 to 0*	*0 to -1*	*-1 to -2*	*< -2*
> 1	676	277	58	*0*	*0*
1 to 0	*0*	132	314	38	*0*
0 to -1	*0*	*0*	101	174	23
-1 to -2	*0*	*0*	*0*	12	59
< -2	*0*	*0*	*0*	*0*	80

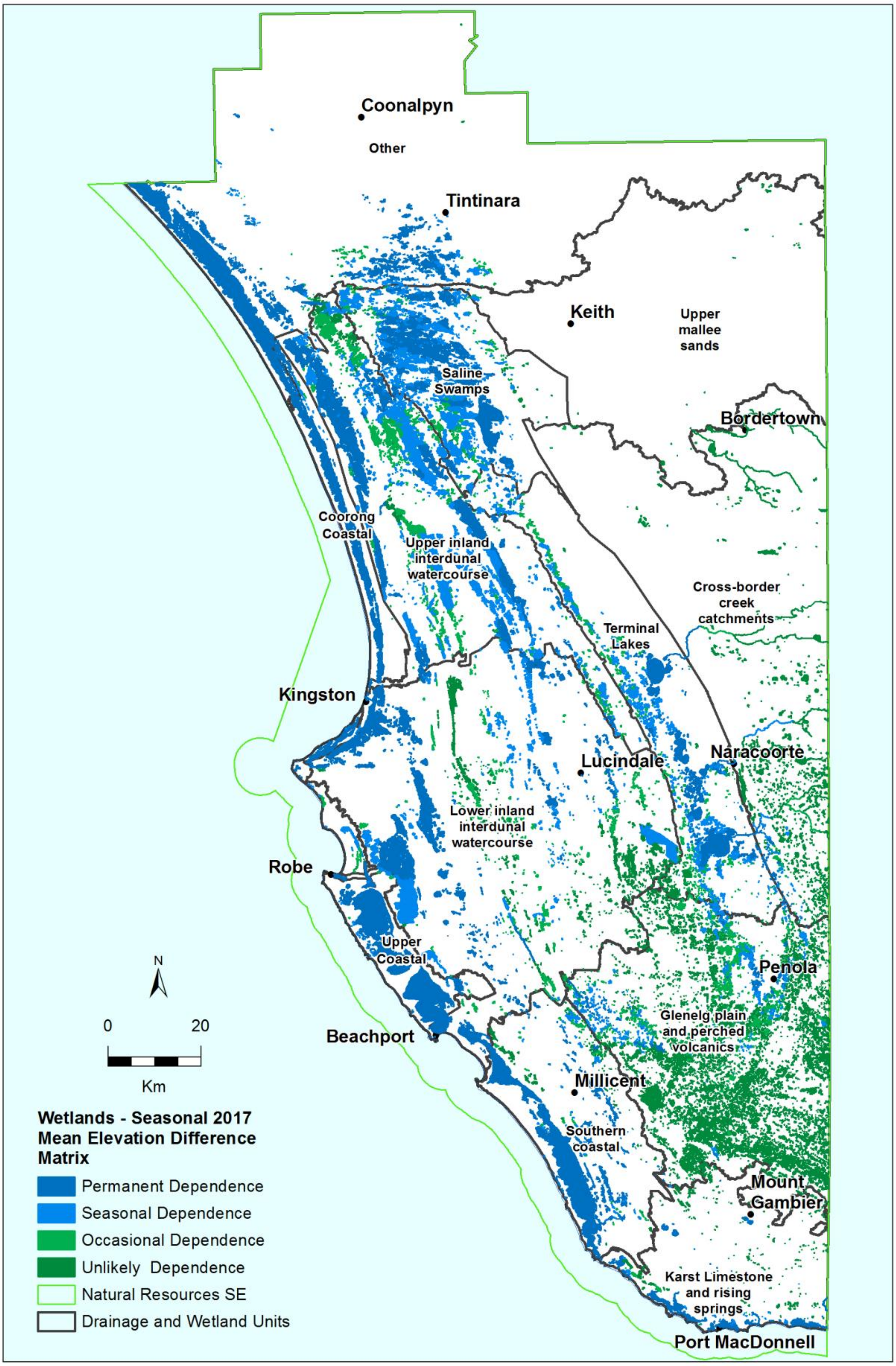

Figure 4.32. Likely seasonality of groundwater discharge into wetlands using autumn and spring 2017 surfaces

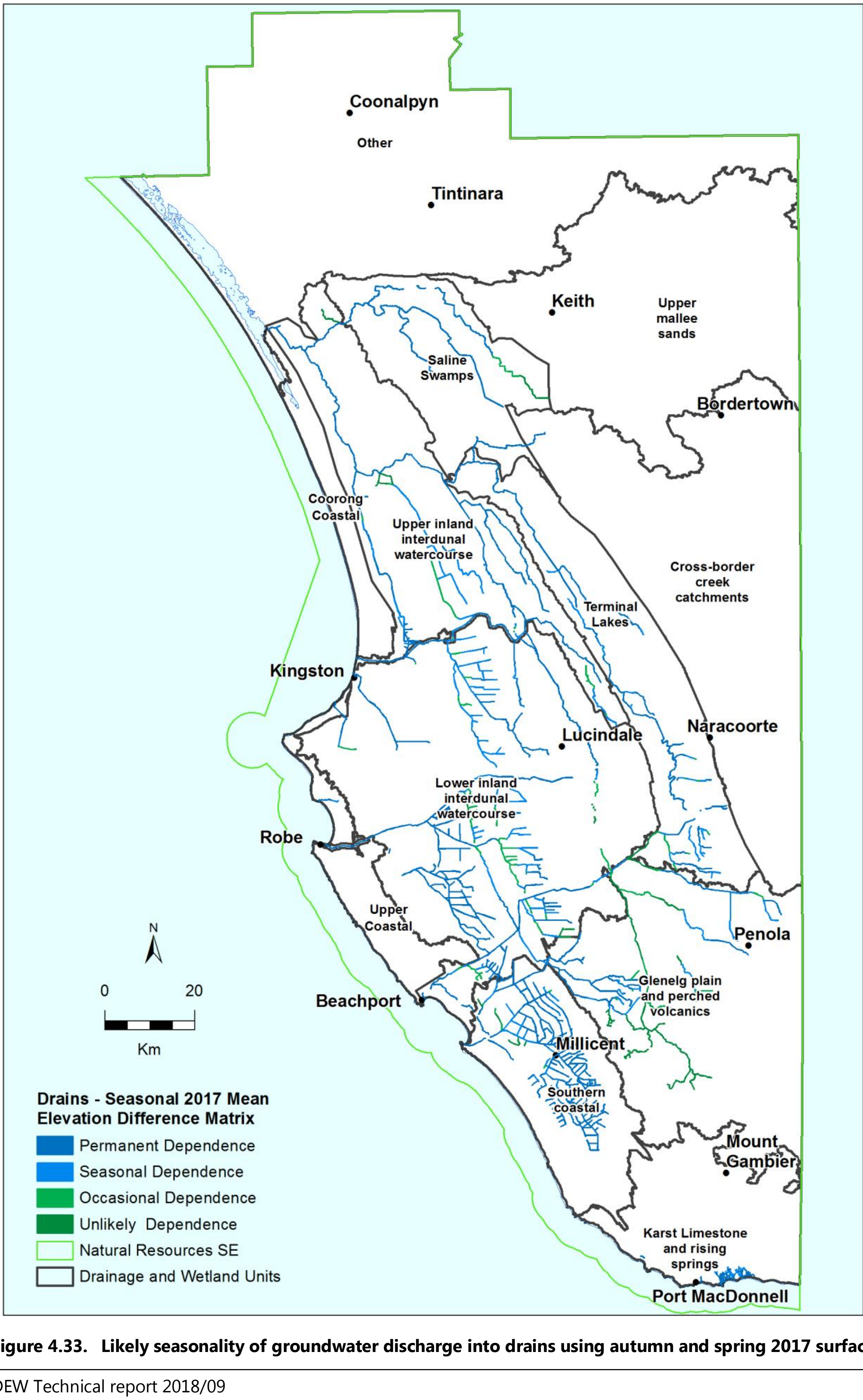

Figure 4.33. Likely seasonality of groundwater discharge into drains using autumn and spring 2017 surfaces

5 Conclusions and recommendations

5.1 Conclusions

The widespread declines in groundwater levels across parts of the South East NRM region over the past 30 years have led to changes in the way groundwater interacts with surface water features. This project has assessed the likelihood of gaining conditions for each wetland, drain and watercourse feature for a number of representative time periods. This was done by first developing a series of watertable surfaces using (1) intervals of five-year average groundwater levels from 1985 to the end of 2014 and an additional period from 2015 to the end of 2017, and (2) the autumn and spring seasons of 2017. These watertable surfaces were compared with the minimum surface water levels based on the 2 m LiDAR digital elevation model to classify the likelihood of gaining conditions for each surface water feature (and for each watertable surface created) as either very high, high, moderate, low or very low. This assessment allows changes through time to be assessed on both site-specific and regional scales, to inform a range of future water planning and management decisions.

Environmental consultants, SKM, employed a similar but temporally-coarser approach by using a 15-year average period for spring and autumn data to derive a classification scheme that describes the likelihood of gaining conditions (SKM, 2009). SKM's approach is subject to greater uncertainty than the shorter time periods used in the current project (i.e. any large changes in groundwater levels over this 15-year period are not resolved unless shorter time periods are used). Nevertheless, there is also considerable uncertainty and potential error within this current assessment due to the reduction in monitoring frequency and number of wells within the observation network over time, which reduces the accuracy of the watertable surface interpolation. Additionally, using yearly averaged groundwater levels masks the seasonal variability that the watertable often exhibits which is however captured by the spring and autumn 2017 analysis. Thus the results presented here are best used to show the relative changes for site specific features, or summarised at the regional scale, and are conservatively accurate to within ±1 m (i.e. ± one likelihood classification).

Results show that the greatest reduction in the likelihood of gaining condition classifications has occurred along the boundary between the Cross-Border Creek Catchments Drainage Management Unit (DMU) and the DMUs on the low-lying flats (see Figure 1.1), in addition to areas that are now under plantation forest. Many other DMUs have shown a decline in the likelihood of gaining condition classifications after the early-1990s and then a recovery in more recent five-year periods, but few show a full recovery to a 'very high' likelihood of gaining conditions. A number of DMUs have transitioned from being dominated by gaining condition classifications in the earlier five-year periods (i.e. late-1980s to 1990s) to more recently being dominated by losing conditions.

There are areas where there is potential for enhancing recharge using the drainage network, however the salinity of both surface and groundwater sources should first be better described to ensure a benefit to groundwater users. It should be noted that the wetlands that interact with perched watertables are not assessed in detail within this report due to the lack of continuous observation datasets and limitations in spatial data coverage. These wetlands should be investigated separately to the analysis shown in this report, which pertains primarily to features interacting to the regional unconfined aquifer.

5.2 Recommendations

It is recommended that the classifications for the likelihood of gaining conditions and their characterisation of wetlands and drain networks be considered for use as a revised baseline in the South East region (i.e. updating the earlier assessment completed by SKM (2009)). The 2015–17 period could be used to represent recent average conditions, while the autumn and spring 2017 classifications could be used to inform the likely seasonality of the interaction between the groundwater and surface water features. These could be incorporated into any future assessments of groundwater dependent ecosystems (GDEs) and their environmental water requirements, within the context of the changes that have occurred in the past 30 years, but using the most up-to-date information.

6 Appendices

A. Watertable surfaces

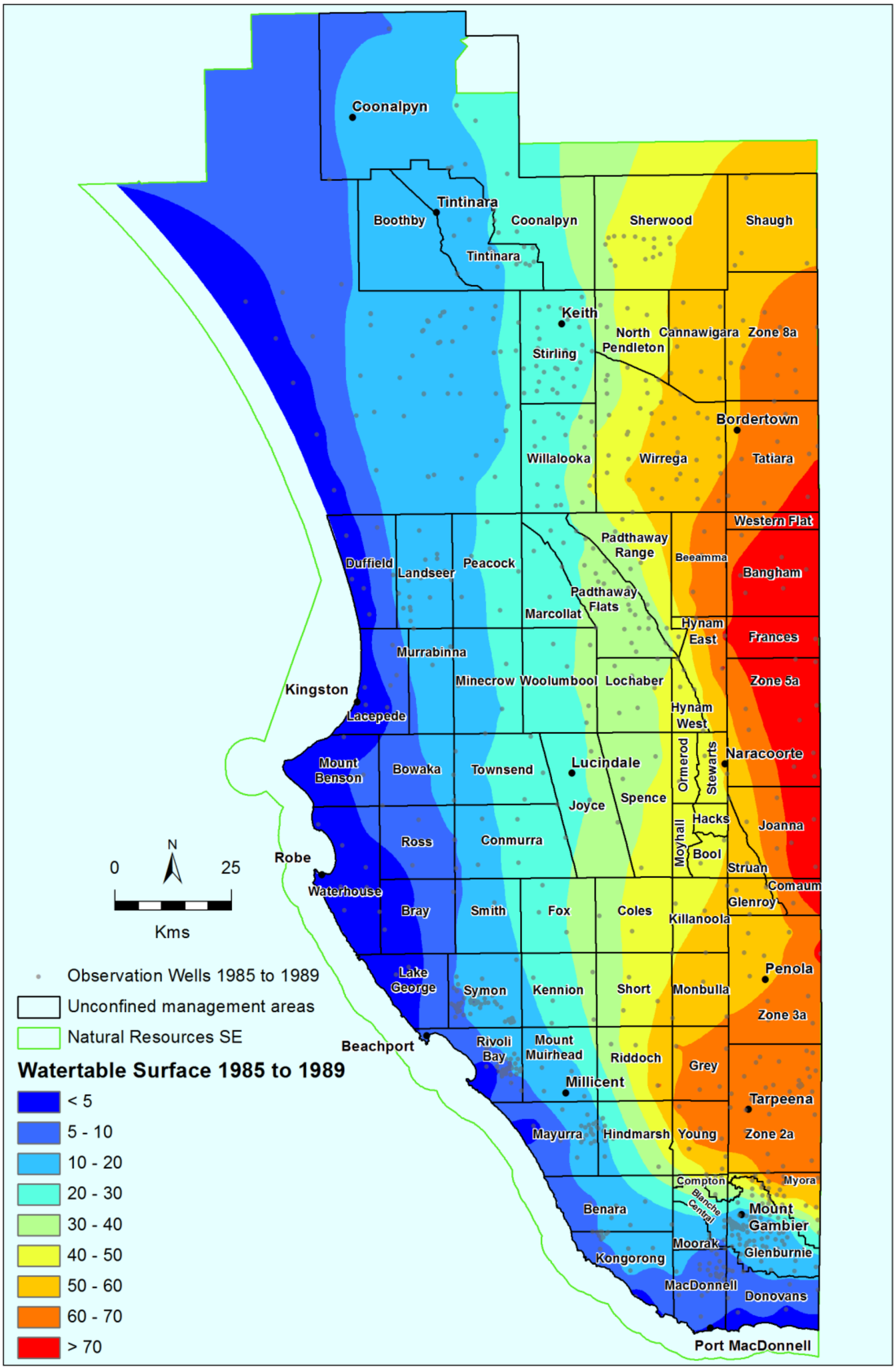

Figure 6.1. Watertable surface for the average period 1985–89

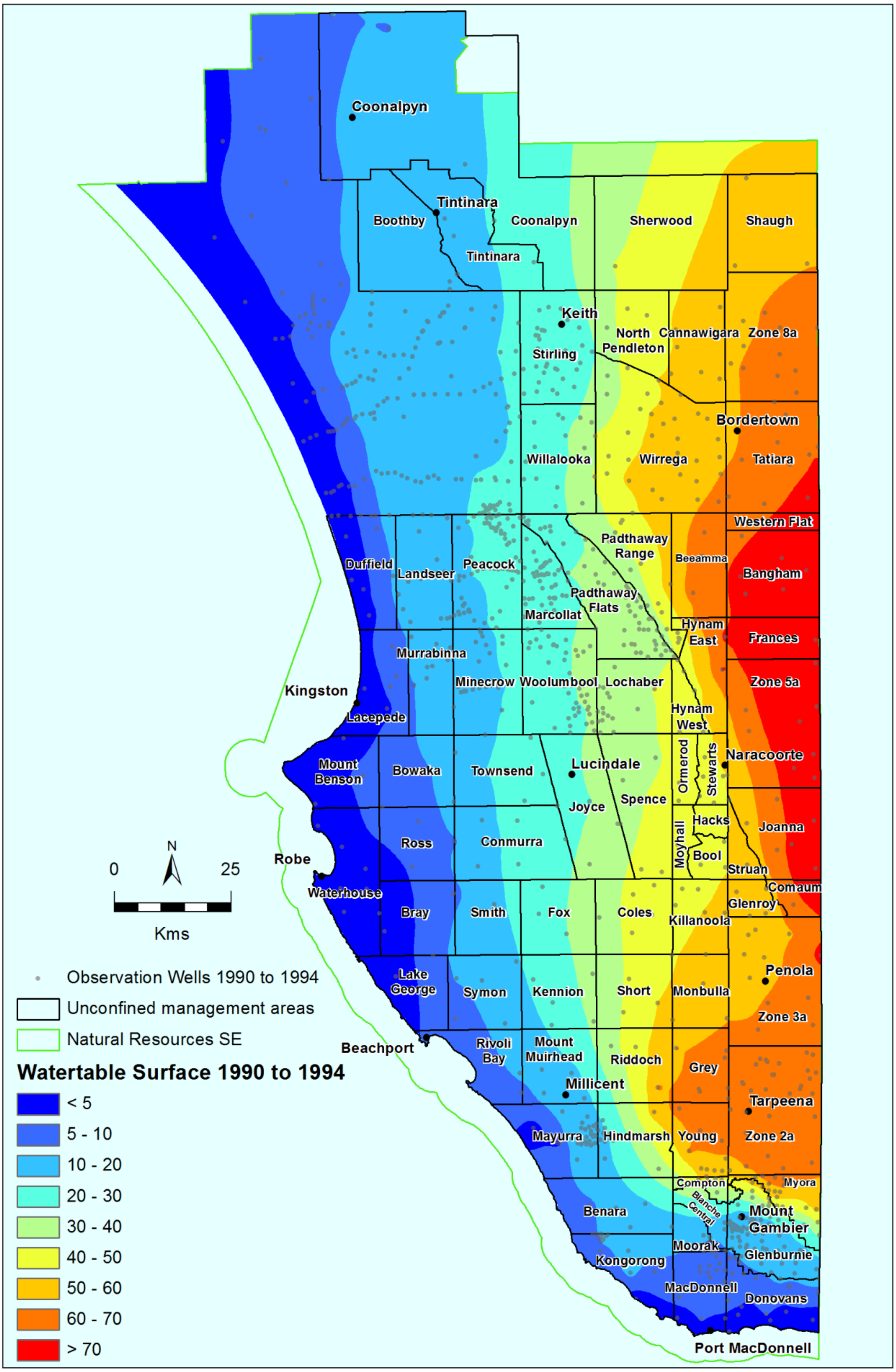

Figure 6.2. Watertable surface for the average period 1990–94

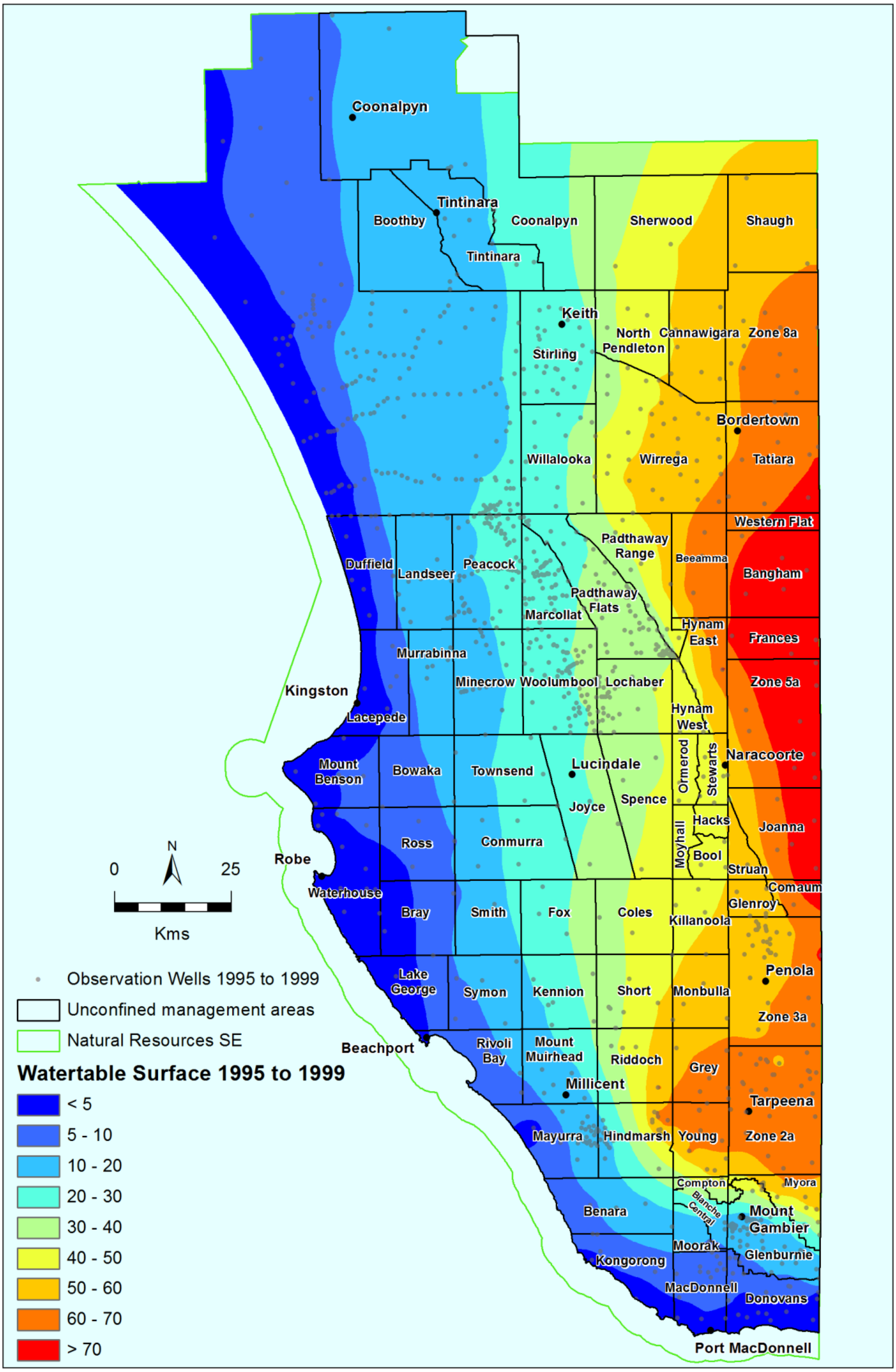

Figure 6.3. Watertable surface for the average period 1995–99

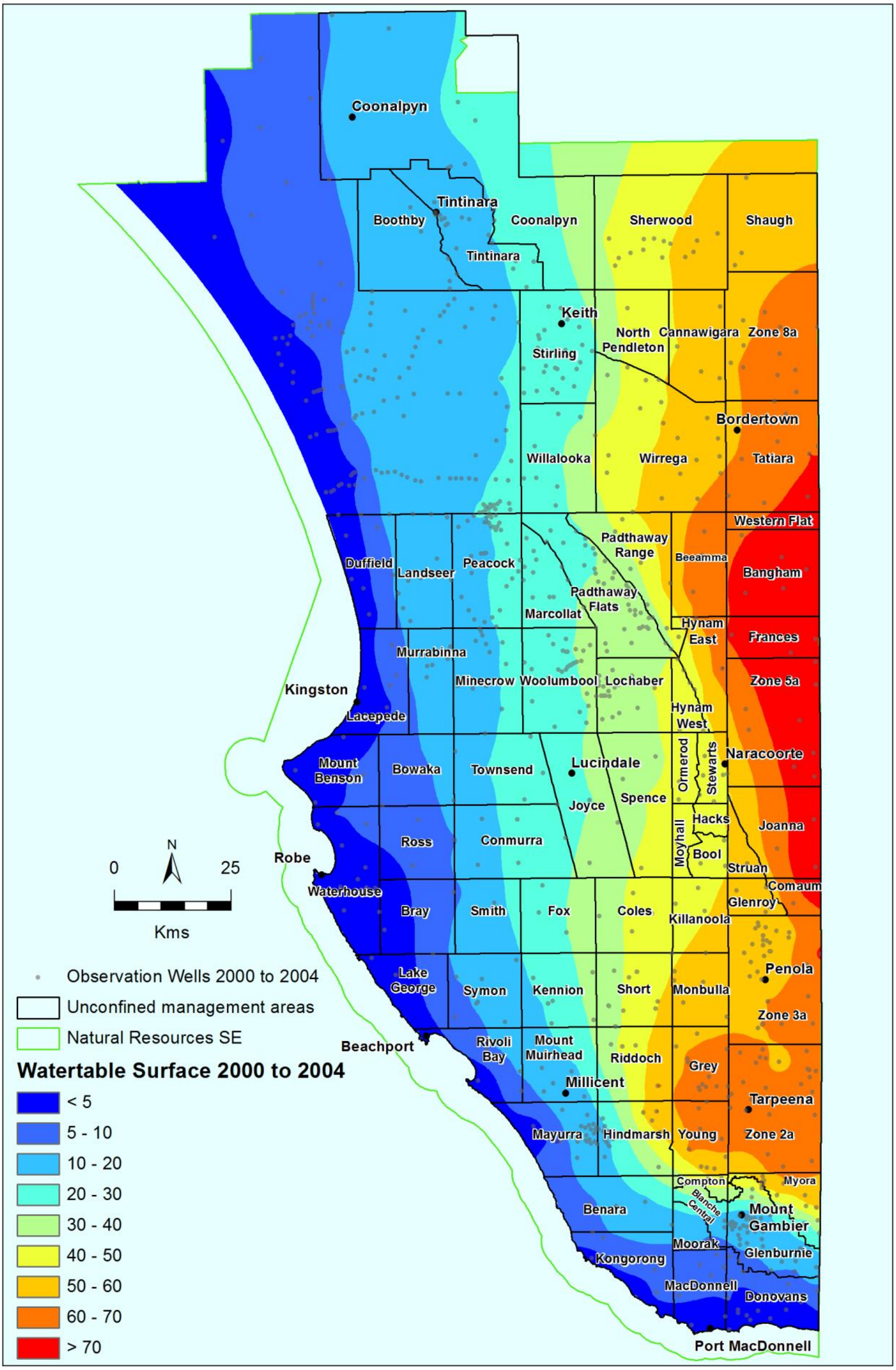

Figure 6.4. Watertable surface for the average period 2000–04

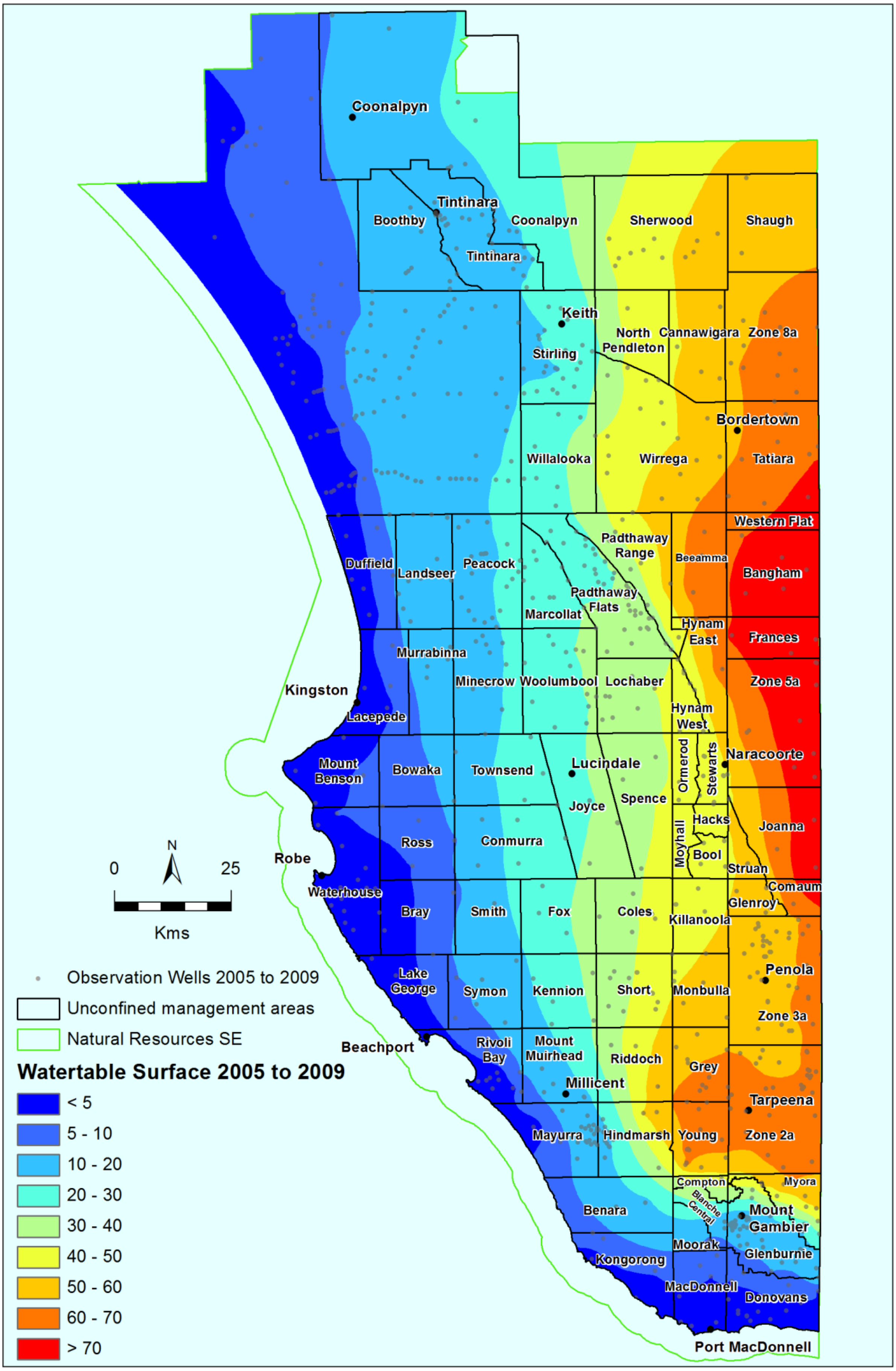

Figure 6.5. Watertable surface for the average period 2005–09

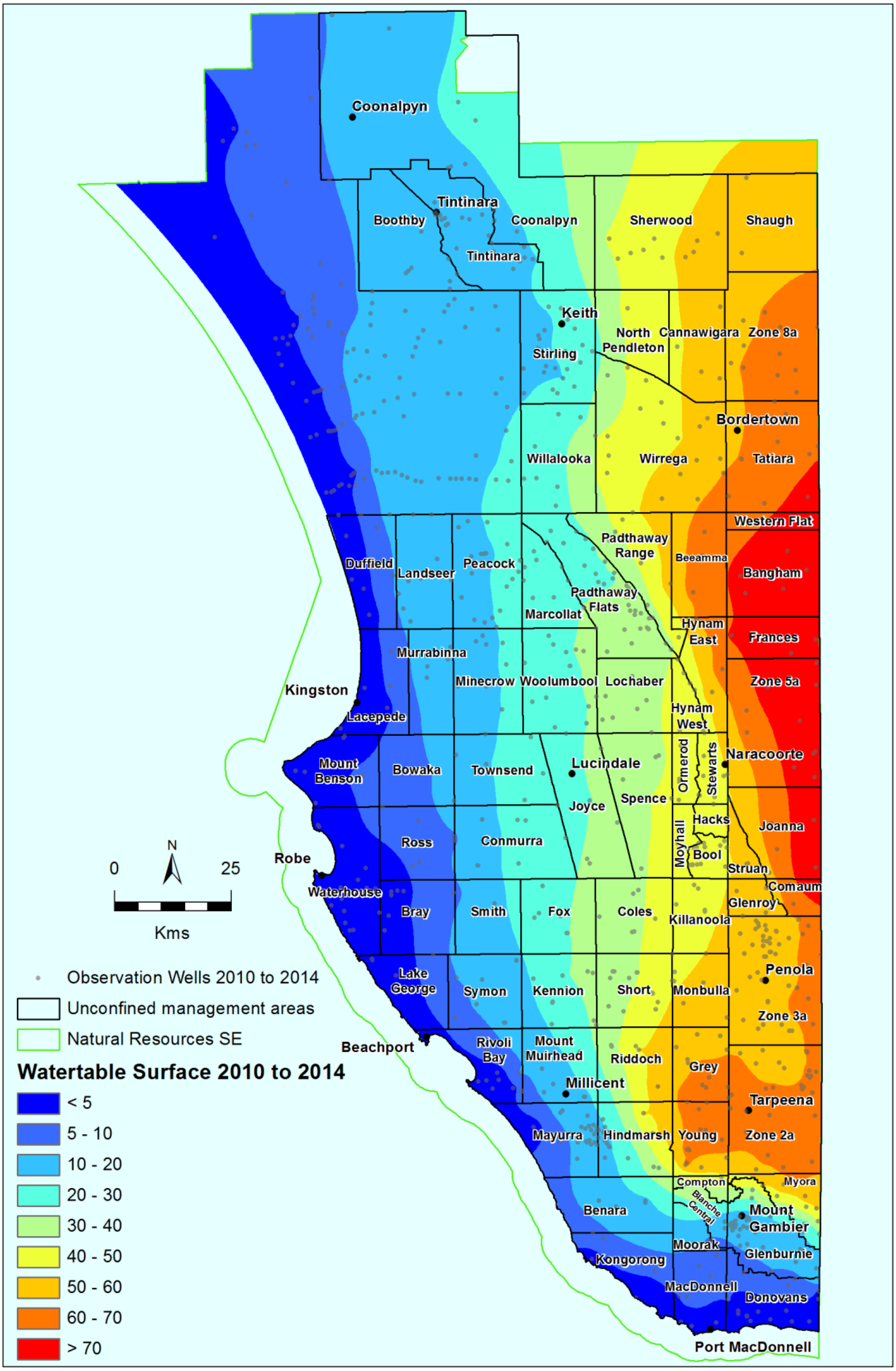

Figure 6.6. Watertable surface for the average period 2010–14

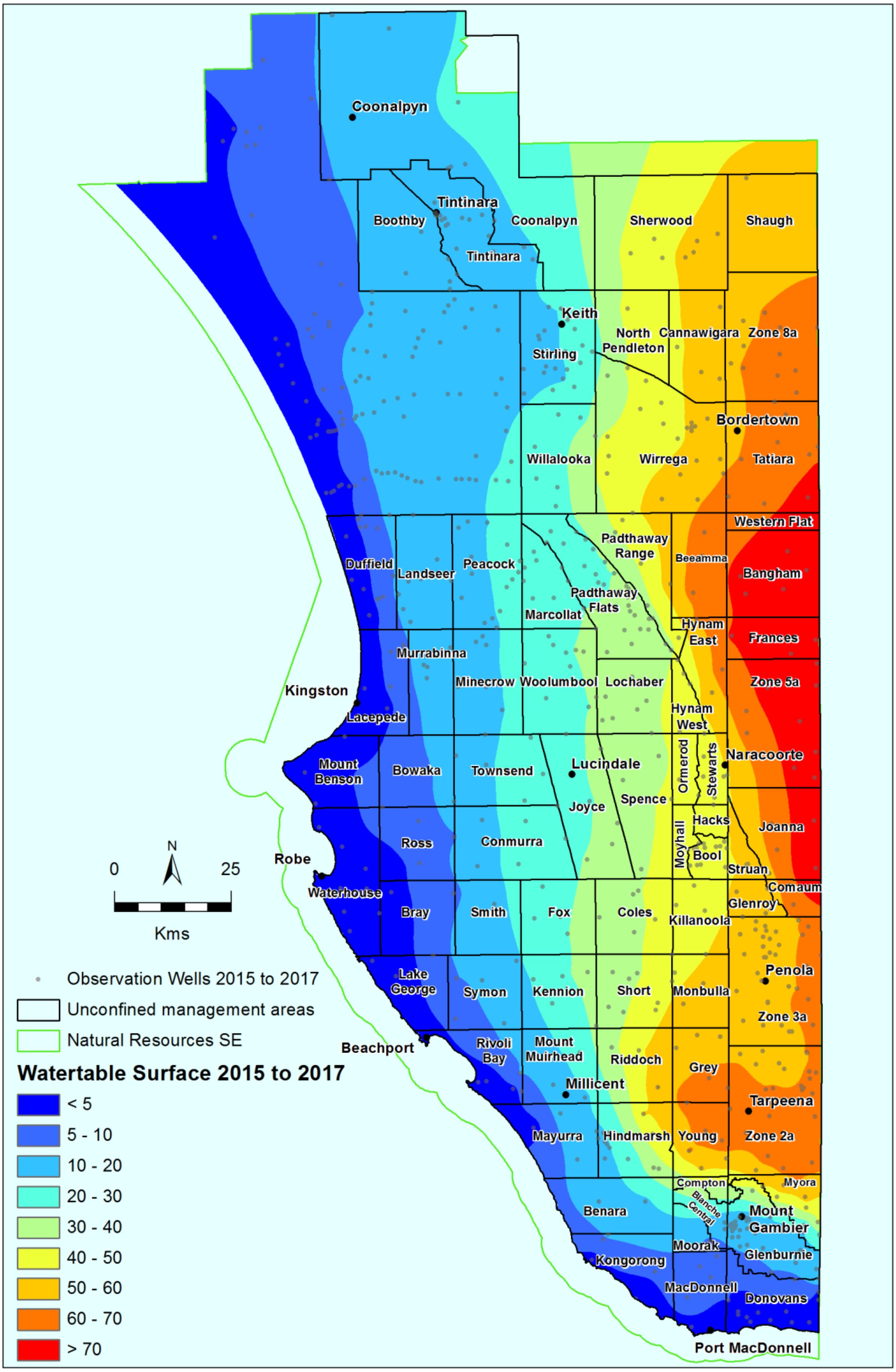

Figure 6.7. Watertable surface for the average period 2015–17

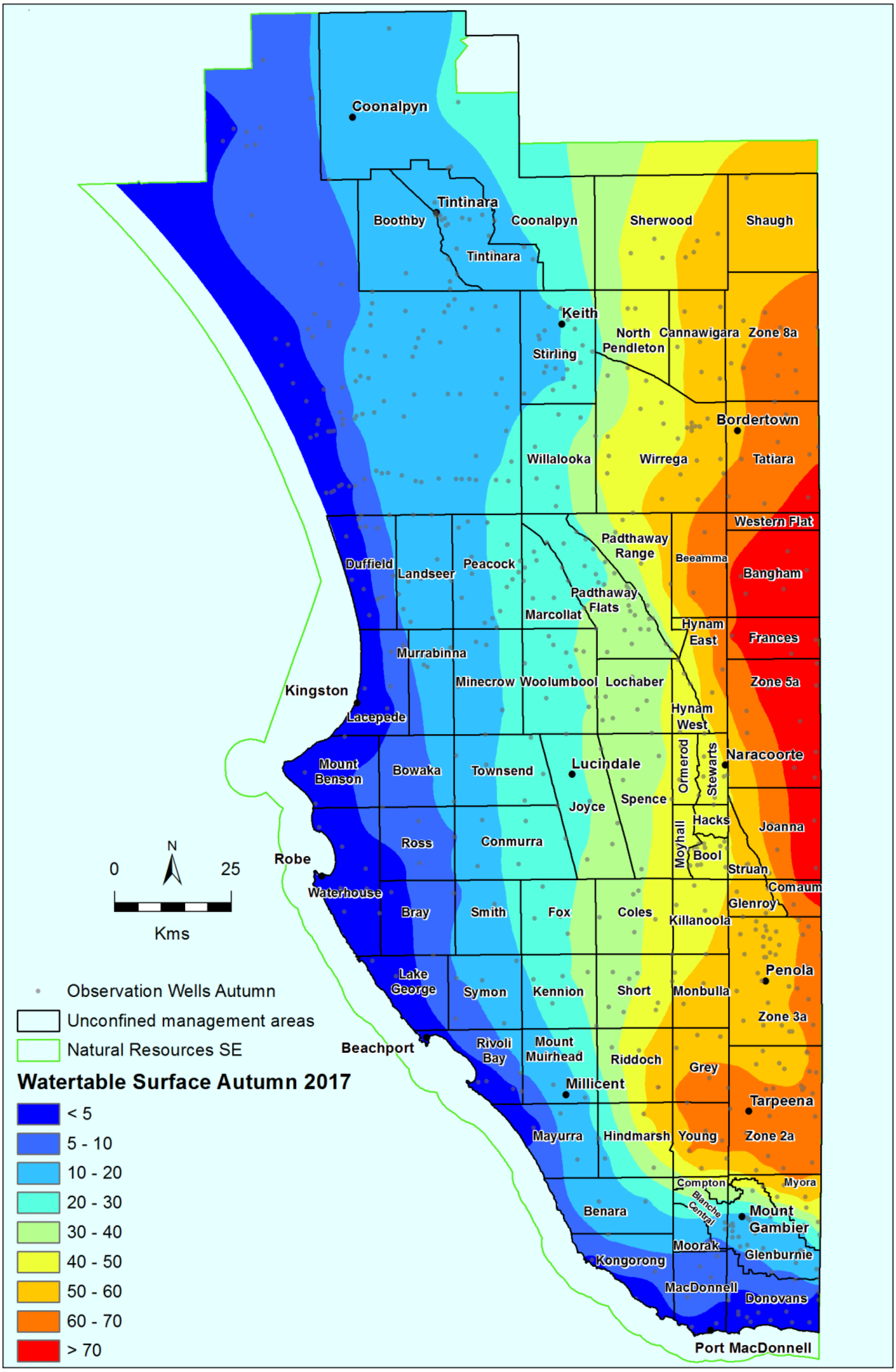

Figure 6.8. Watertable surface for the autumn of 2017

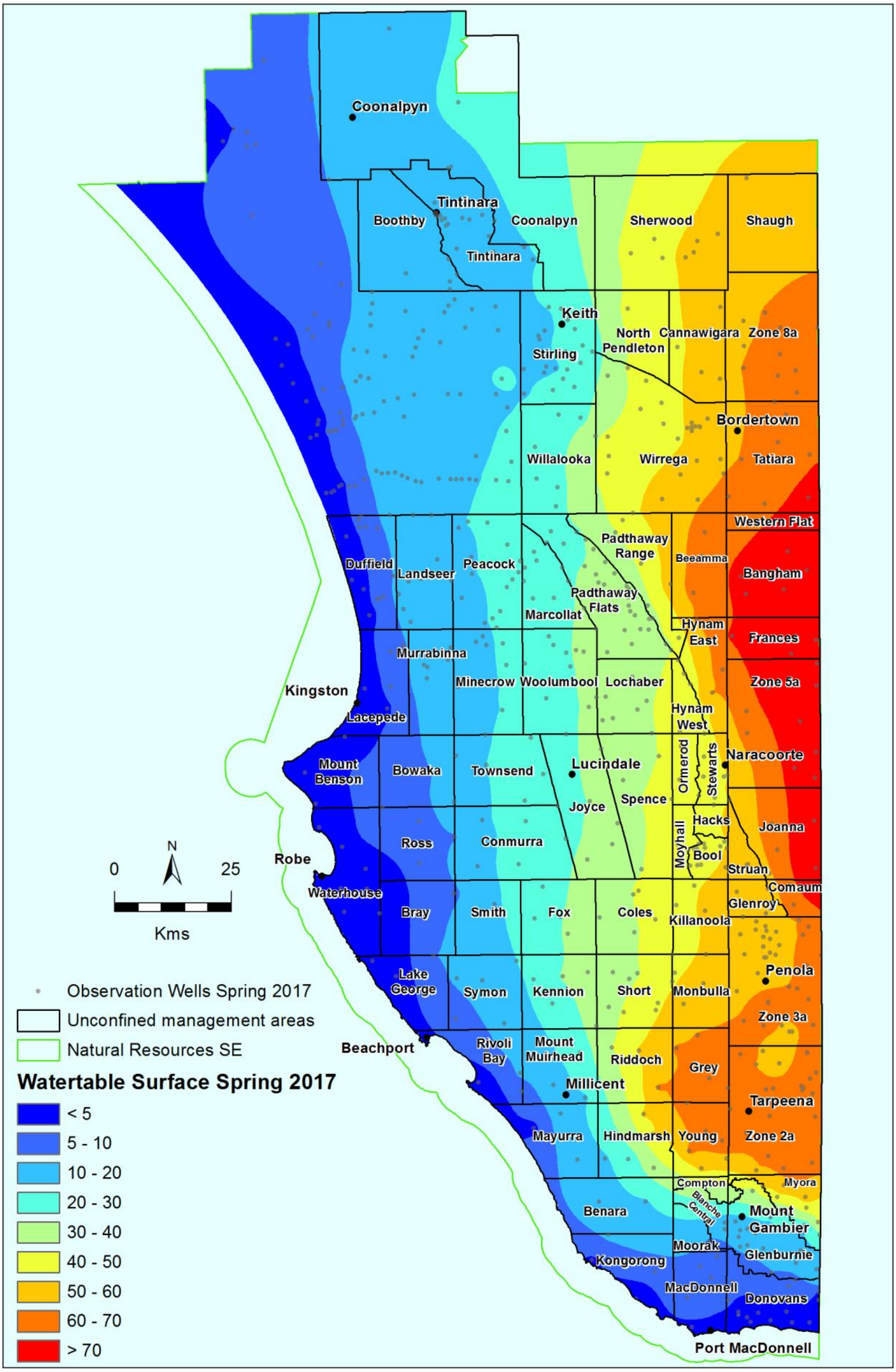

Figure 6.9. Watertable surface for the spring of 2017

The following is a list of wells that were excluded from the watertable surface development based on the criteria described in Section 3.2 and/or upon hydrogeological assessment on a case by case basis.

682300374, 682300398, 682300536, 682300949, 682300977, 682301140, 682301414, 682301443, 682301529, 682301585, 682400016, 682400024, 682400026, 682400085, 682400222, 682400238, 682400252, 682400406, 682400804, 682401072, 682401074, 682401076, 682401126, 682401180, 682401252, 682401549, 682401720, 682401918, 682402255, 682500448, 682500547, 682500557, 682500645, 682600031, 682600037, 682600056, 682600058, 682600130, 682601012, 682601068, 682601103, 682601129, 682601137, 682601138, 682601144, 682601145, 682601168, 682601180, 682601221, 682601230, 682601231, 682601233, 682601242, 682601247, 682601252, 682601255, 682601284, 682601294, 682601299, 682601309, 682601319, 682601320, 682601335, 682601408, 692200004, 692200037, 692200039, 692200058, 692200165, 692200167, 692200400, 692200401, 692200516, 692200520, 692200537, 692200911, 692201042, 692201076, 692201129, 692201156, 692201172, 692201267, 692201268, 692201300, 692201306, 692201308, 692201309, 692201320, 692201372, 692201373, 692201376, 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B. Hydrographs for 12 GDE wetlands (WOfS) with nearby observation wells

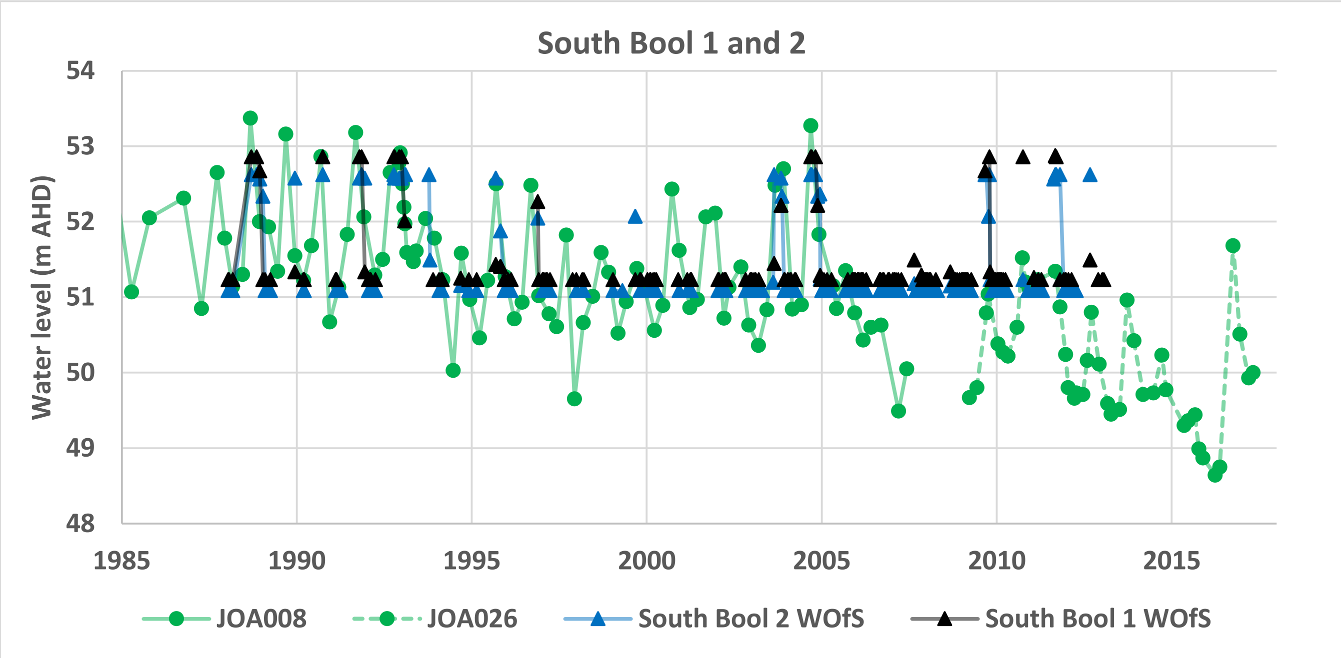


Figure 6.10. Hydrographs for South Bool 1 and 2 with observation wells JOA008 and JOA026

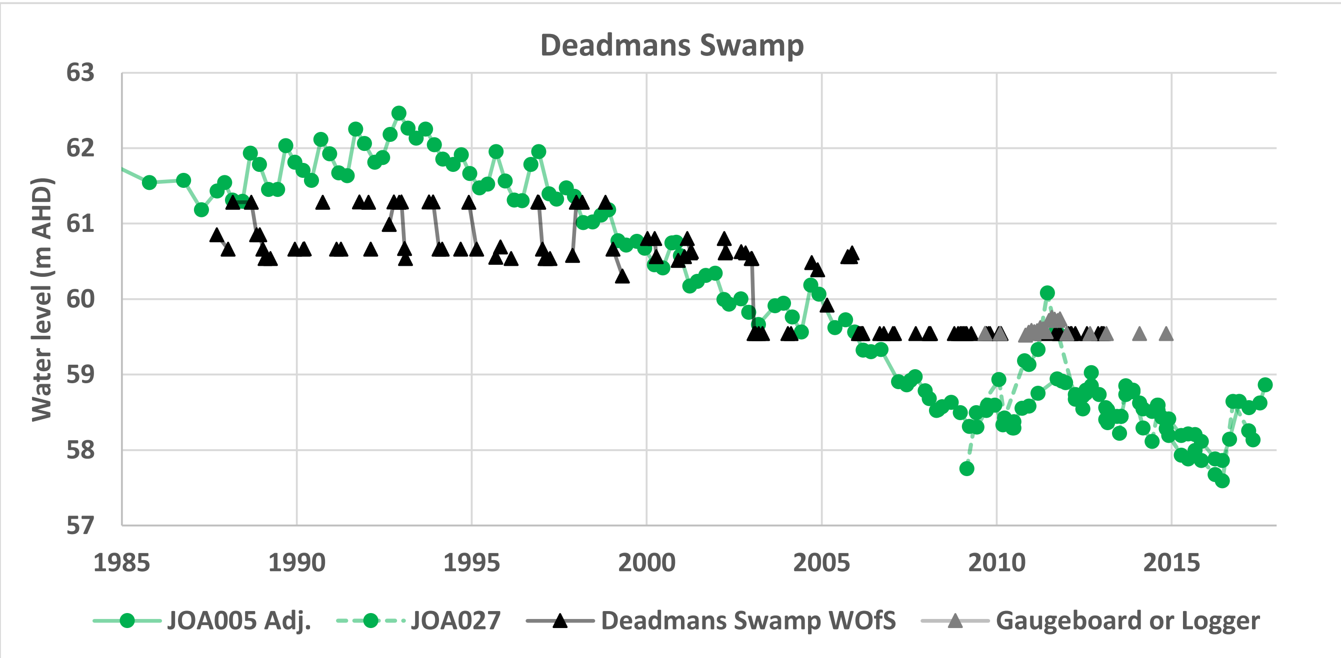


Figure 6.11. Hydrographs for Deadmans Swamp with observation wells JOA005 (adjusted -6.574 m) and JOA027

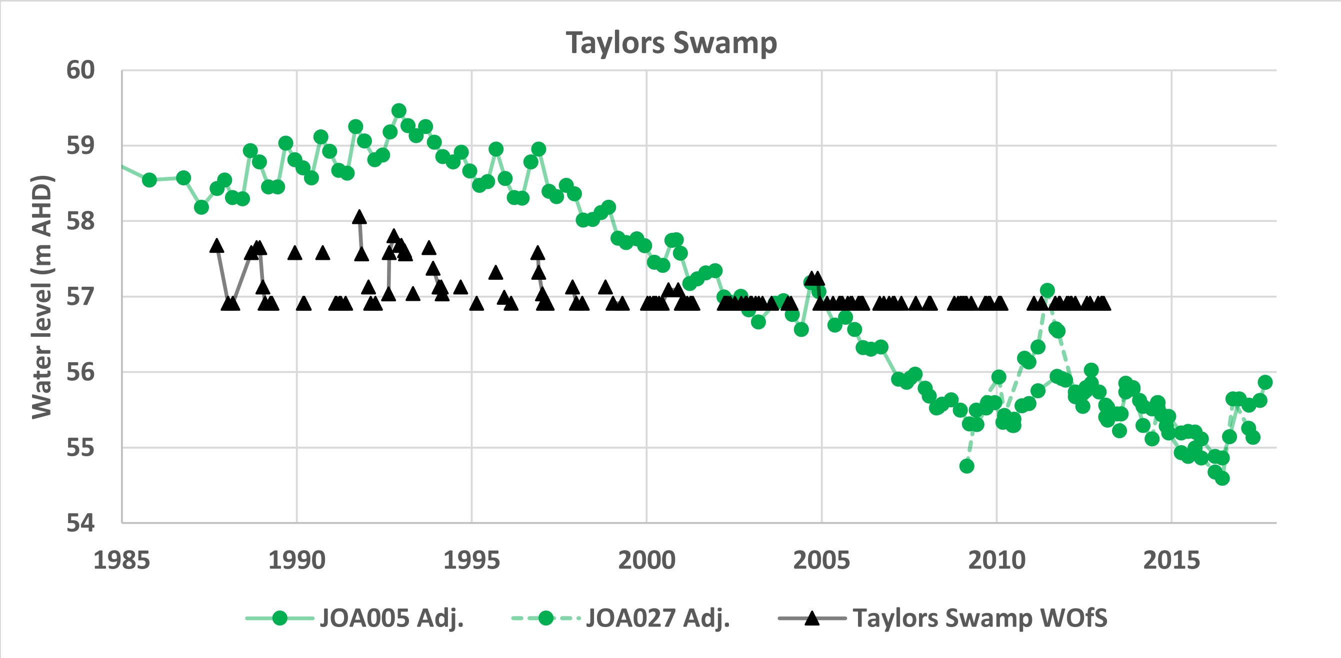


Figure 6.12. Hydrographs for Taylors Swamp with observation wells JOA005 (adjusted -9.574 m) and JOA027 (adjusted -3 m)

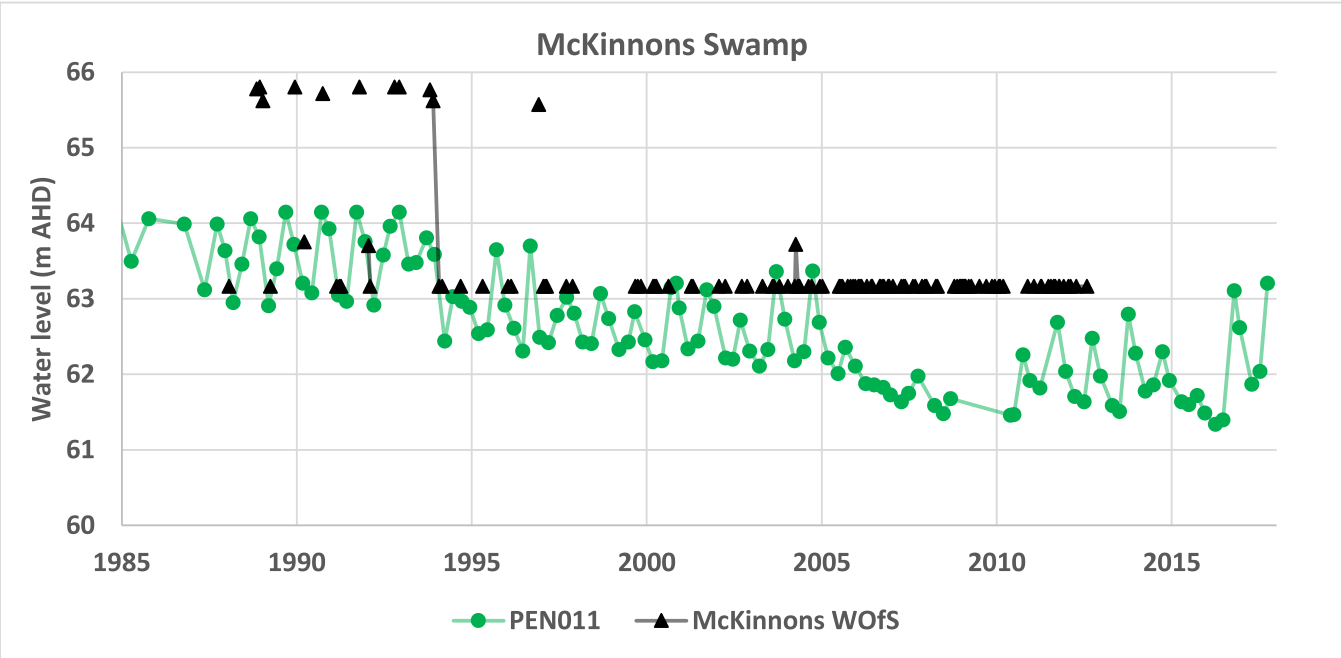


Figure 6.13. Hydrographs for McKinnons Swamp with observation well PEN011

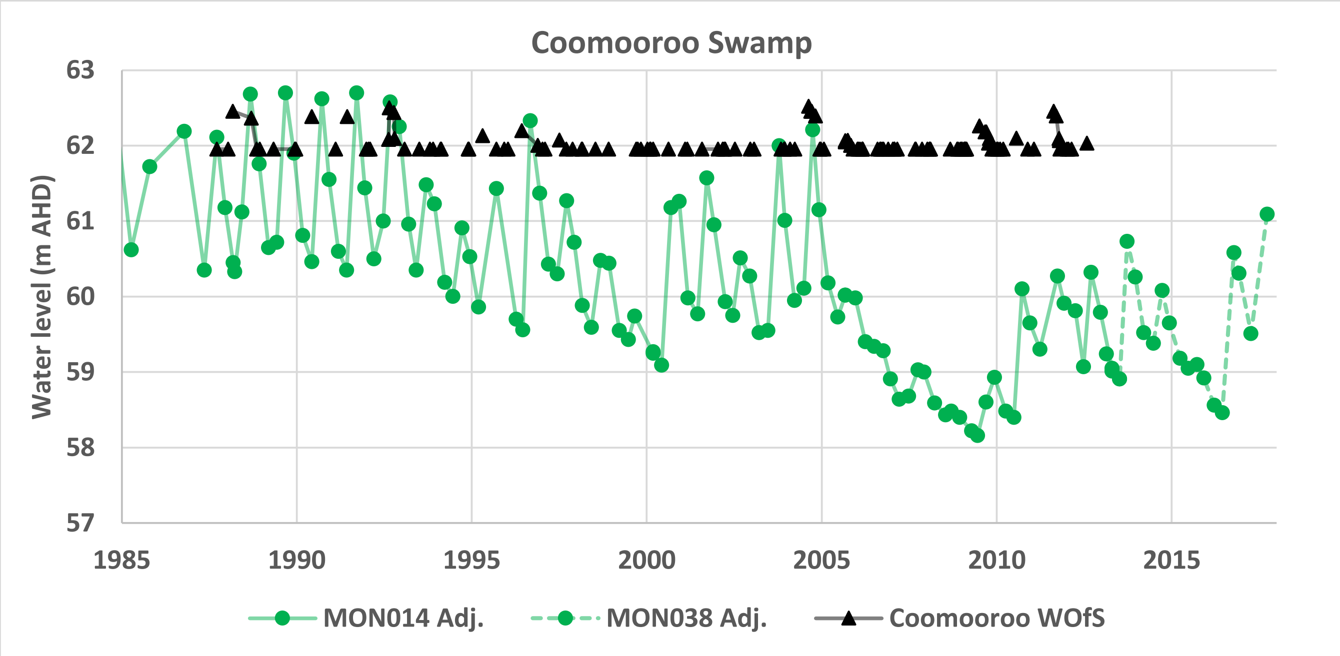


Figure 6.14. Hydrographs for Coomooroo Swamp with observation wells MON014 (adjusted 0.35 m) and MON038 (adjusted 0.8 m)

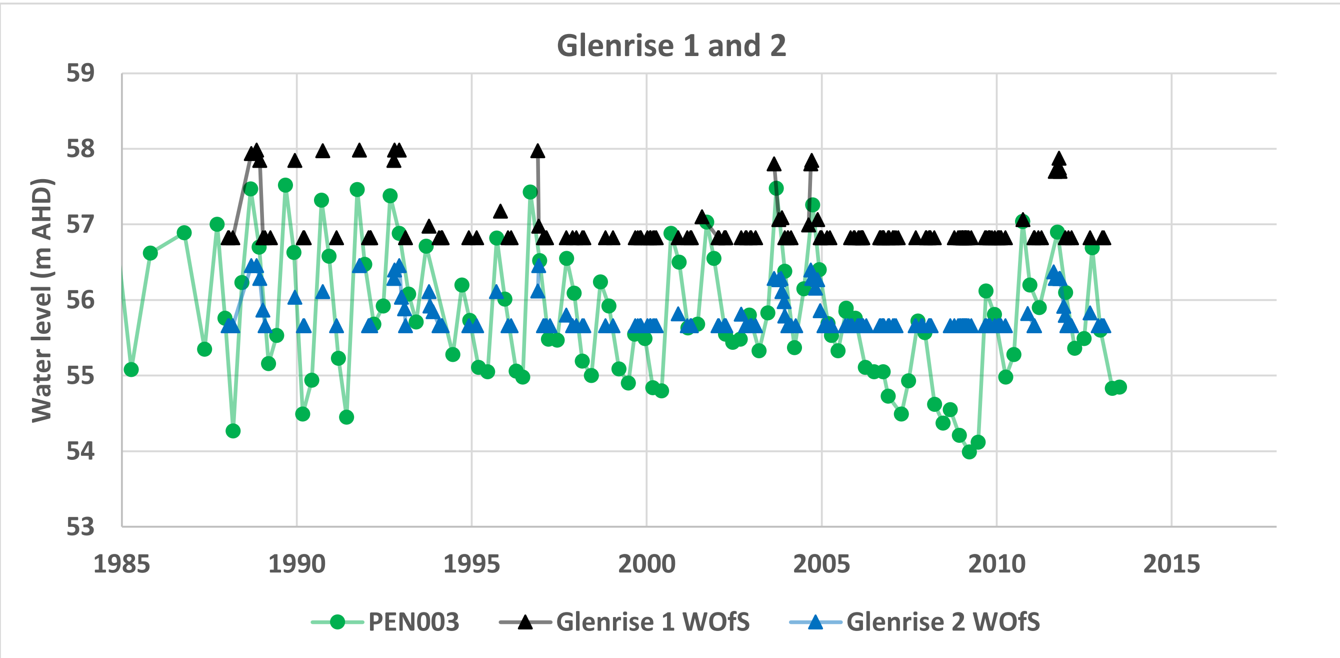


Figure 6.15. Hydrographs for Glenrise 1 and 2 with observation well PEN003

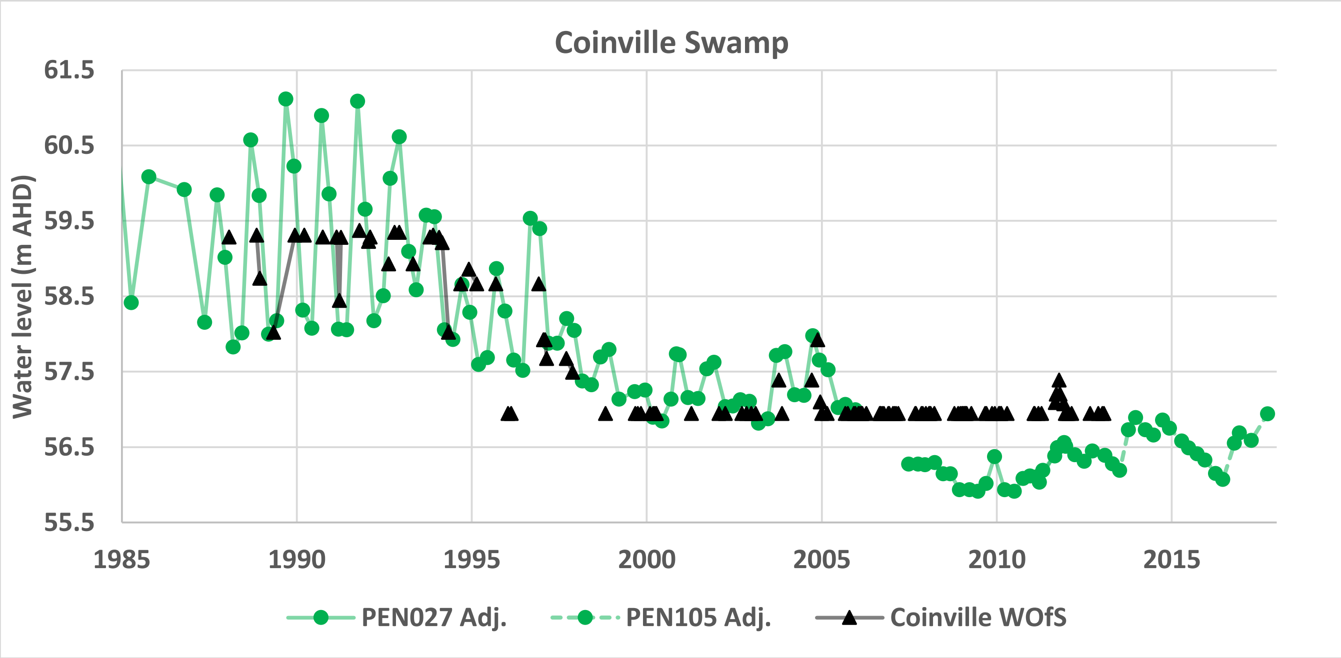


Figure 6.16. Hydrographs for Coinville Swamp with observation wells PEN027 (adjusted -2 m) and PEN105 (adjusted -2 m)

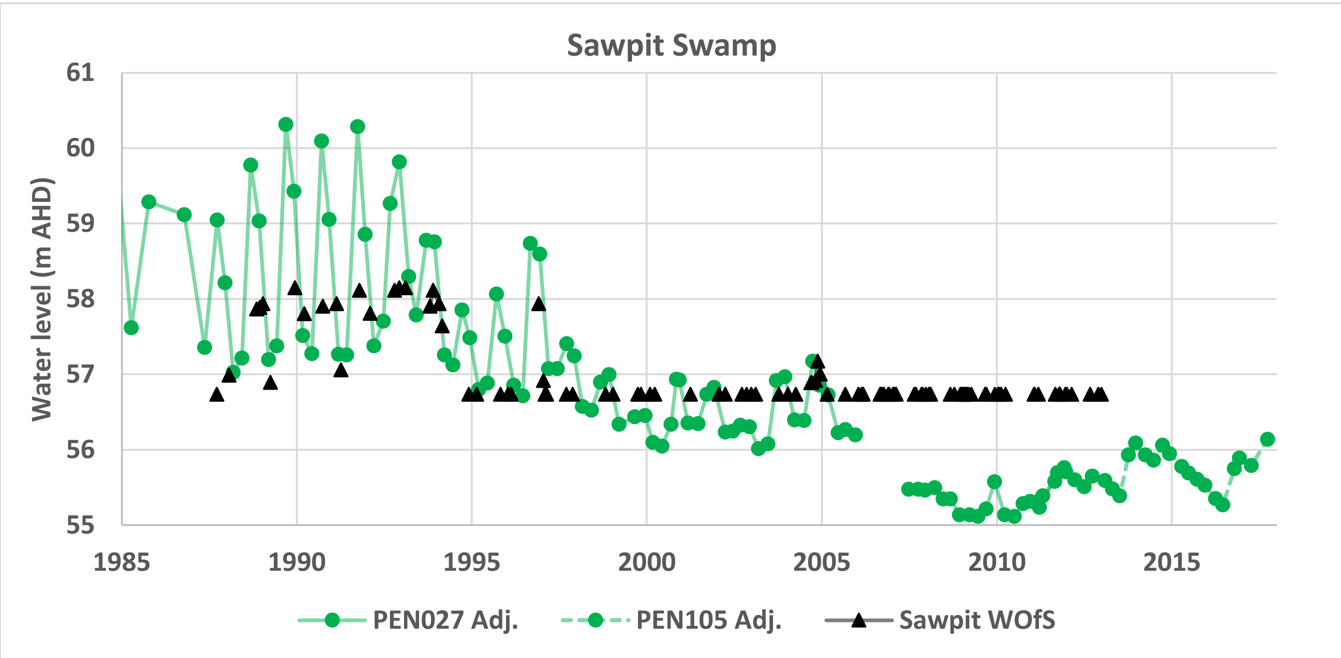


Figure 6.17. Hydrographs for Sawpit Swamp with observation wells PEN027 (adjusted -2.8 m) and PEN105 (adjusted -2.8 m)

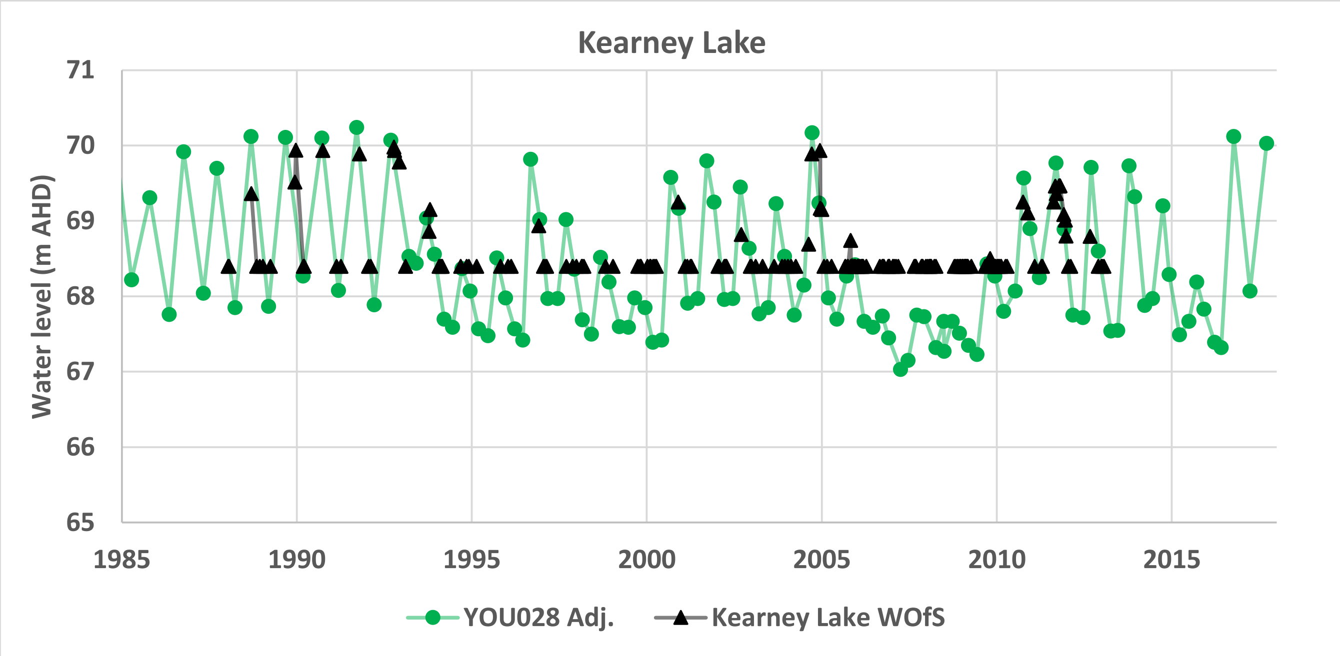


Figure 6.18. Hydrographs for Kearney Lake with observation well YOU028

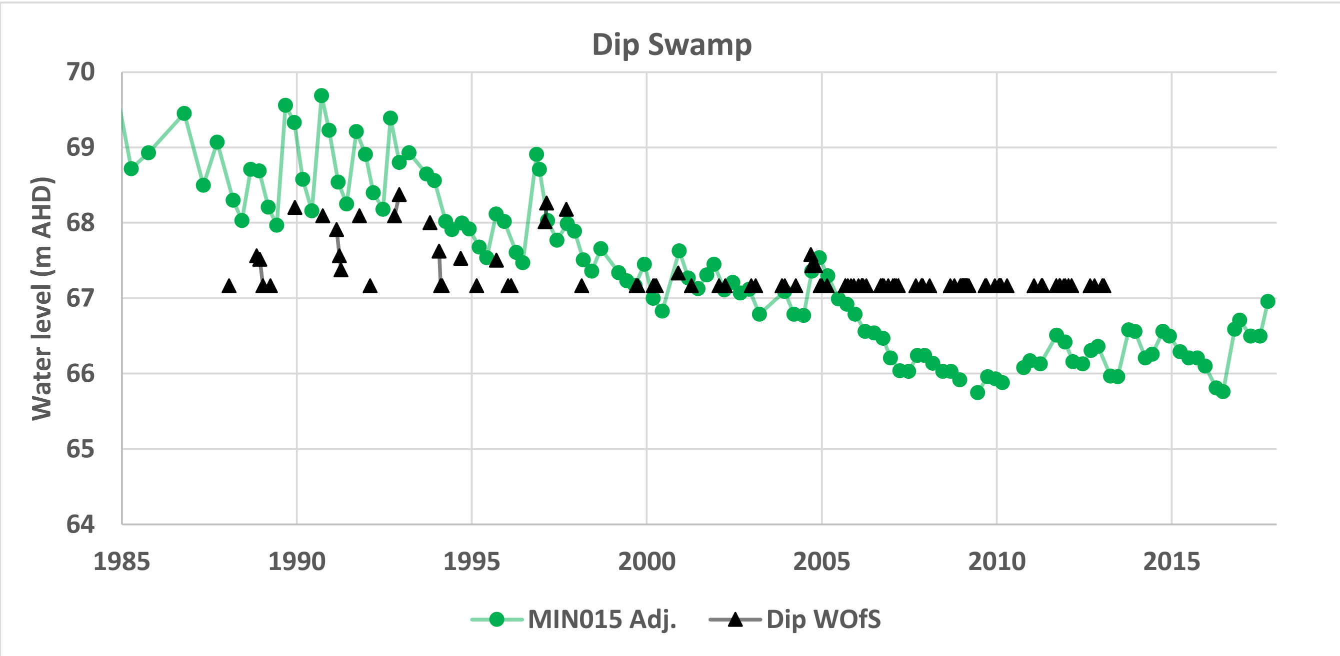


Figure 6.19. Hydrographs for Dip Swamp observation well MIN015 (adjusted 0.8 m)

Table 6.1. Details of paired surface water and groundwater monitoring locations for water level comparisons and adjustments

GDE Wetland or Drain Site	Data Source	Obswells	Dist from SW (m)	GW Adj.	SW Adj.	Classification	Hydrogeo-logical zone
Taylors Swamp	WOfS	JOA005, JOA027	3700 E, 5500 S	-9.57, -3	n/a	Variable–losing	HZ3
Deadmans Swamp	WOfS	JOA005, JOA027	4900 N, 0 SW	-6.57, 0	n/a	Gaining–losing	HZ3
Sawpit Swamp	WOfS	PEN027, PEN105	3400 E, 2200 E	-2.8, -2.8	n/a	Gaining–losing	HZ7
Coinville Swamp	WOfS	PEN027, PEN105	2500 E, 1300 E	-2, -2	n/a	Gaining–variable	HZ7
McKinnon Swamp	WOfS	PEN011	20 W	0	n/a	Variable–losing	HZ7
Dip Swamp	WOfS	MIN015	3500 S	0.8	n/a	Gaining–losing	HZ7
South Bool 1	WOfS	JOA008, JOA026	1200 SE, 1250 SE	0	n/a	Gaining–variable	HZ5
South Bool 2	WOfS	JOA008, JOA026	1700 SE, 1750 SE	0	n/a	Gaining–variable	HZ5
Glenrise 1	WOfS	PEN003	80 m NE	0	n/a	Variable	HZ5
Glenrise 2	WOfS	PEN003	600 ESE	0	n/a	Variable	HZ5
Coomooroo Swamp	WOfS	MON014, MON038	4500 W, 1250 SW	0.35, 0.8	n/a	Variable	HZ5
Kearney Lake	WOfS	YOU028	700 S	0.12	n/a	Variable	HZ6
Bakers Range Watercourse (D/S Well and Bridge)	A2391007	MSN006, MCN001	750, 600	0	n/a, 1 km south	Losing	HZ1
Blackford Drain (Amtd 4.0km)	A2390506	LAC006	150	0	2.5 km U/S	Gaining–variable	HZ1
Drain L (U/S Princes Highway)	A2390510	CNM007	1500	0	0.5 km D/S	Gaining–variable	HZ4
Drain L (Boomaroo Park Amtd 7.3km)	A2390505	WAT009	800	0	2 km U/S	Variable–losing	HZ4
Drain M (D/S Callendale Regulator)	A2390514	CLS004	600	0	3.5 km D/S	Gaining–losing	HZ5
Drain M (Woakwine Amtd 5.1km)	A2390512	SYM013	1500	0	0.5 km D/S	Gaining–variable	HZ4
Reedy Ck - Mt Hope Drain (7.2 km NE South End)	A2390513	RIV008	70	0	0.05 km U/S	Gaining	HZ4
Drain 48 (200m U/S Lake Bonney Rd Bdge)	A2390533	MAY048	120	0	1.6 km U/S	Gaining	HZ4

C. Paired surface water and groundwater monitoring comparison sites

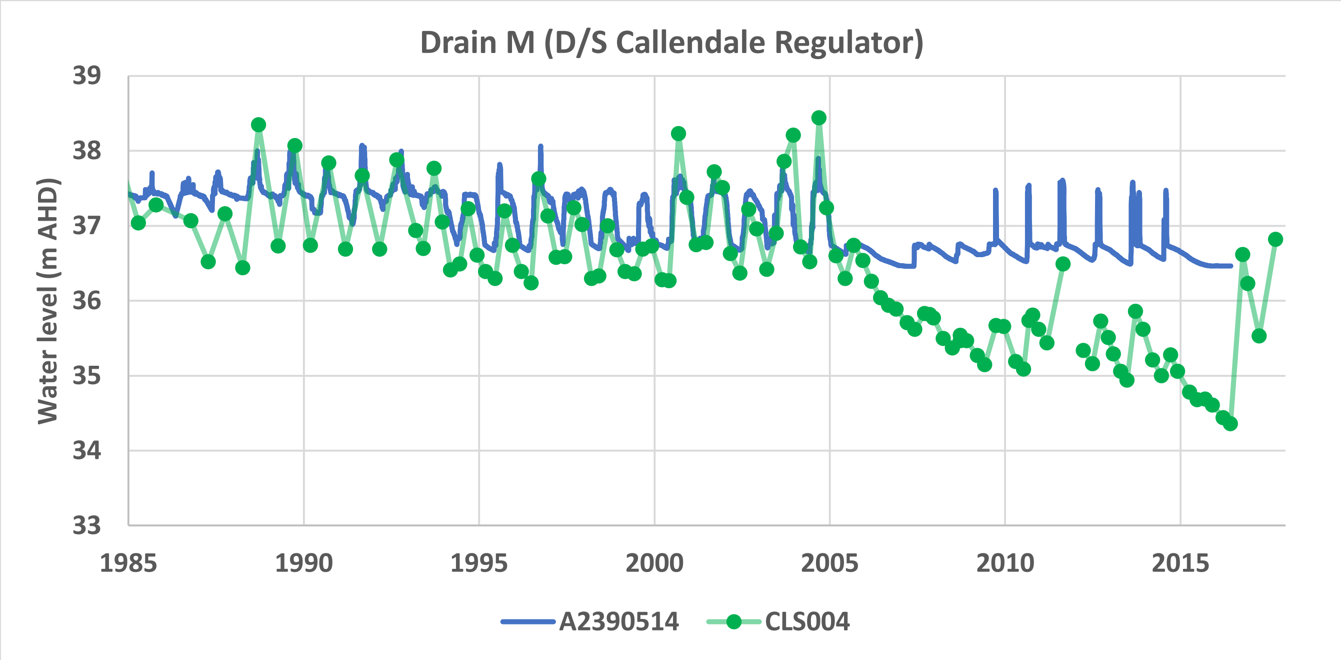


Figure 6.20. Hydrographs for Drain M (A2390514, adjusted) with observation well CLS004

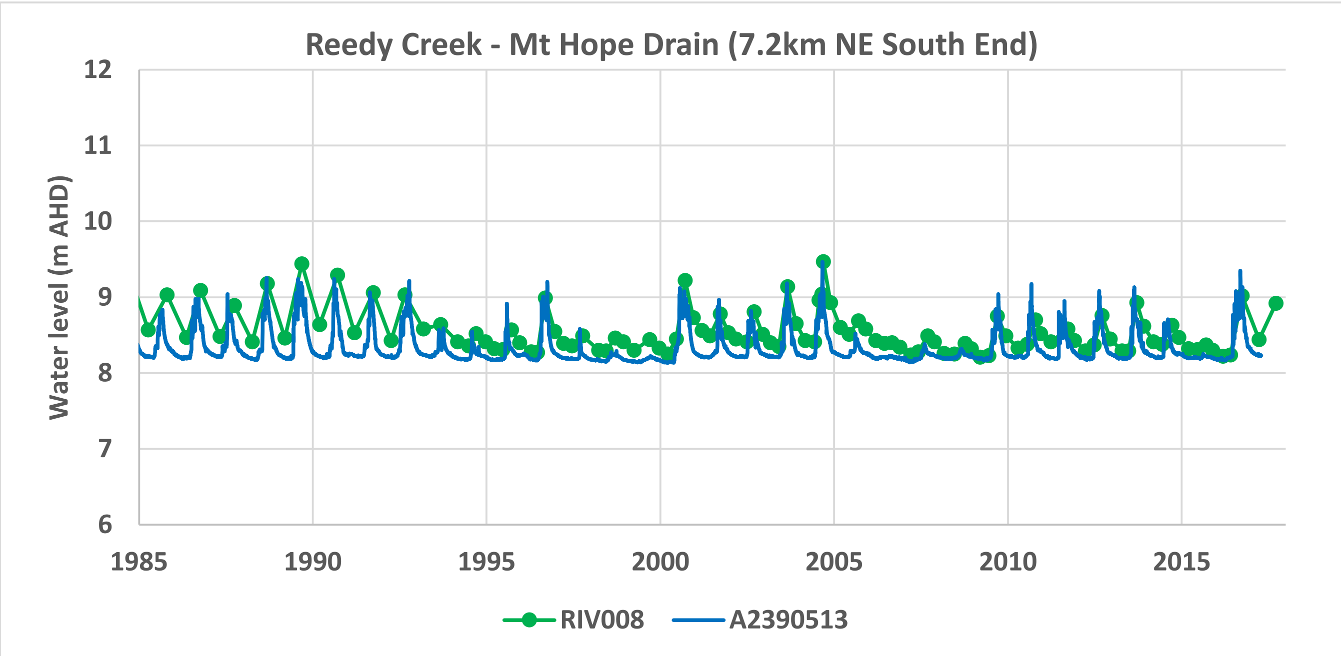


Figure 6.21. Hydrographs for Mount Hope Drain (A2390513) with observation well RIV008 (using old ref. elev.)

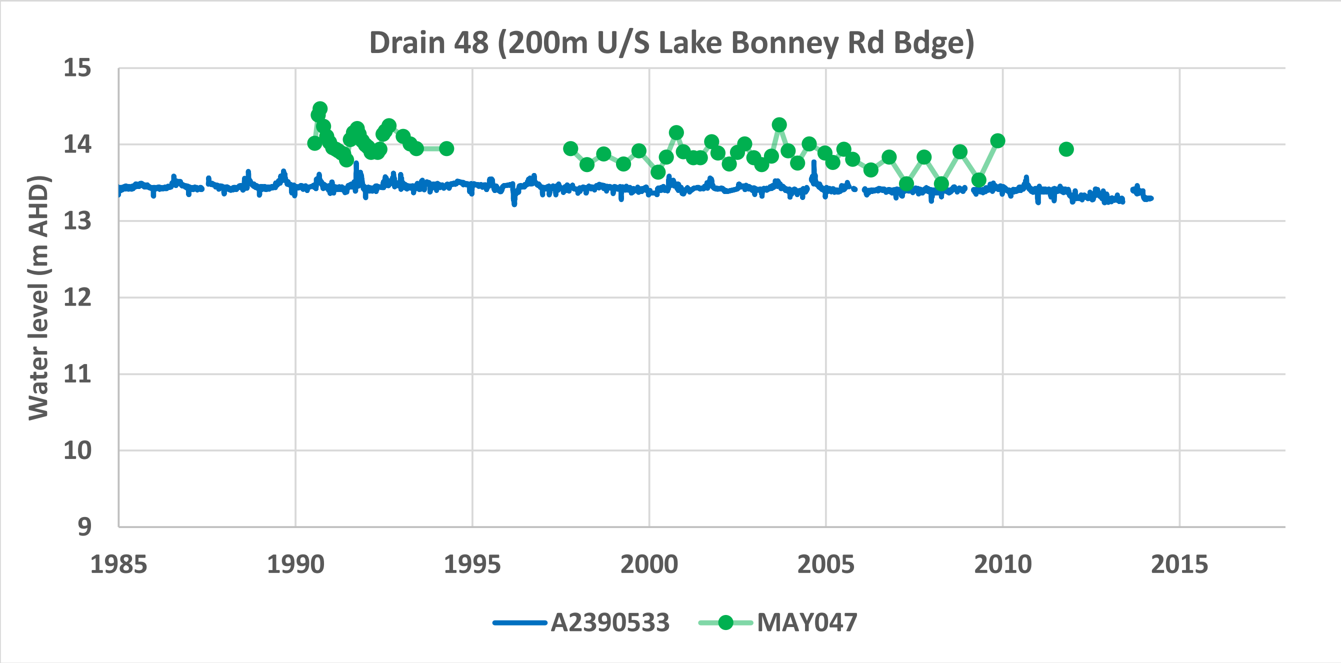


Figure 6.22. Hydrographs for Drain 48 (A2390533, adjusted)) with observation well MAY047

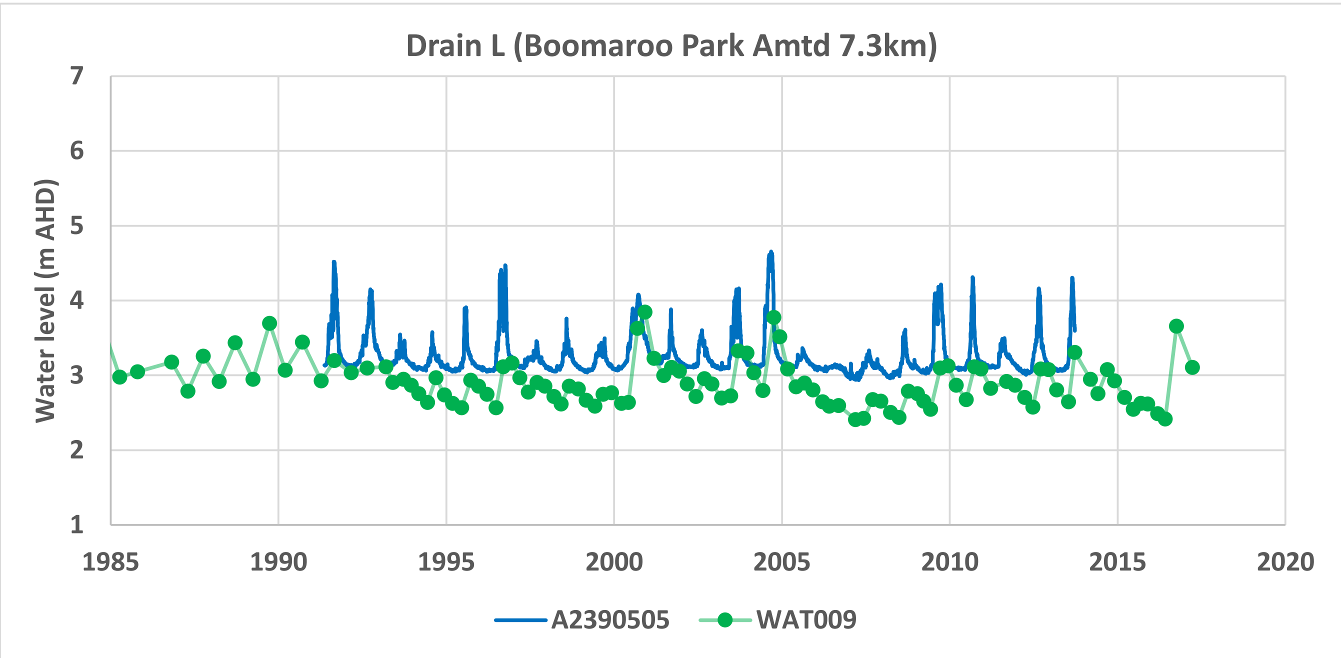


Figure 6.23. Hydrographs for Drain L (A2390505, adjusted) with observation well WAT009

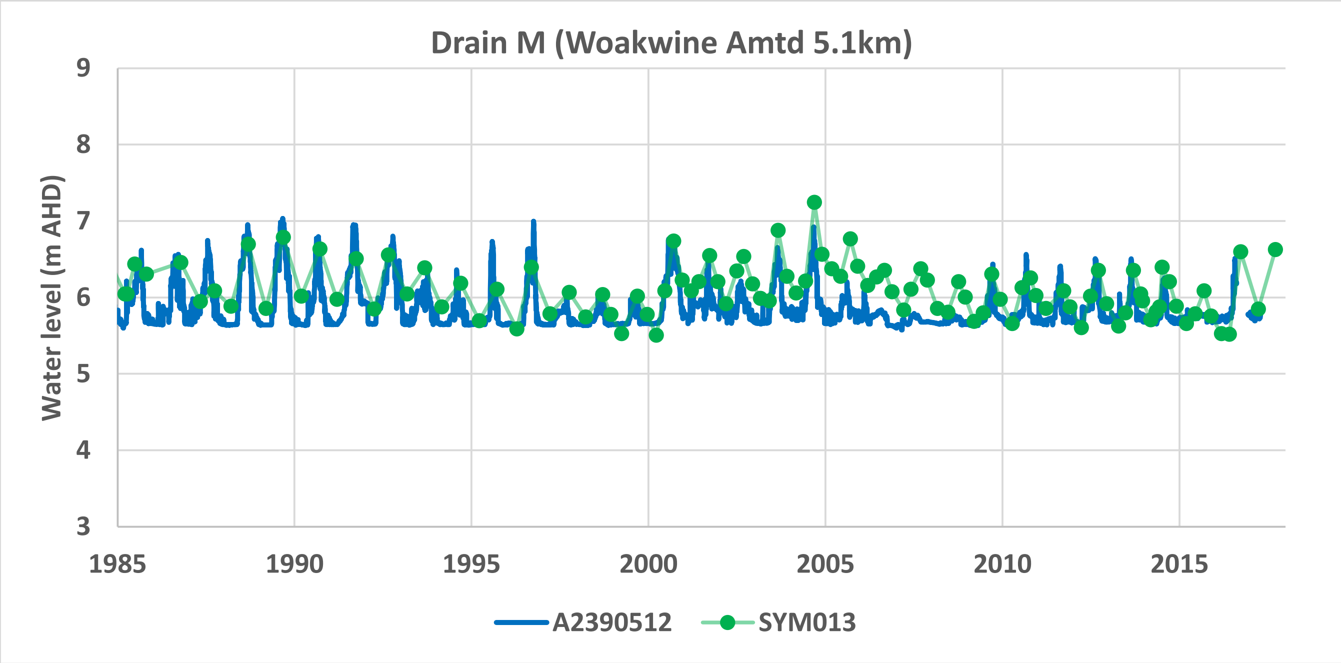


Figure 6.24. Hydrographs for Drain M (A2390512) with observation well SYM013

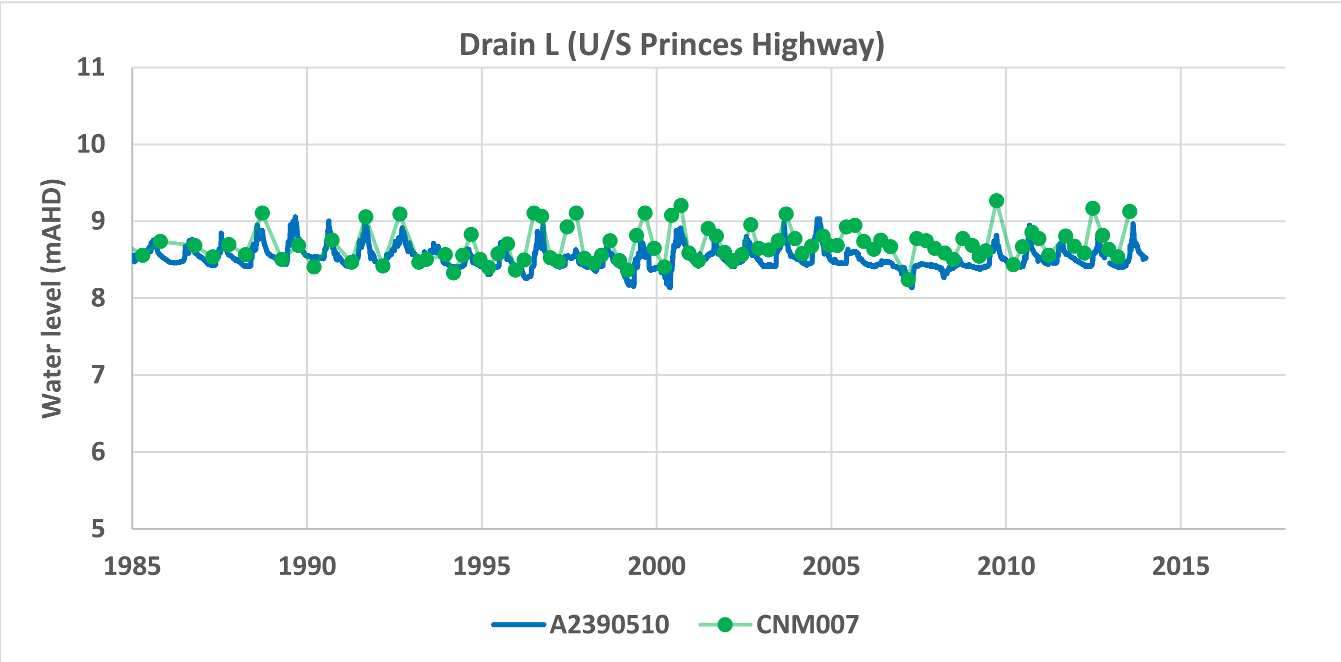


Figure 6.25. Hydrographs for Drain L (A2390510) with observation well CNM007

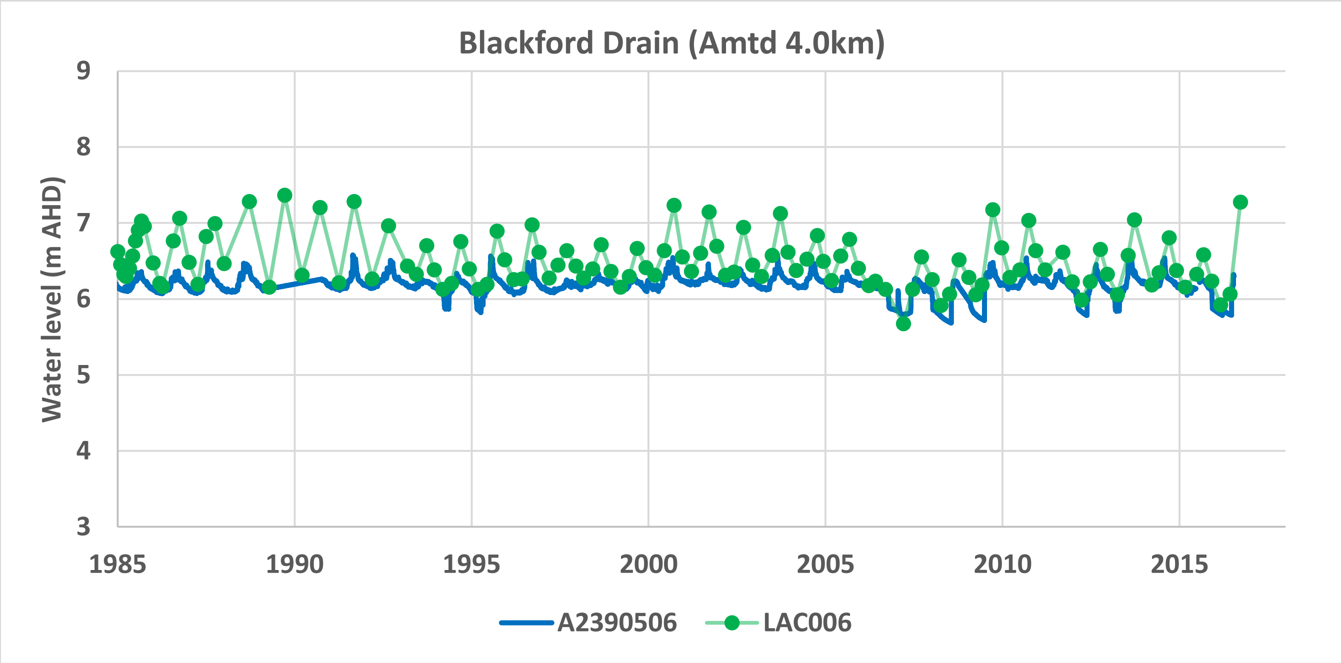


Figure 6.26. Hydrographs for Blackford Drain (A2390506) with observation well LAC006

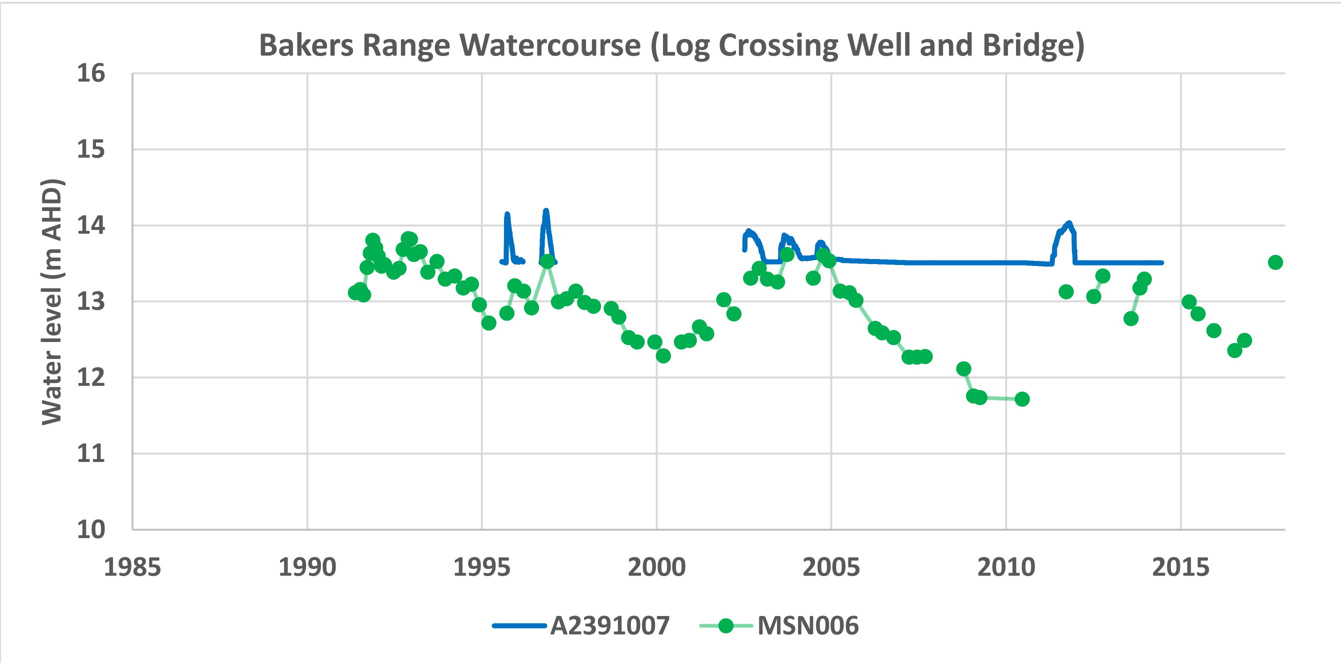


Figure 6.27. Hydrographs for Bakers Range Watercourse @ Log Crossing Well and Bridge (A2391007) with upgradient observation well MSN006

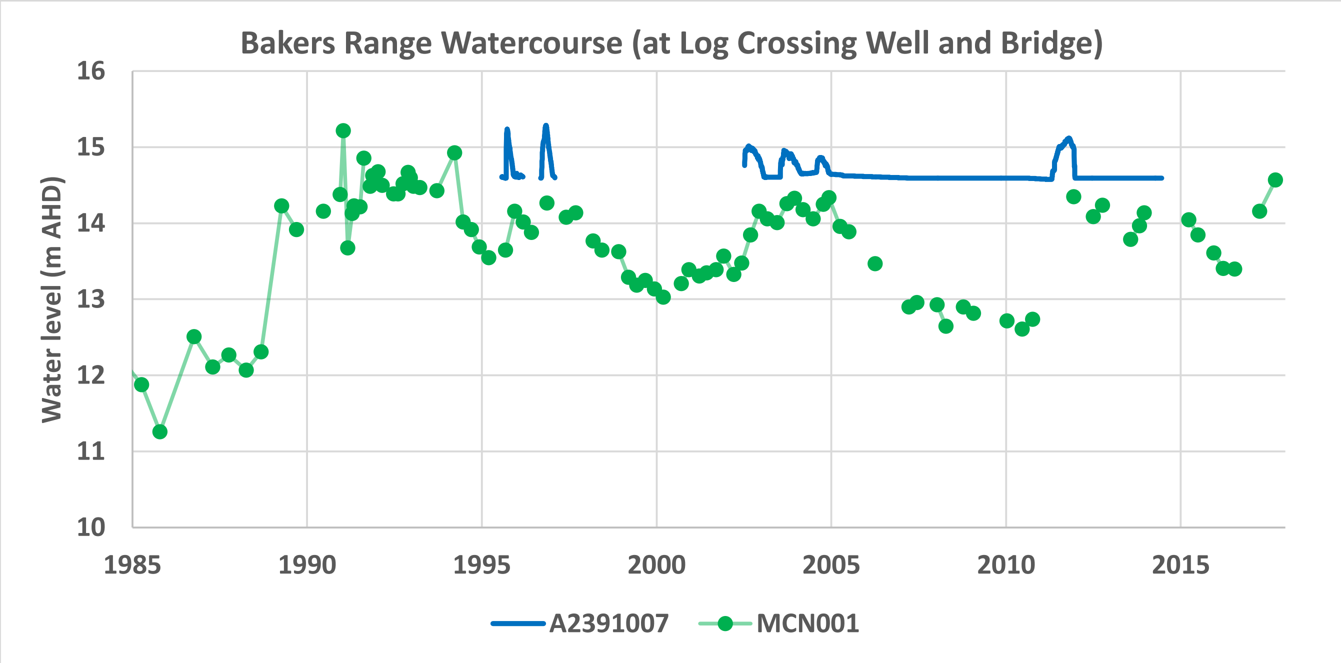


Figure 6.28. Hydrographs for Bakers Range Watercourse @ Log Crossing Well and Bridge (A2391007, adjusted) with downgradient observation well MCN001

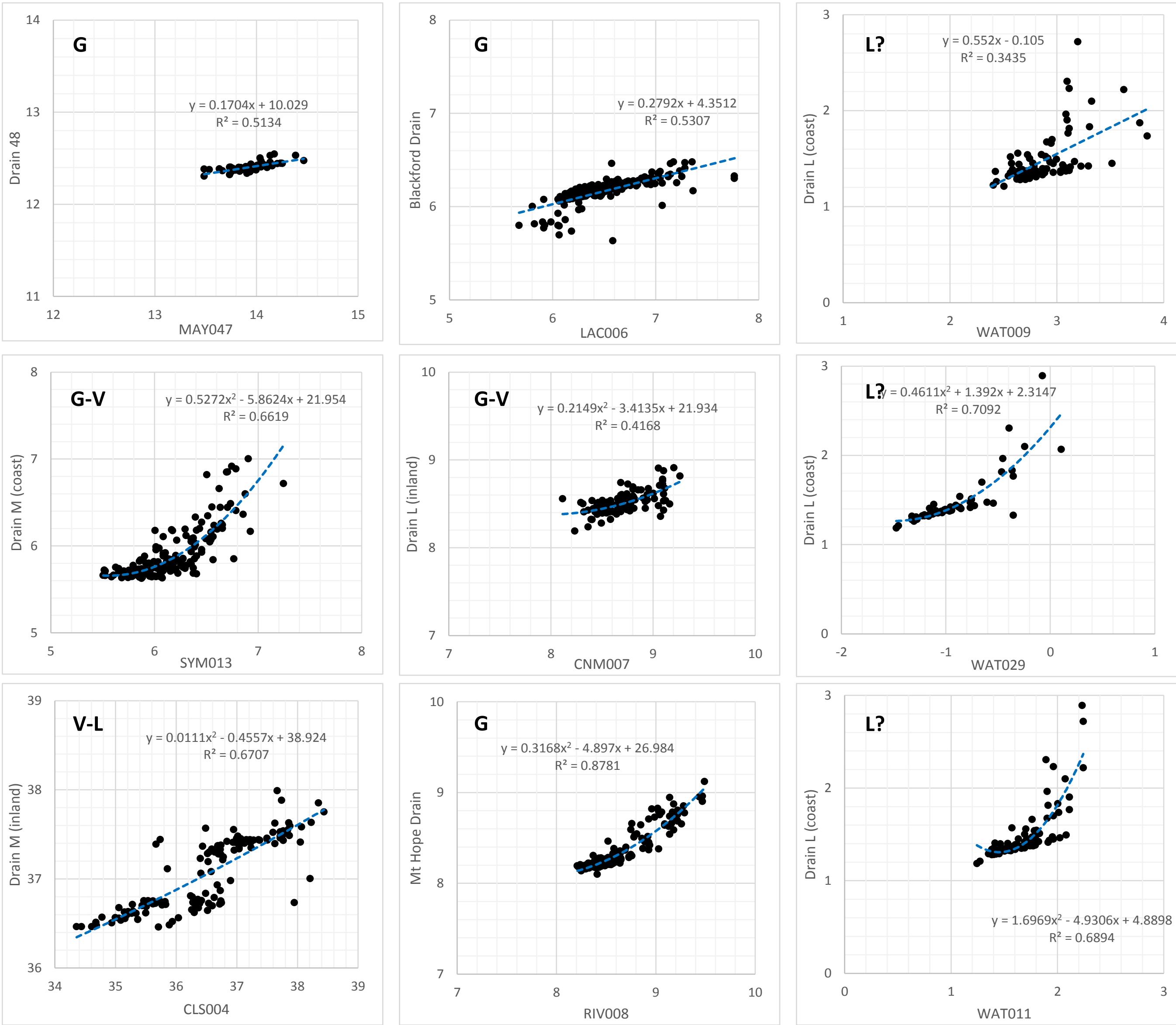


Figure 6.29. Scatter plots between surface water and groundwater levels

D. Likelihood of gaining condition maps

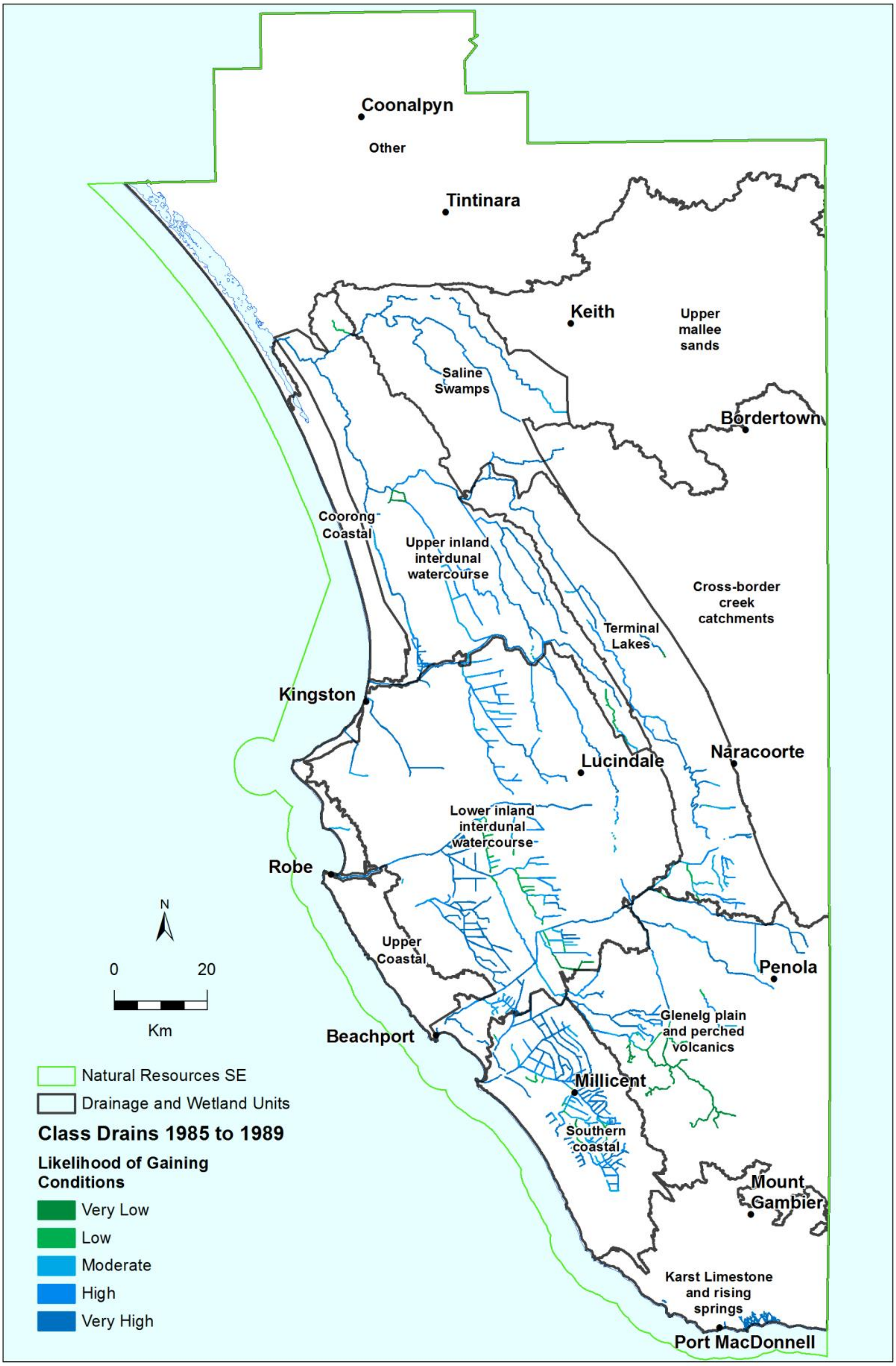


Figure 6.30. Likelihood of gaining conditions for drains for the average period 1985–89

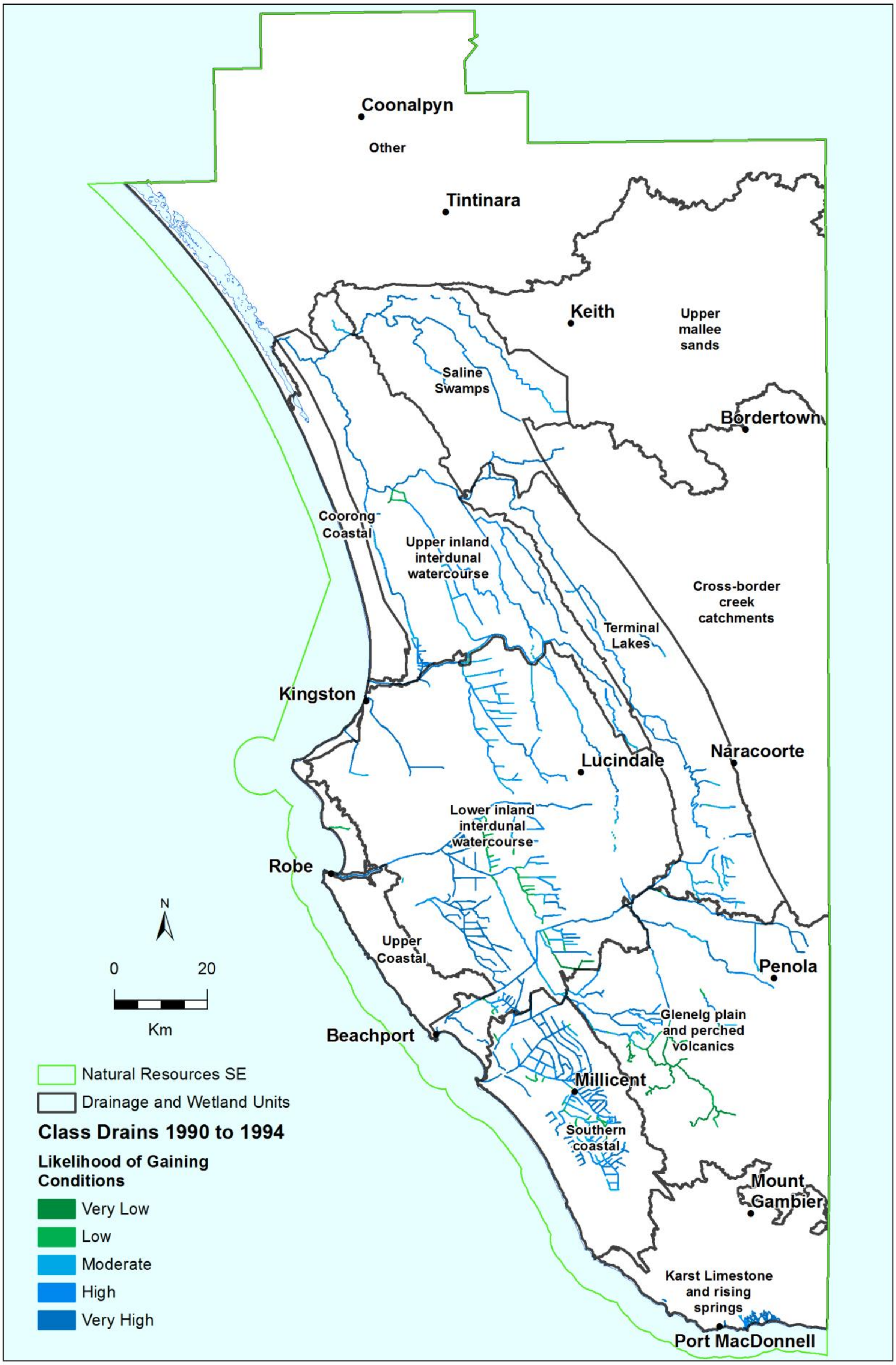


Figure 6.31. Likelihood of gaining conditions for drains for the average period 1990–94

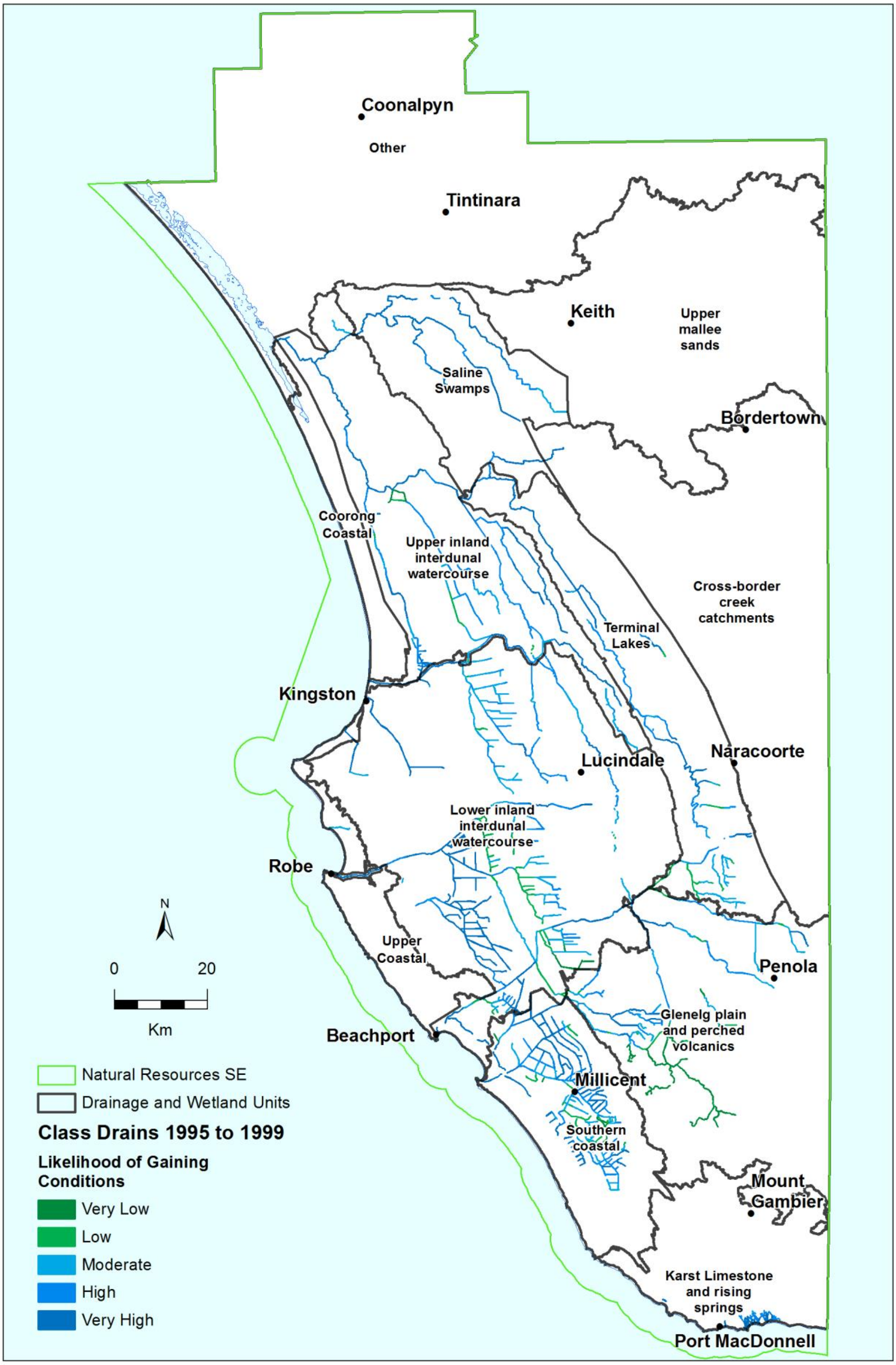


Figure 6.32. Likelihood of gaining conditions for drains for the average period 1995–99

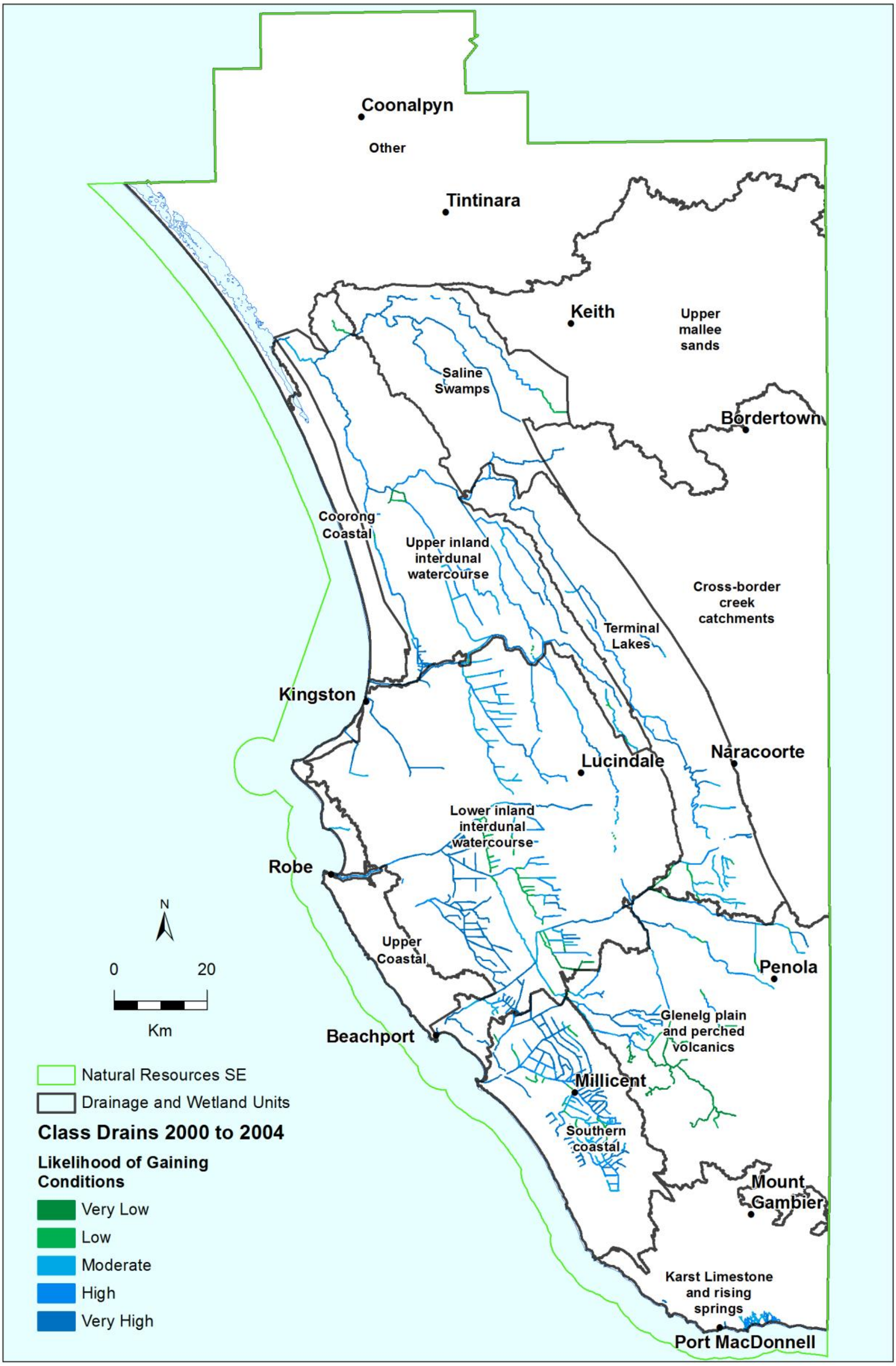


Figure 6.33. Likelihood of gaining conditions for drains for the average period 2000–04

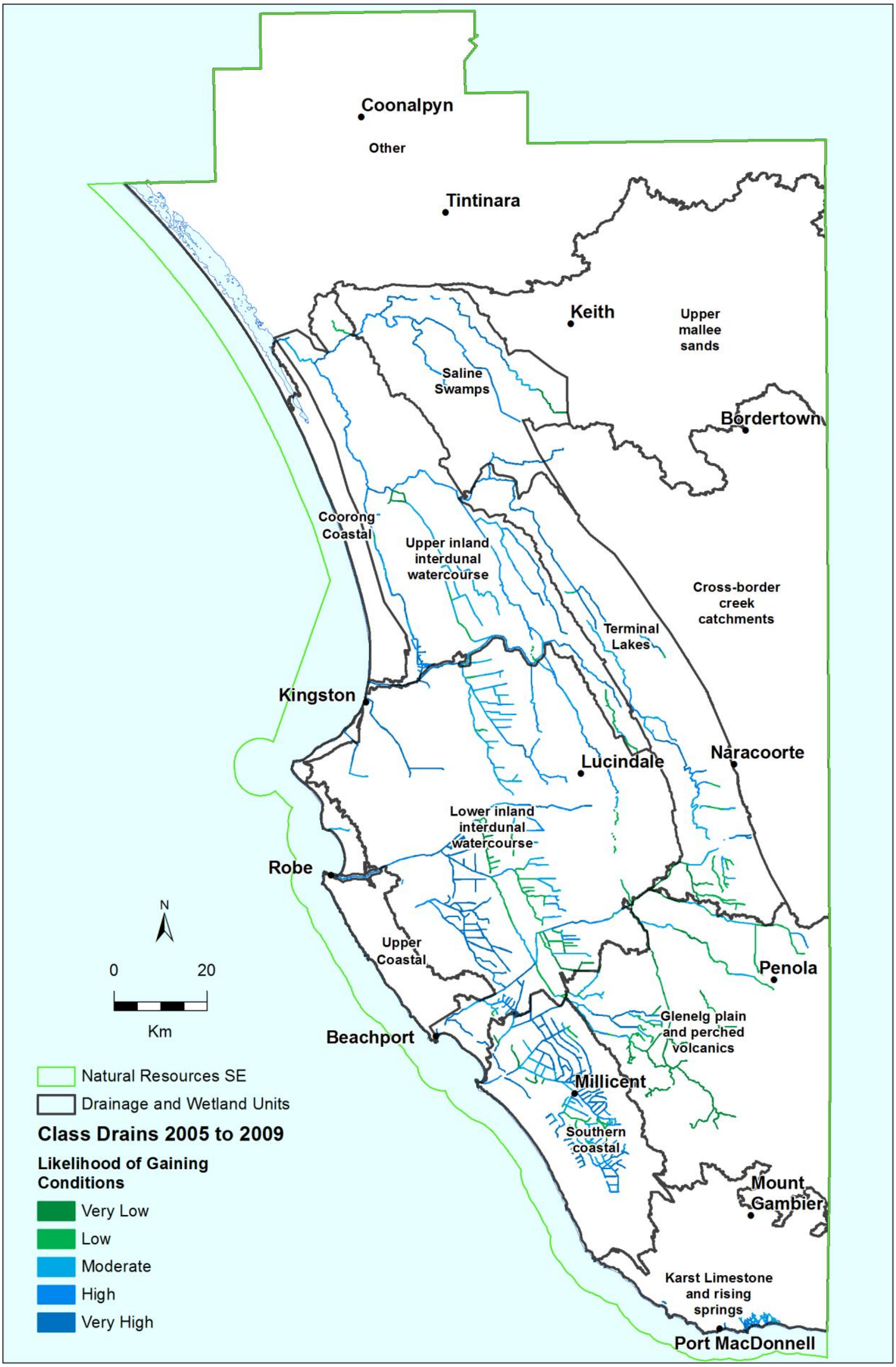


Figure 6.34. Likelihood of gaining conditions for drains for the average period 2005–09

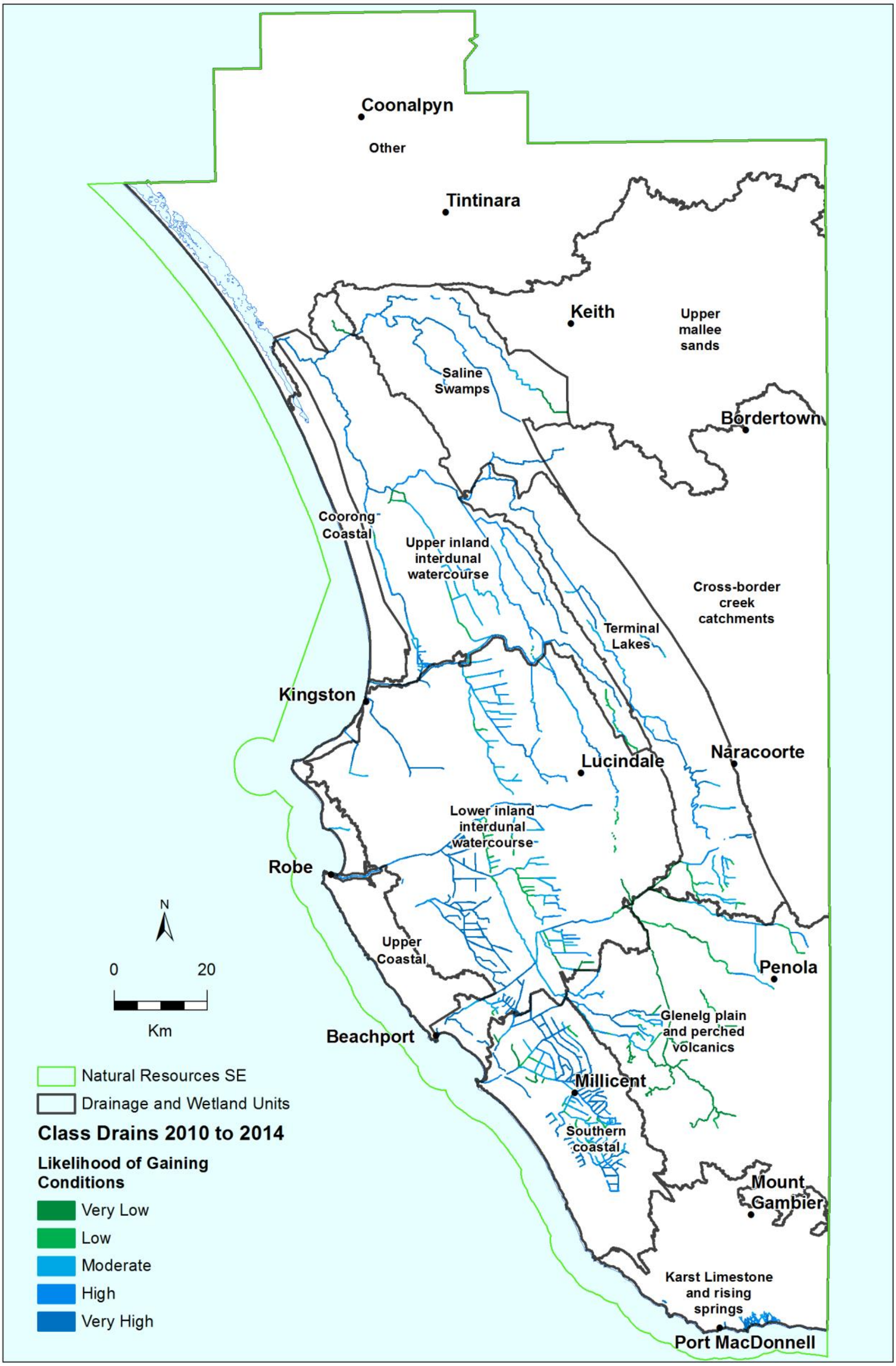


Figure 6.35. Likelihood of gaining conditions for drains for the average period 2010–14

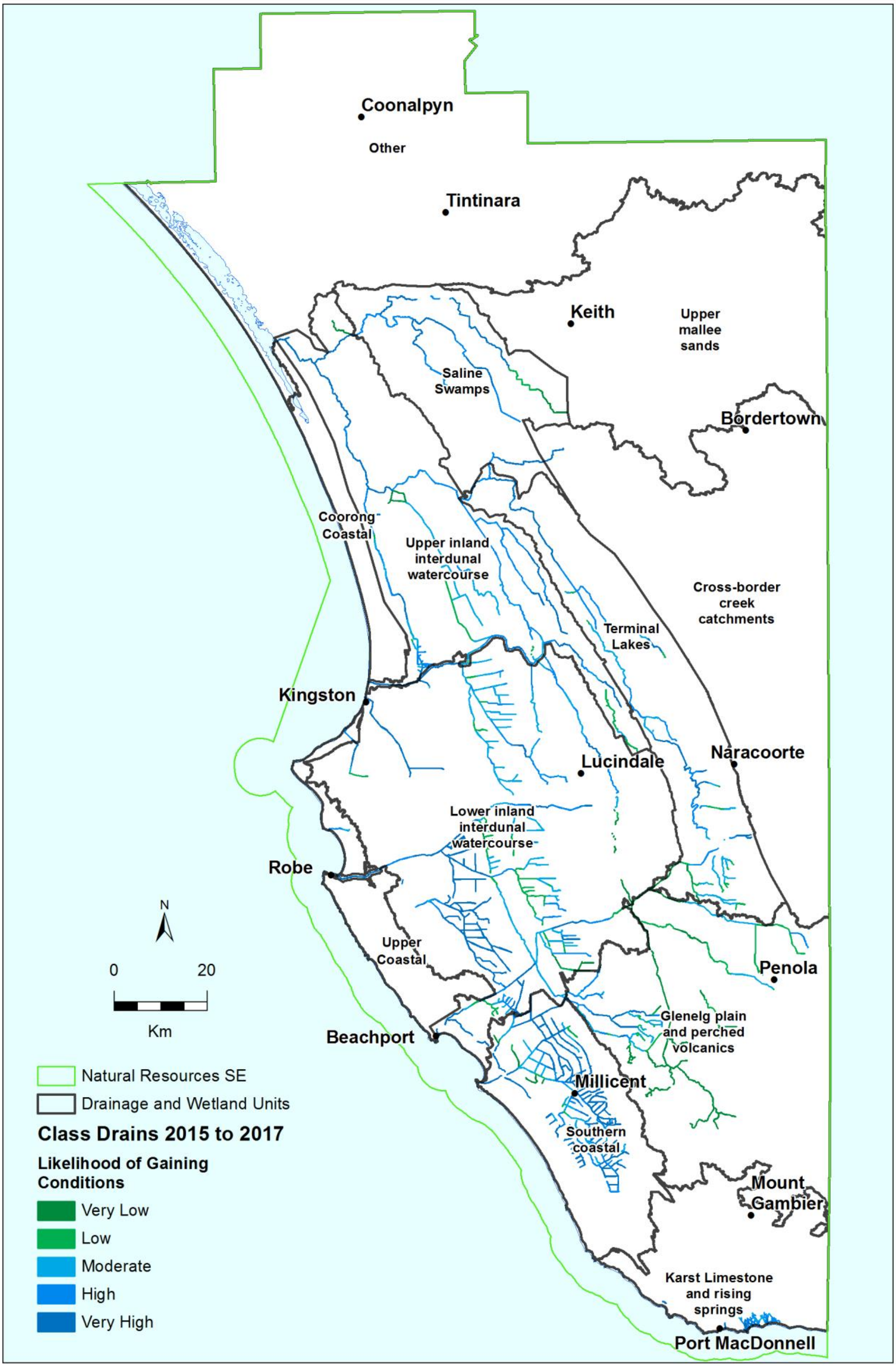


Figure 6.36. Likelihood of gaining conditions for drains for the average period 2015–17

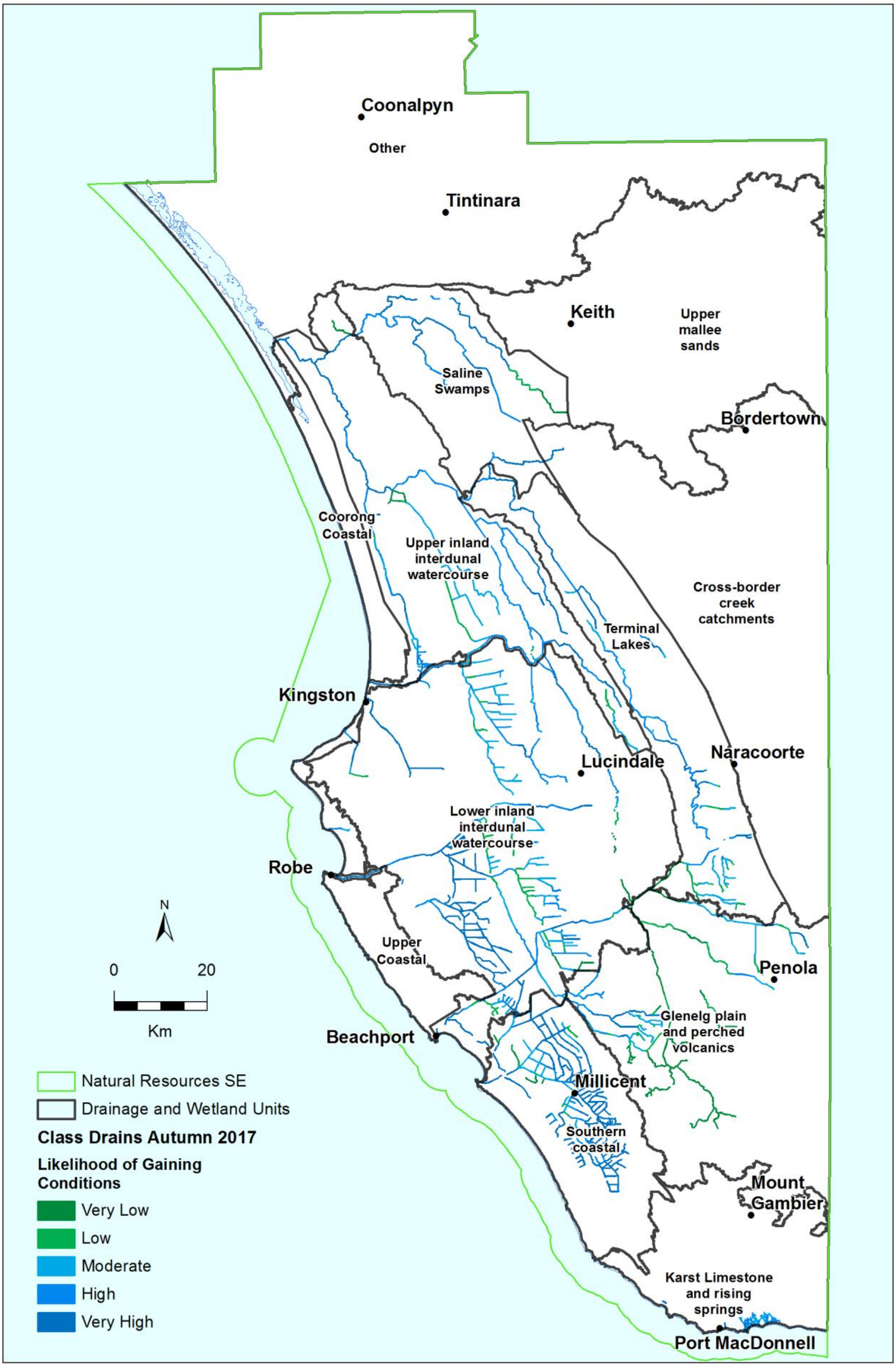


Figure 6.37. Likelihood of gaining conditions for drains for the autumn of 2017

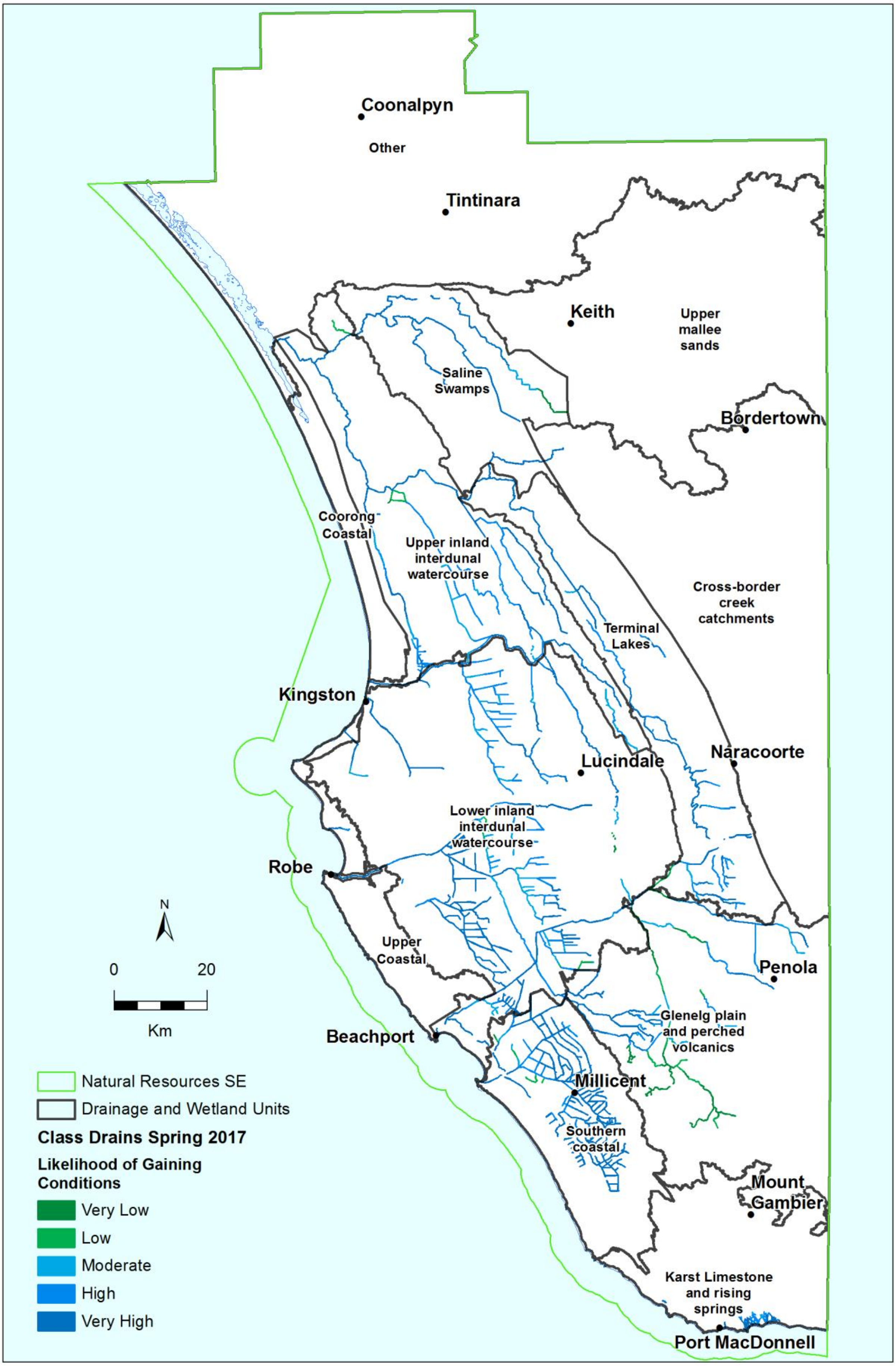


Figure 6.38. Likelihood of gaining conditions drains for the spring of 2017

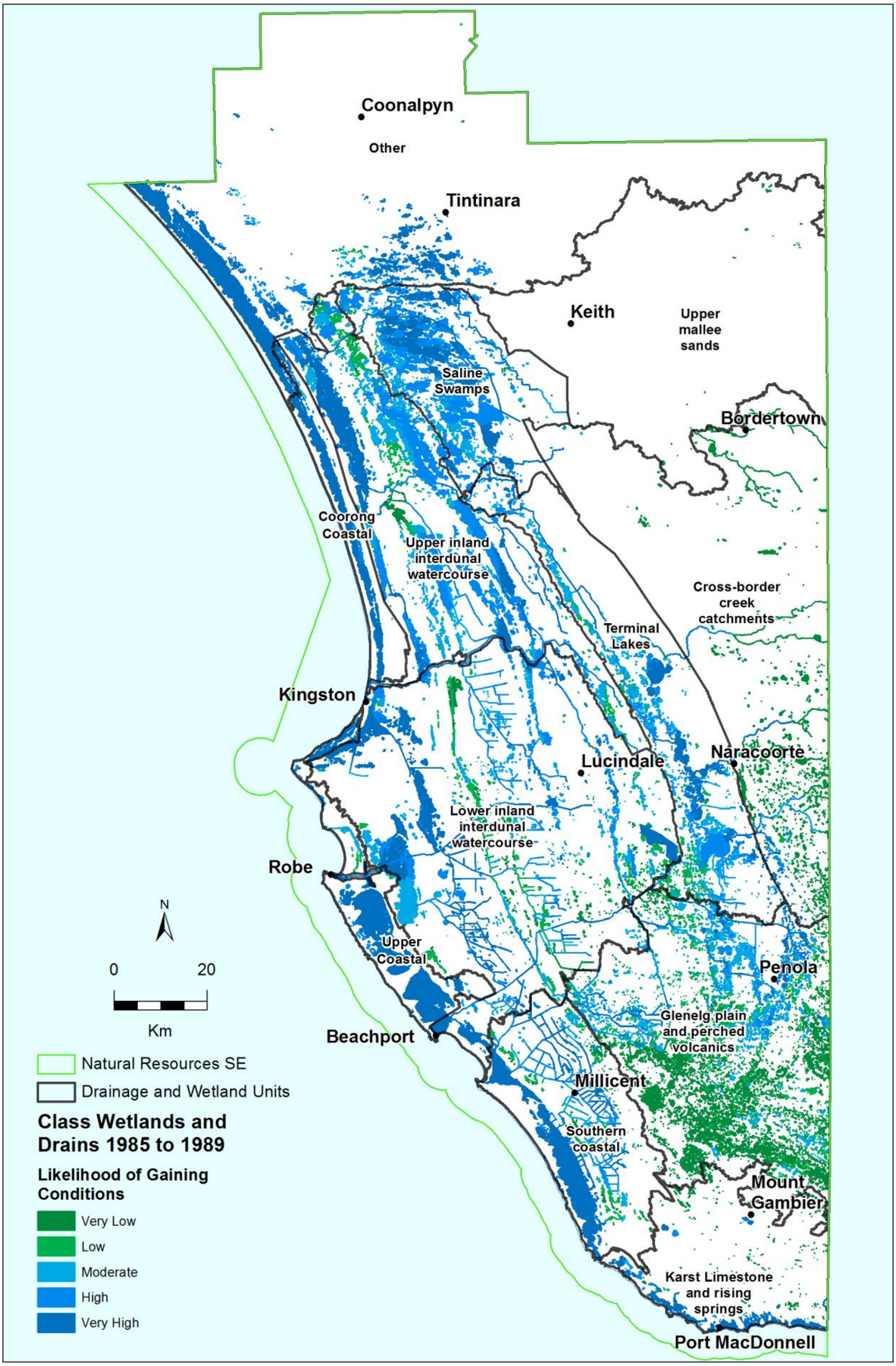


Figure 6.39. Likelihood of gaining conditions for wetlands, drains and watercourses for the average period 1985–89

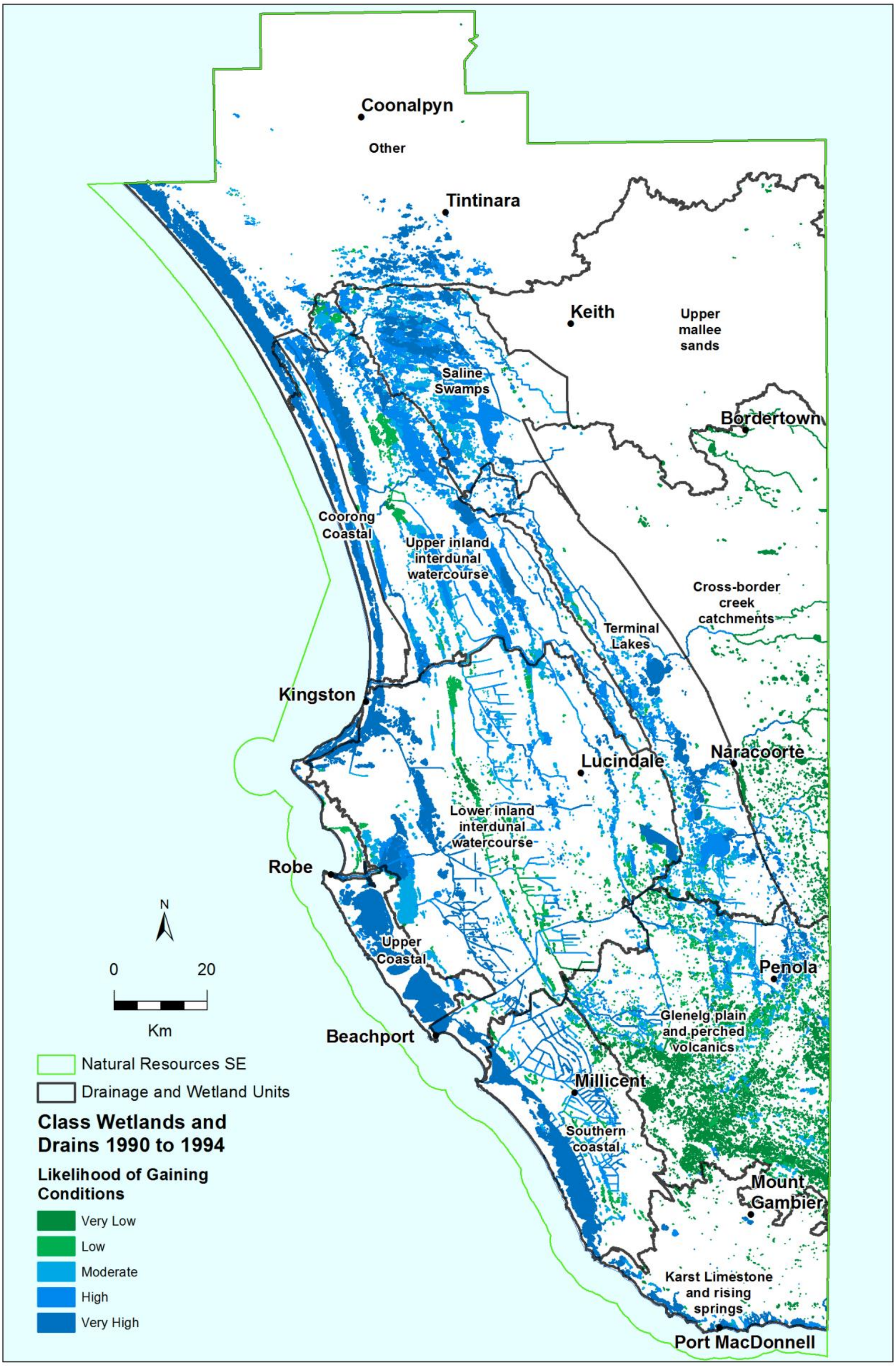


Figure 6.40. Likelihood of gaining conditions for wetlands, drains and watercourses for the average period 1990–94

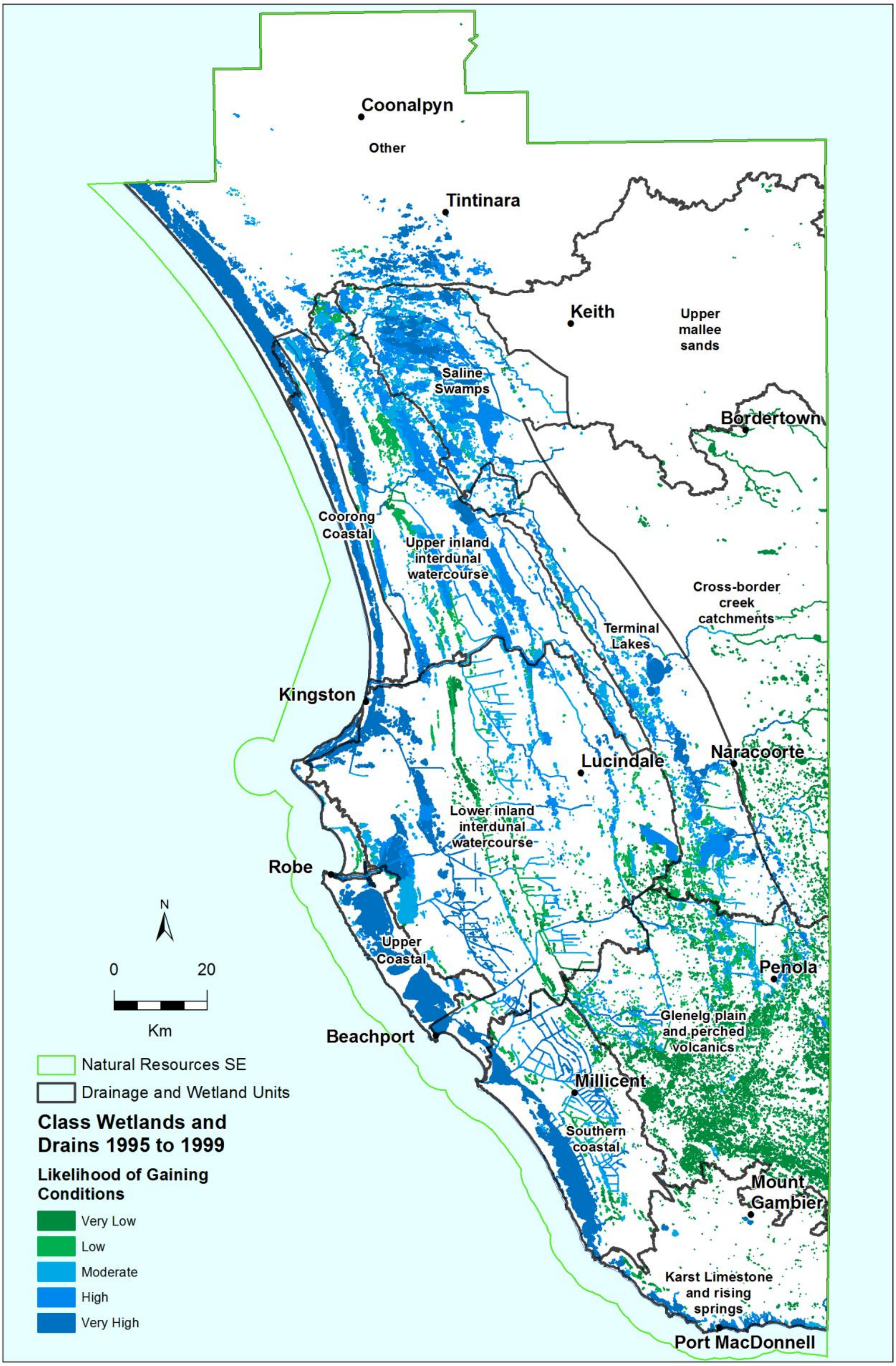


Figure 6.41. Likelihood of gaining conditions for wetlands, drains and watercourses for the average period 1995–99

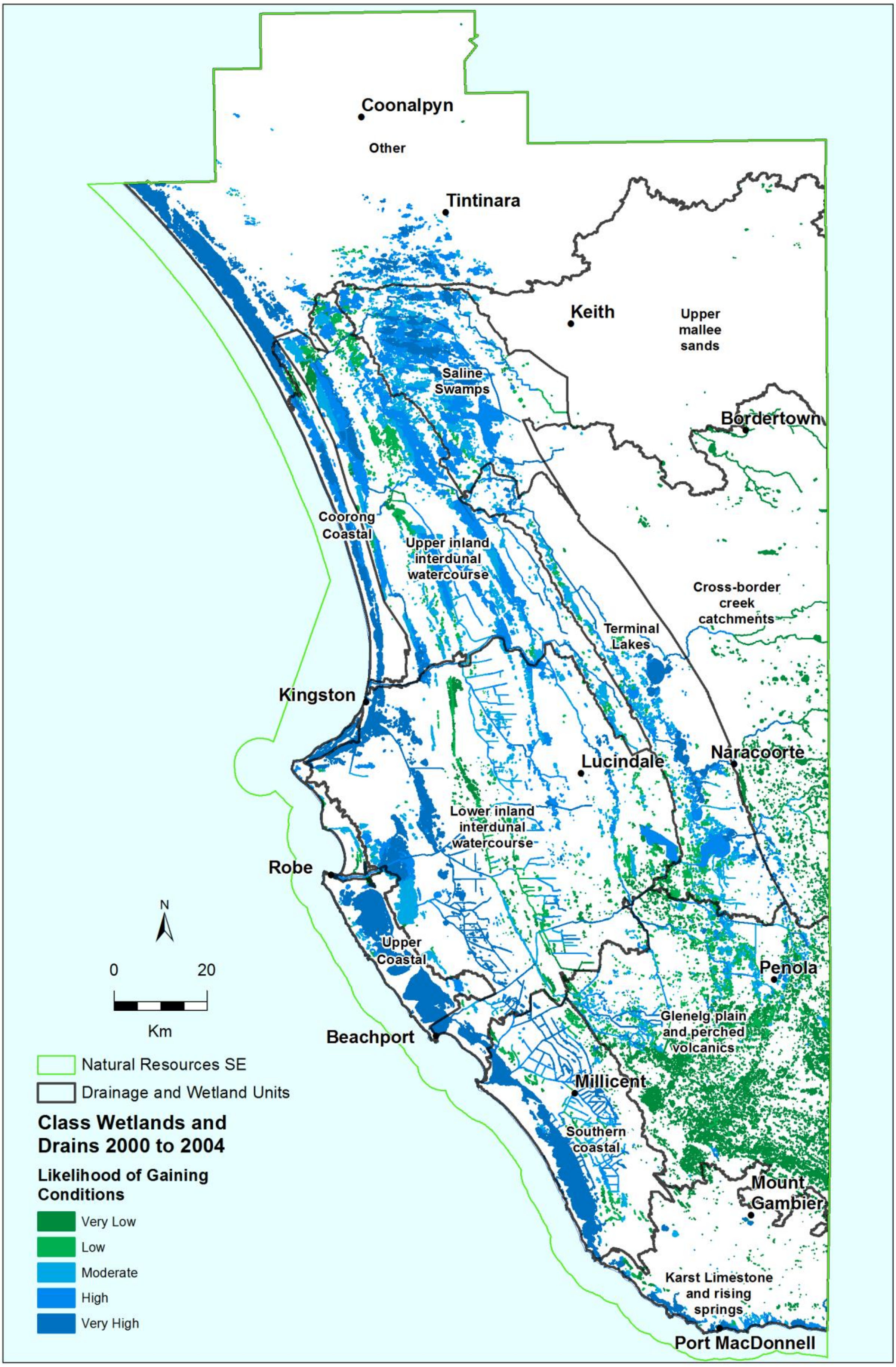


Figure 6.42. Likelihood of gaining conditions for wetlands, drains and watercourses for the average period 2000–04

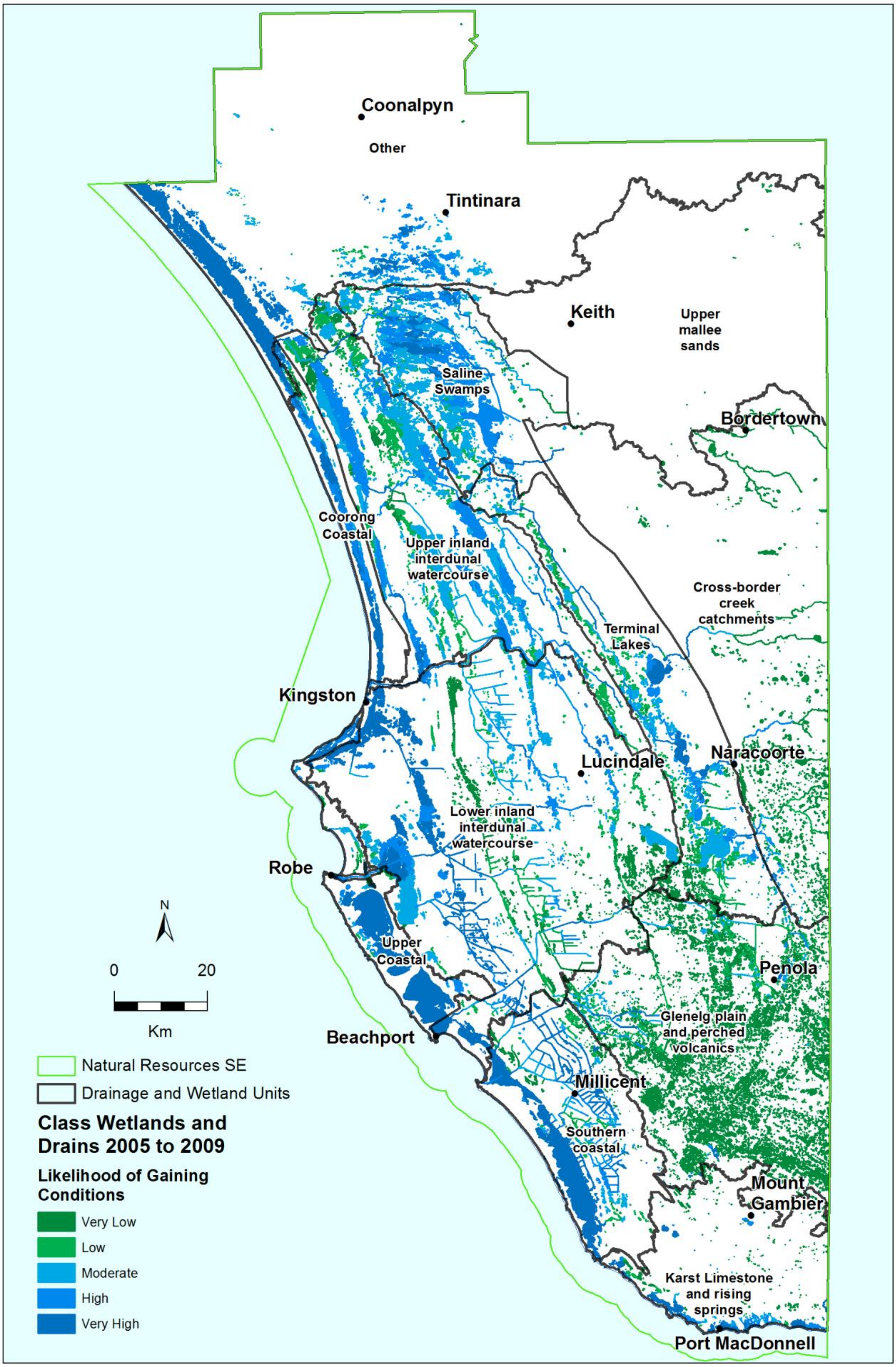


Figure 6.43. Likelihood of gaining conditions for wetlands, drains and watercourses for the average period 2005–09

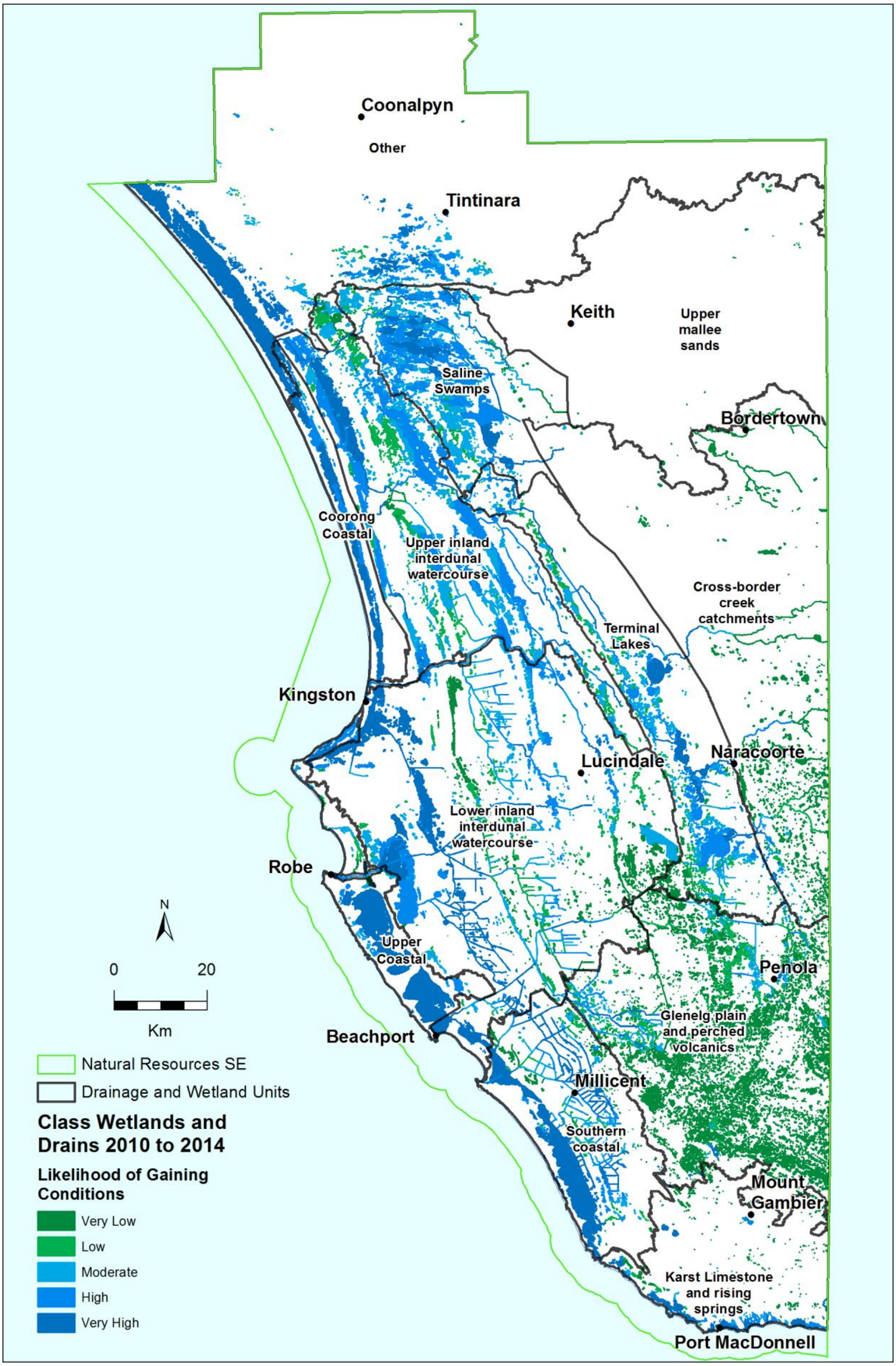


Figure 6.44. Likelihood of gaining conditions for wetlands, drains and watercourses for the average period 2010–14

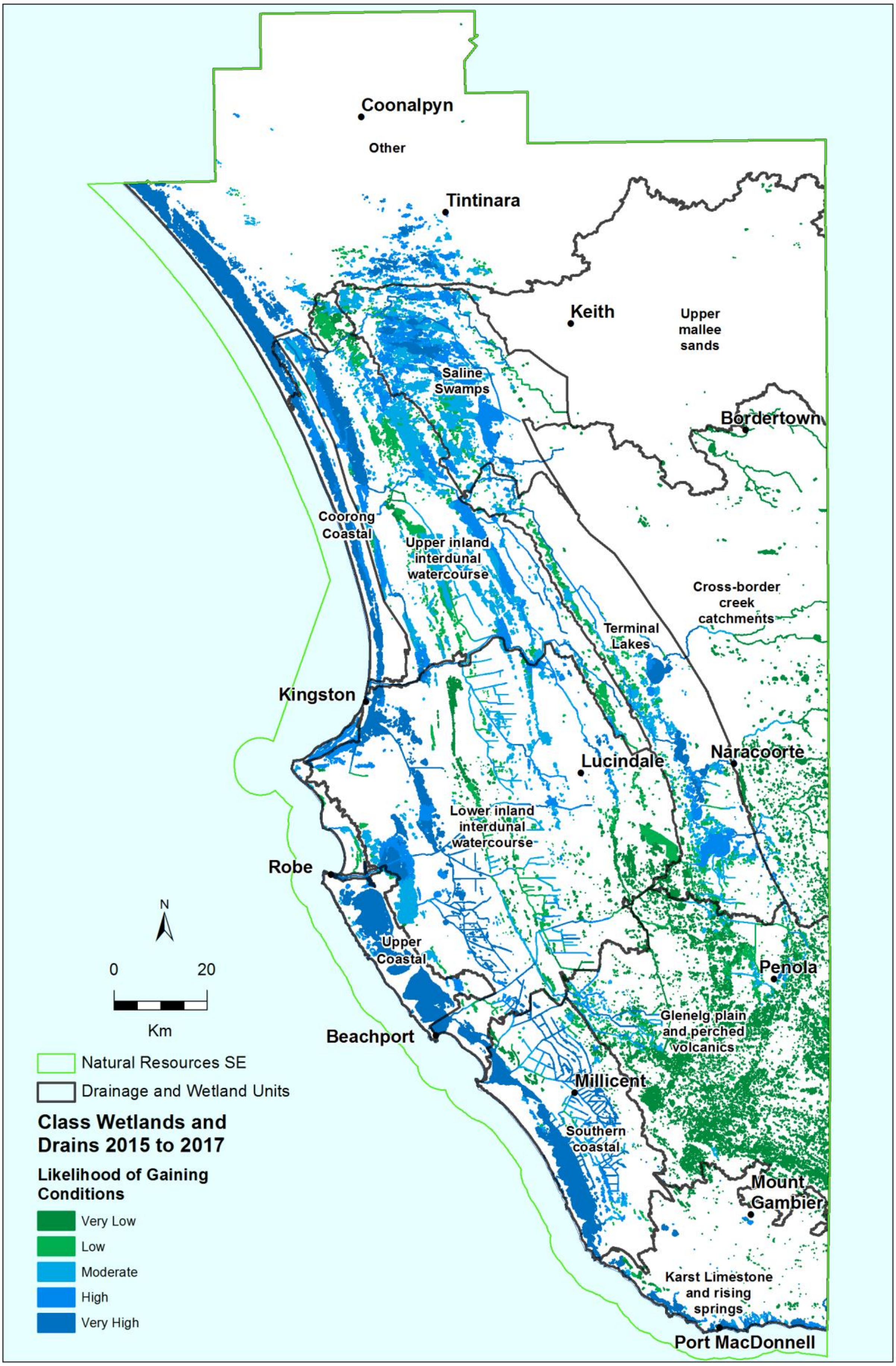


Figure 6.45. Likelihood of gaining conditions for wetlands, drains and watercourses for the average period 2015–17

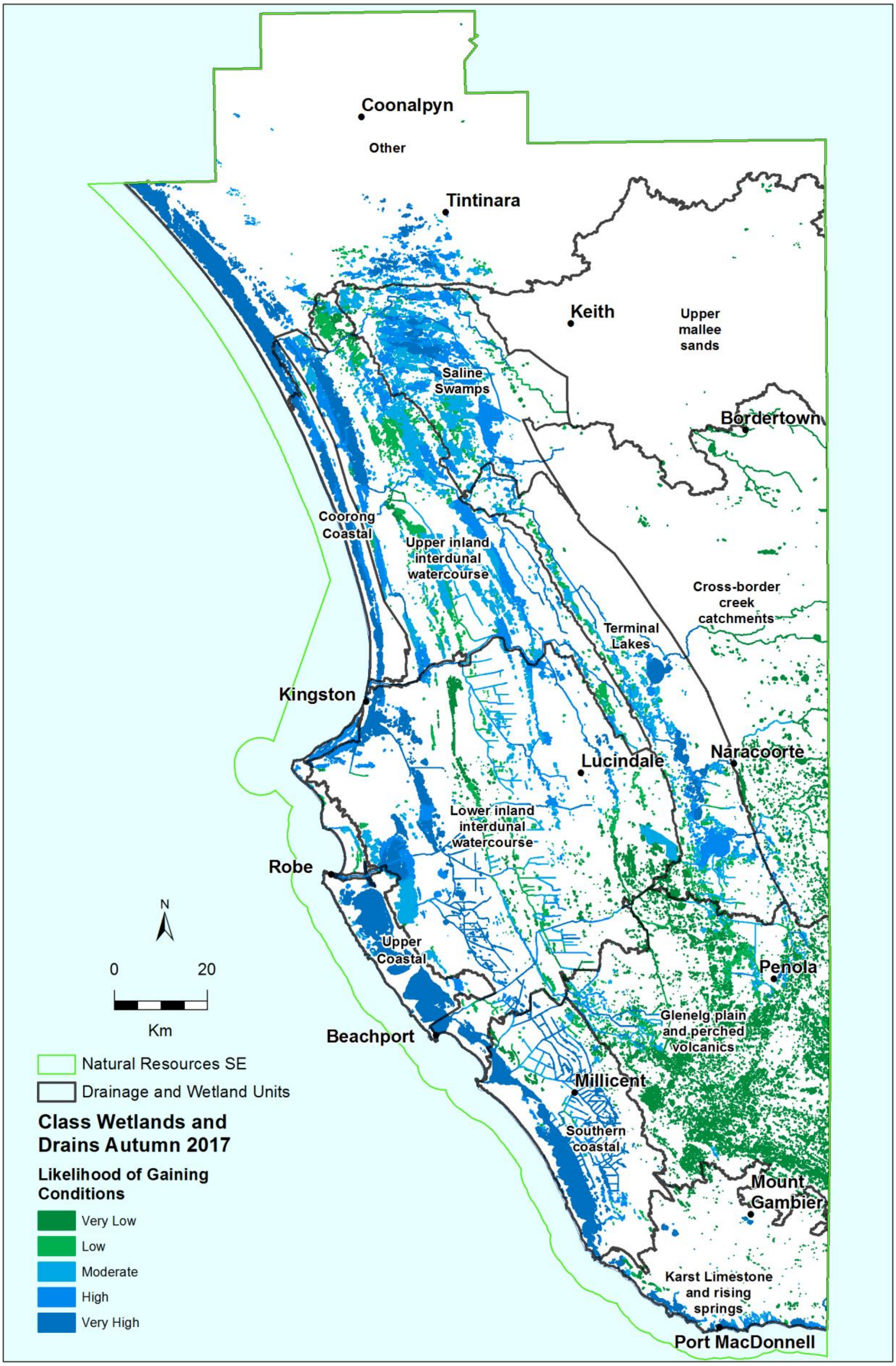


Figure 6.46. Likelihood of gaining conditions for wetlands, drains and watercourses for the autumn of 2017

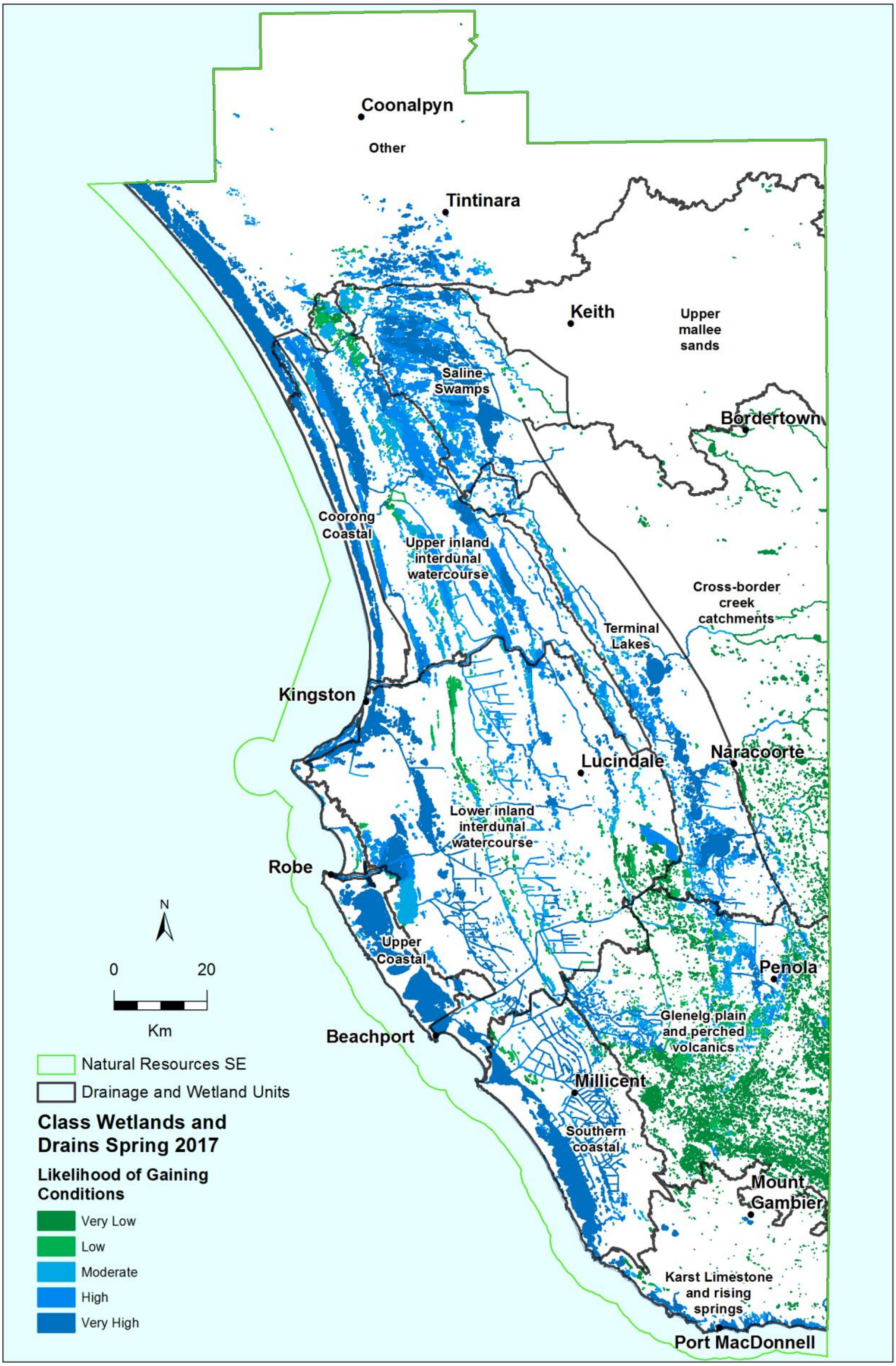
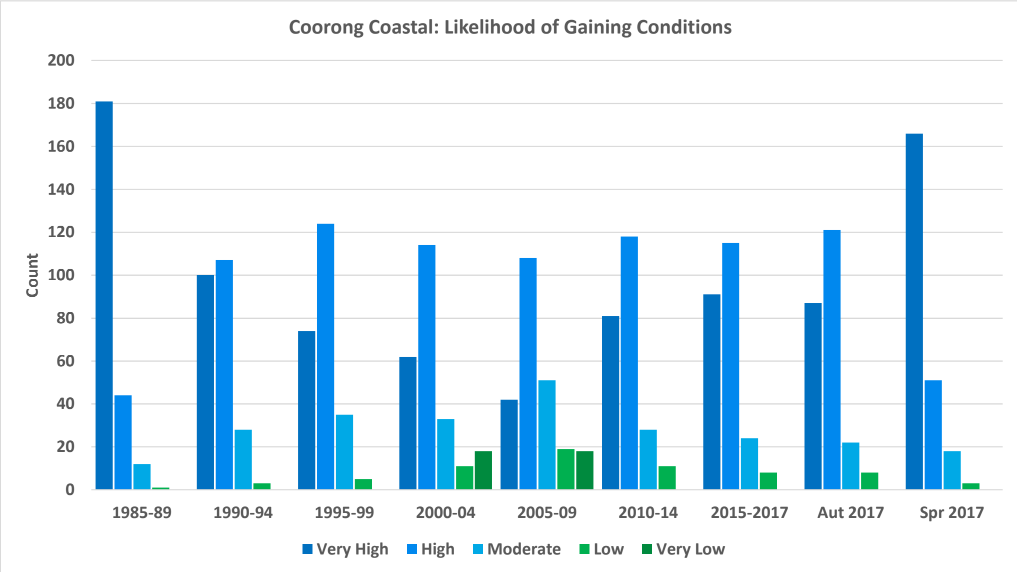
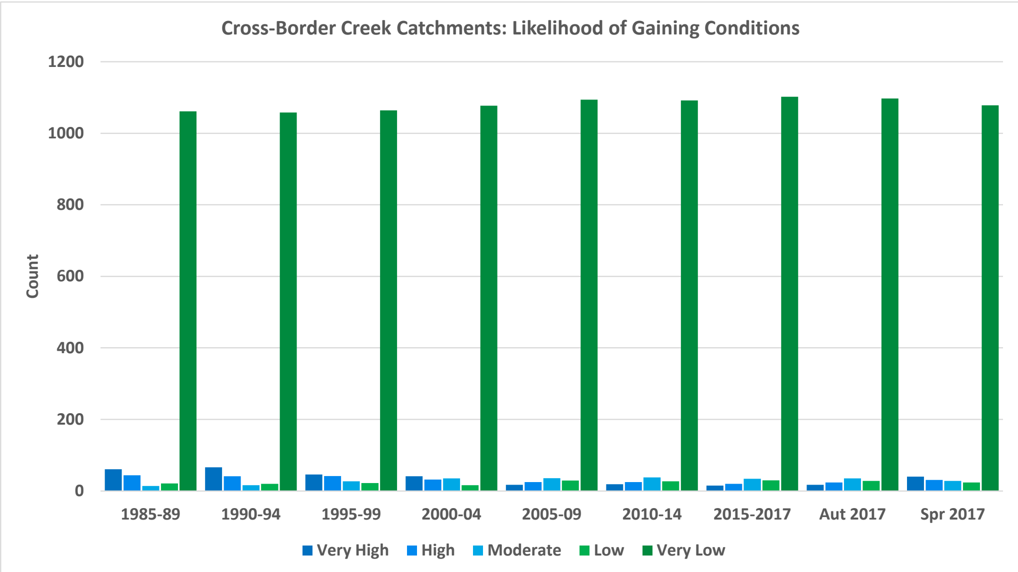


Figure 6.47. Likelihood of gaining conditions for wetlands, drains and watercourses for the spring of 2017

E. Thirty year summary of classifications (wetlands then drains) for each DMU





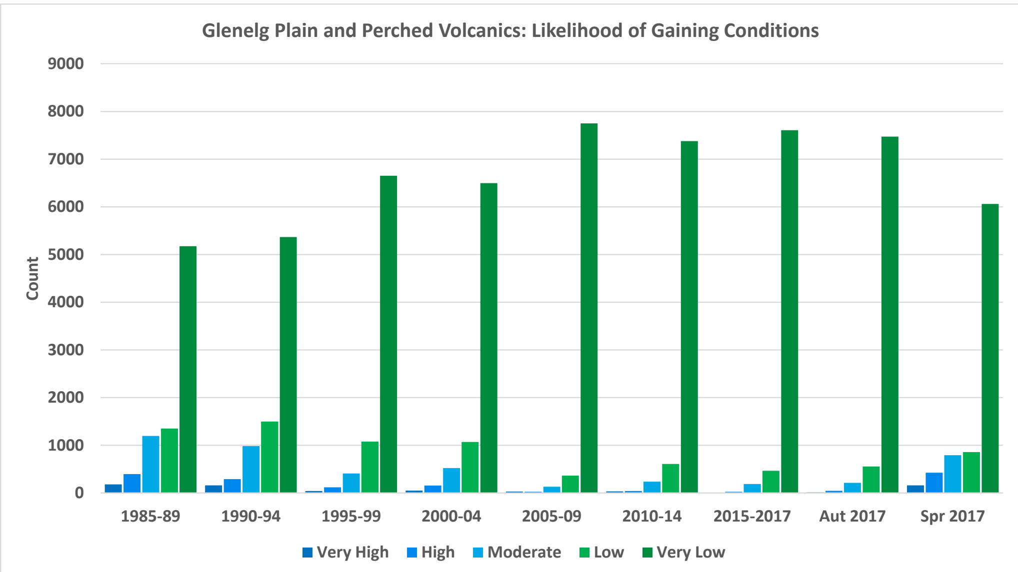
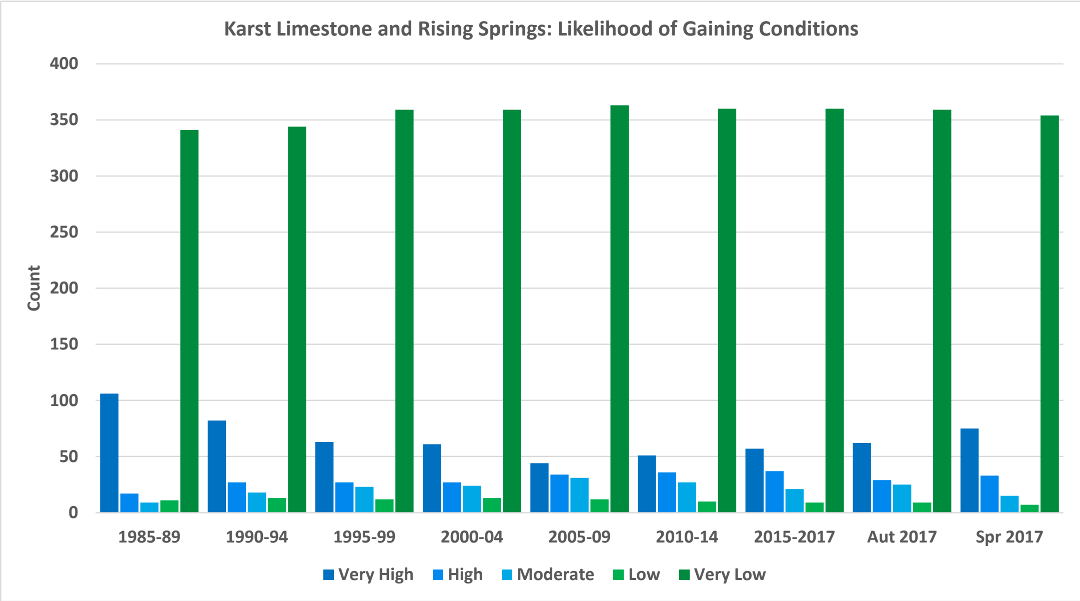
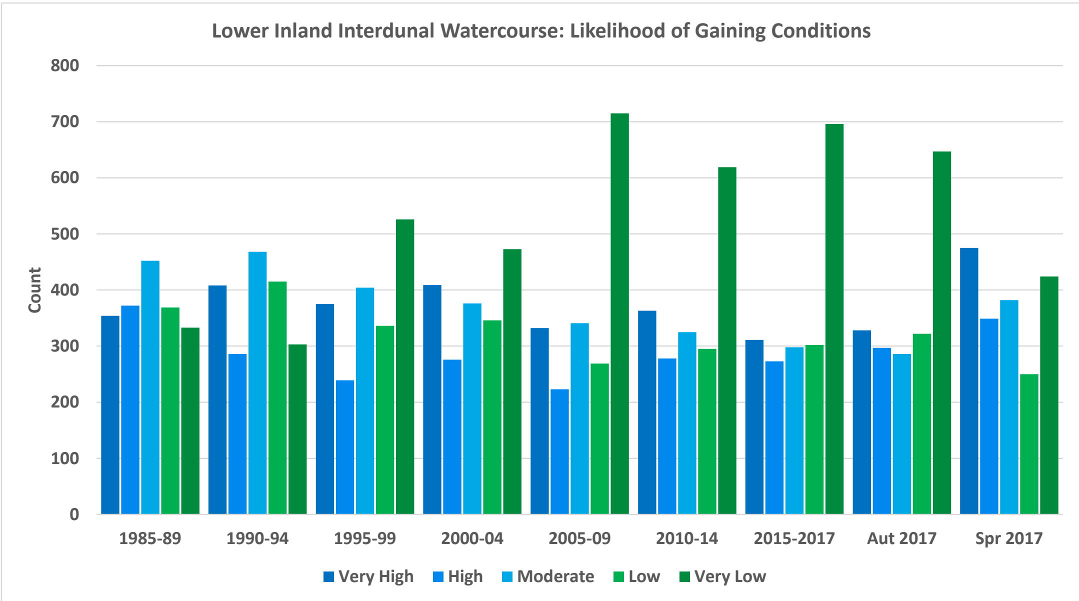


Figure 6.48. Change in GW–SW exchange classification for wetlands in three DMUs (0–3 of 12), segment count





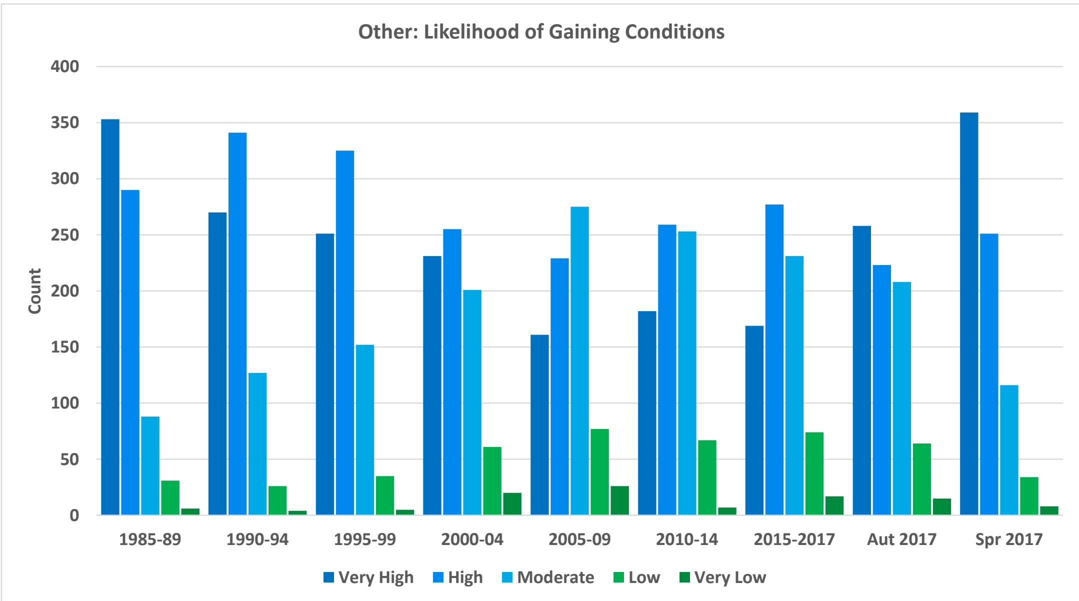
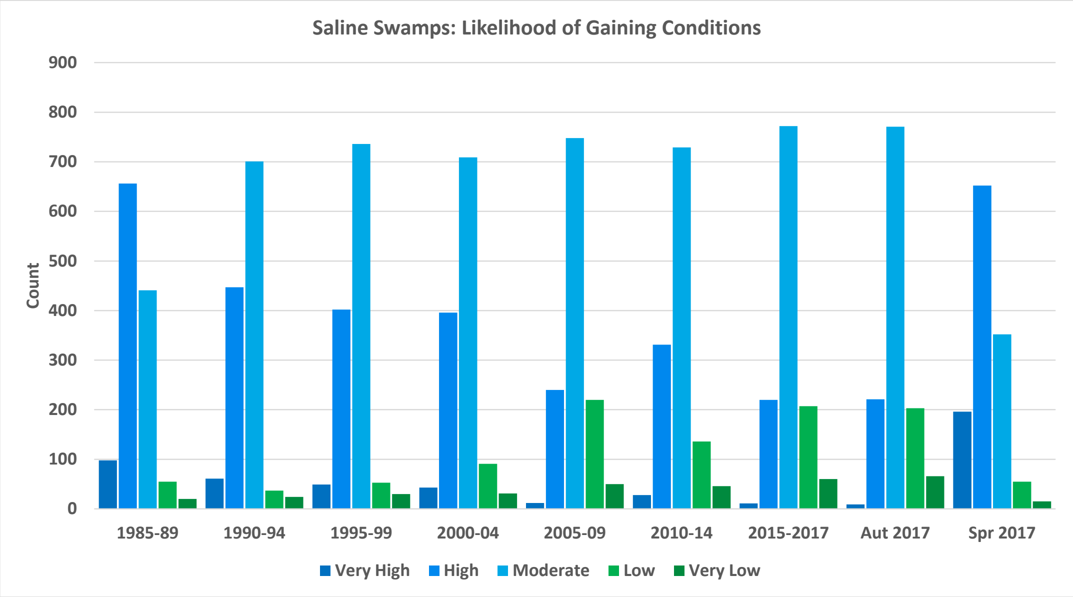
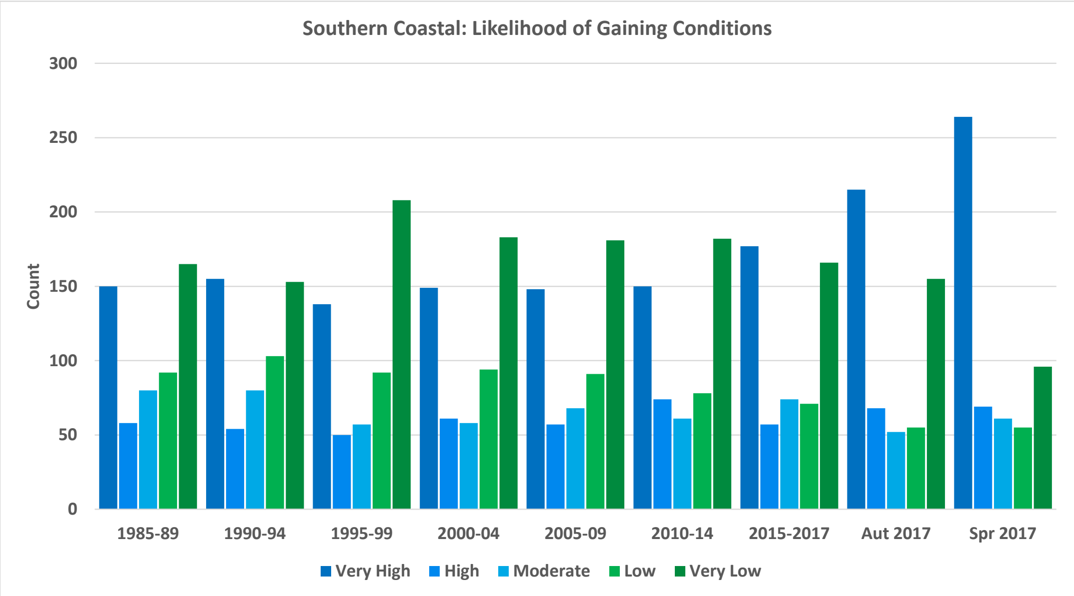


Figure 6.49. Change in GW–SW exchange classification for wetlands in three DMUs (4–6 of 12), segment count





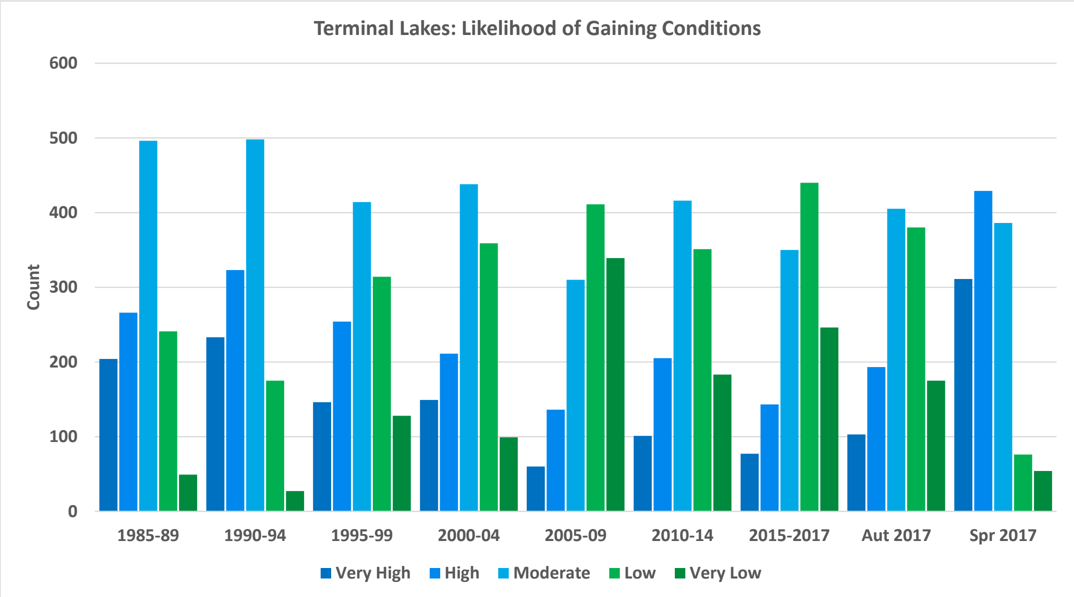
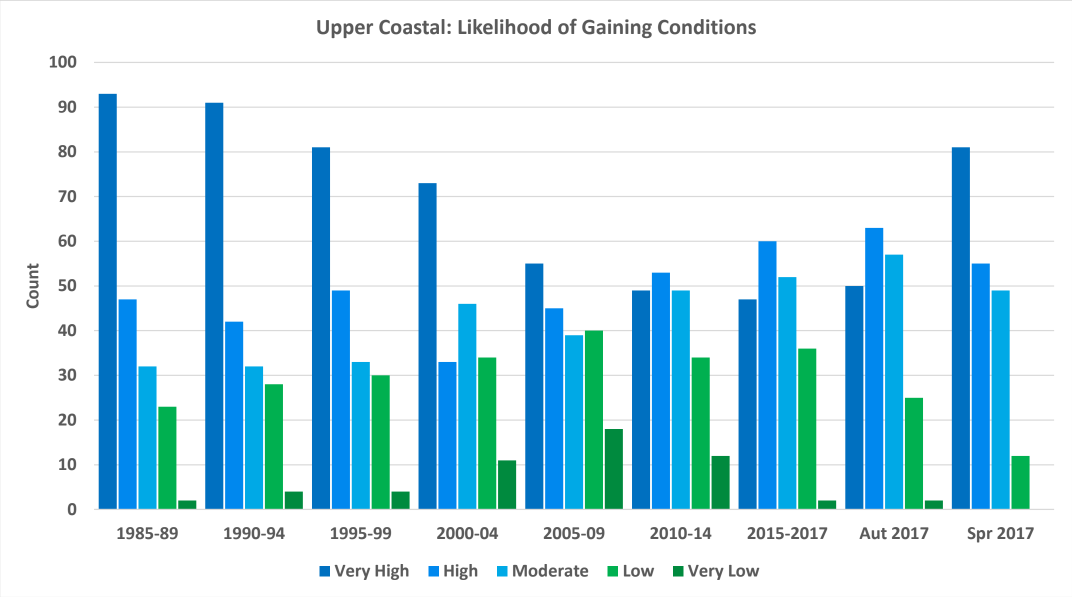
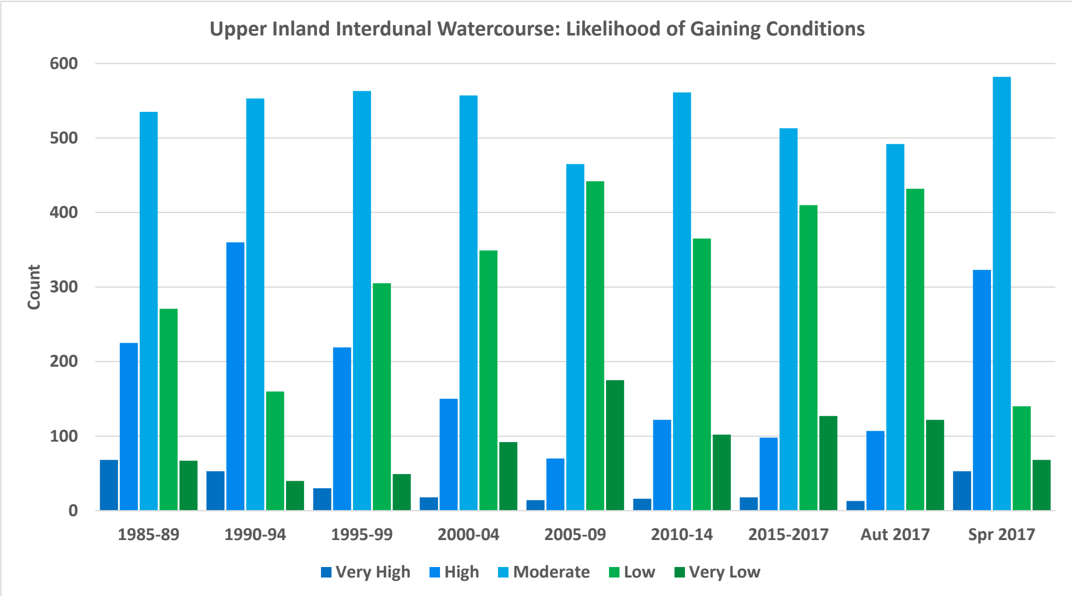


Figure 6.50. Change in GW–SW exchange classification for wetlands in three DMUs (7–9 of 12), segment count





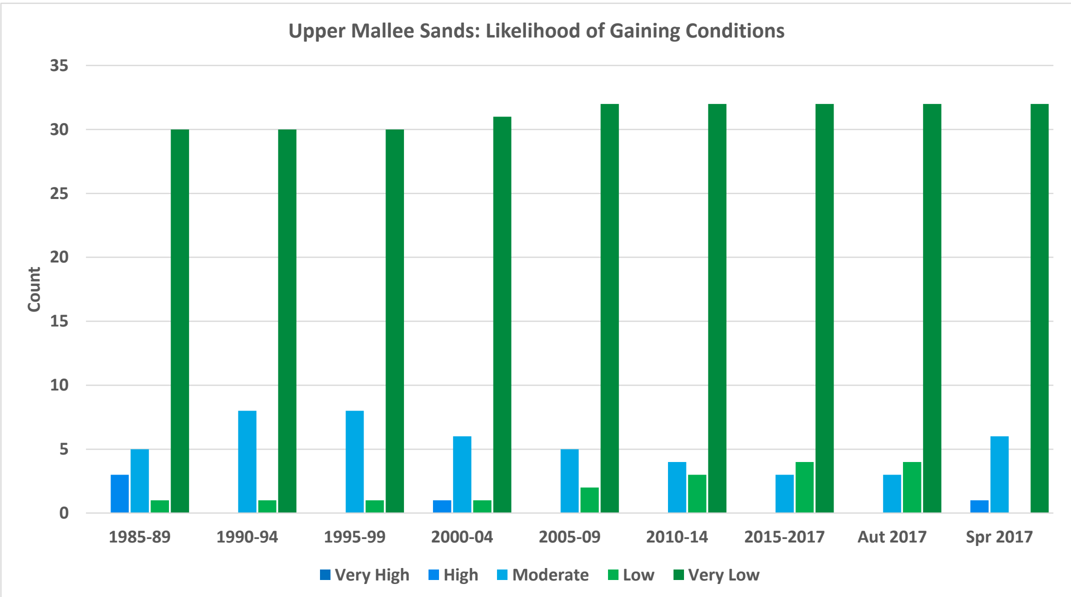
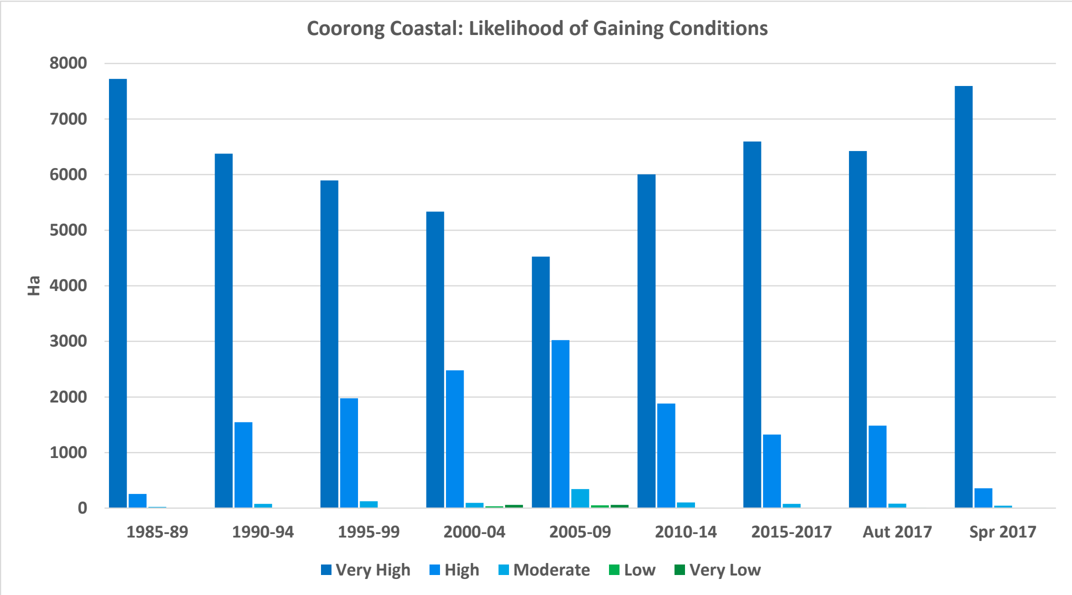
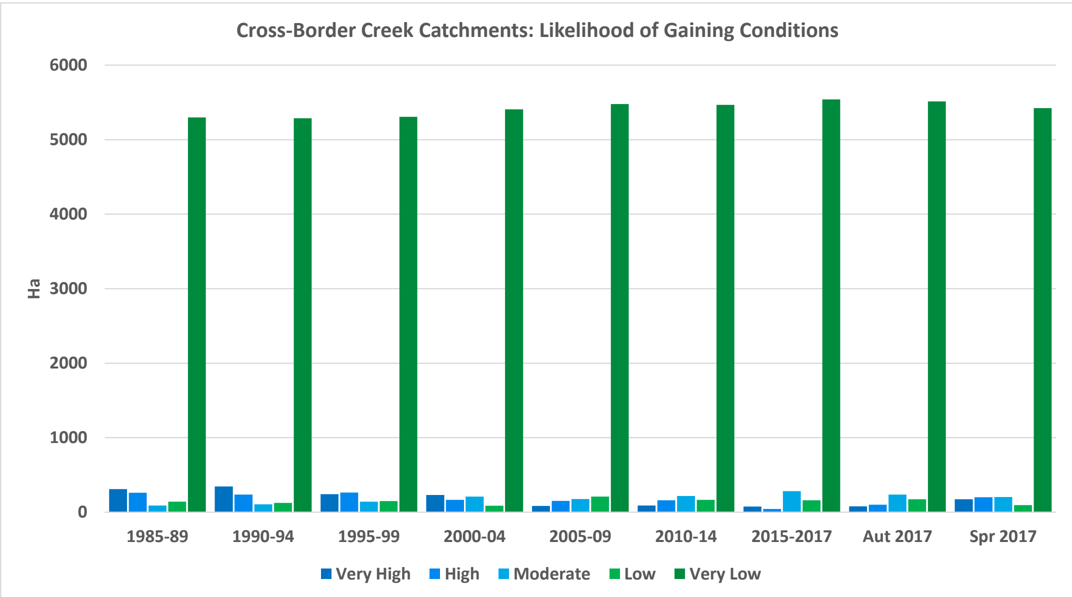


Figure 6.51. Change in GW–SW exchange classification for wetlands in three DMUs (10–12 of 12), segment count





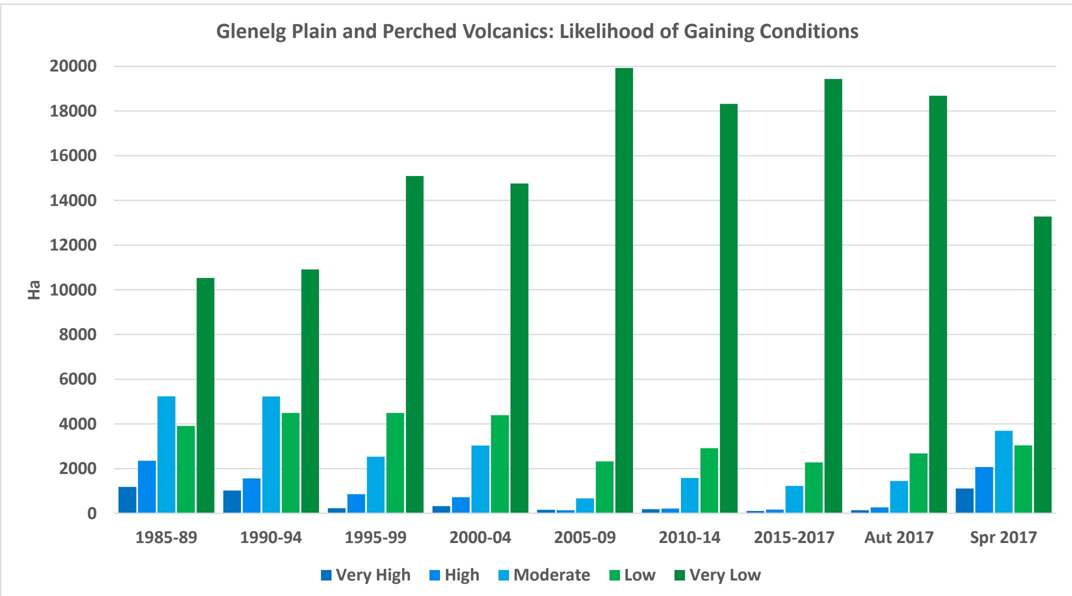


Figure 6.52. Change in GW–SW exchange classification for wetlands in three DMUs (0–3 of 12), length (km)

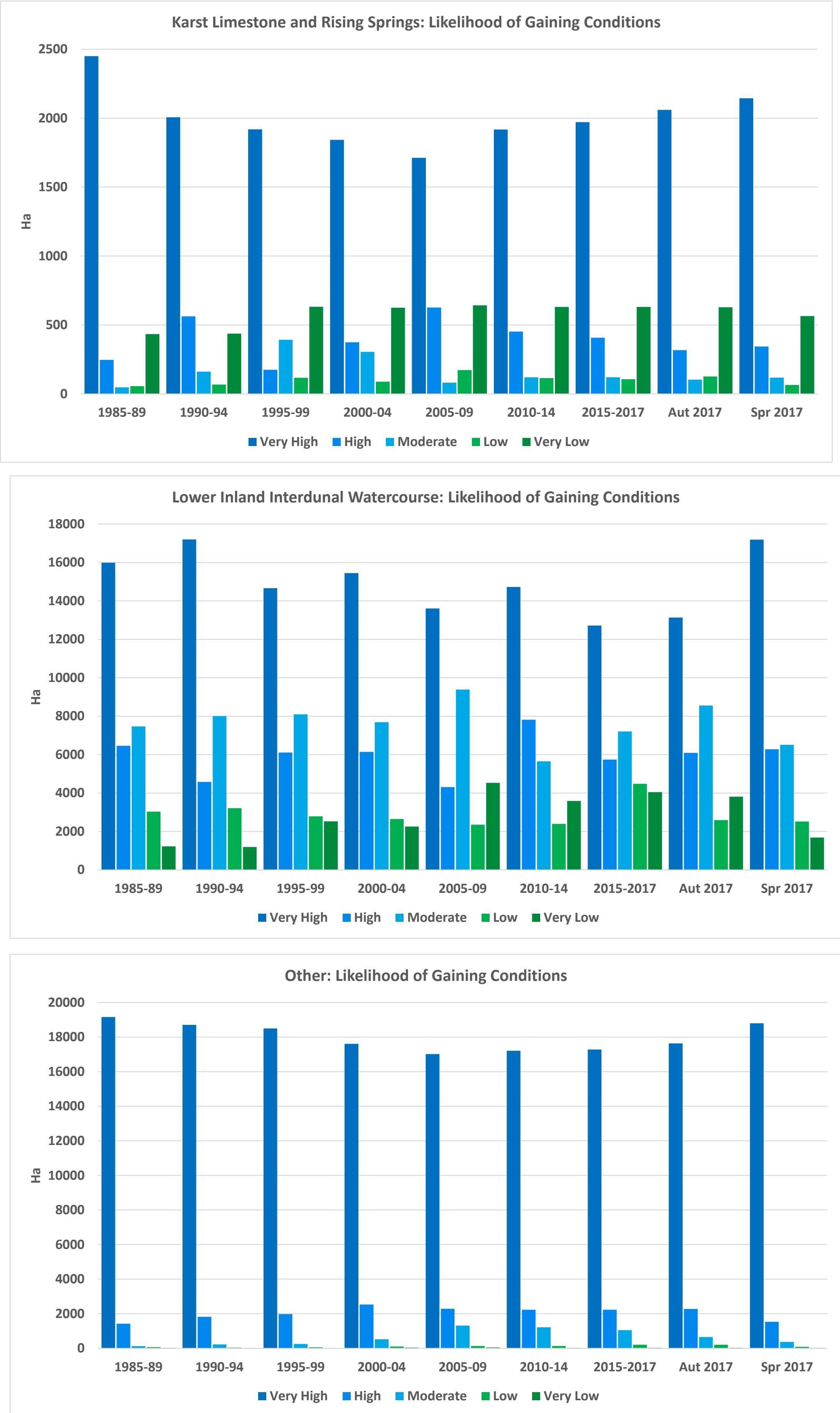
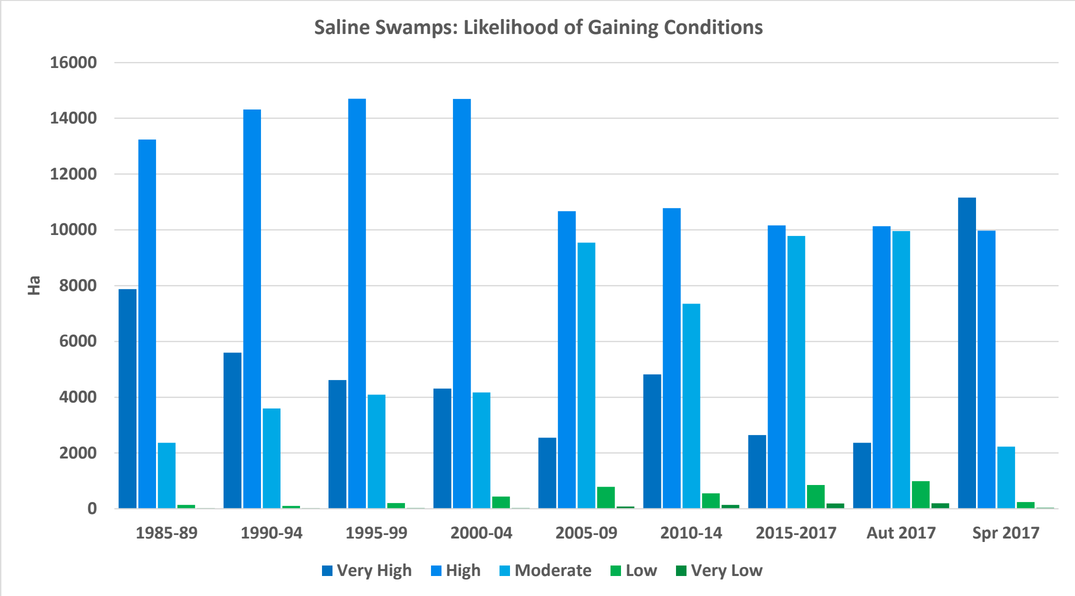
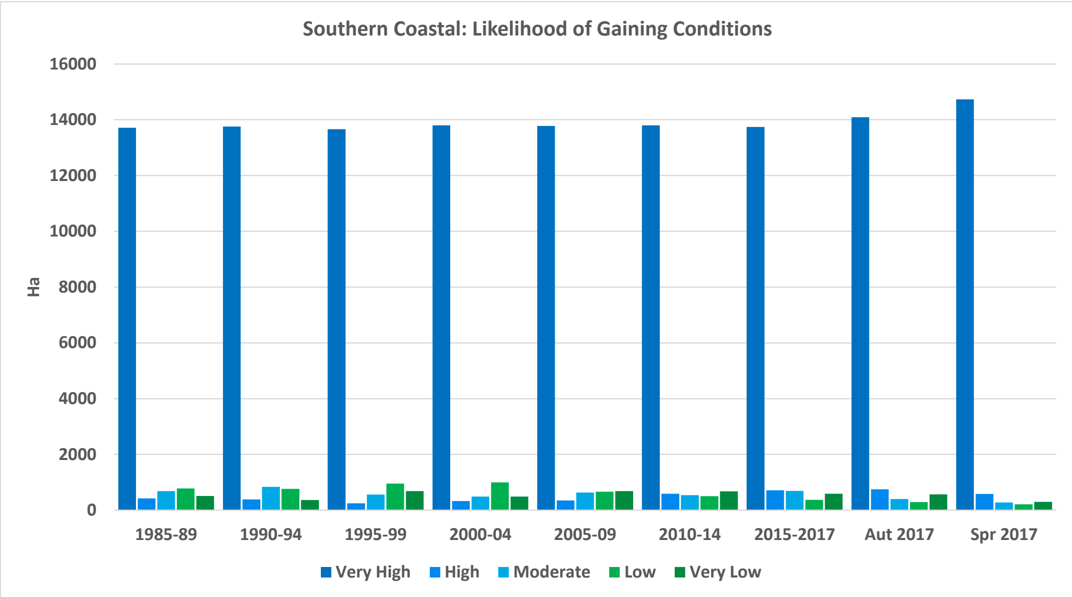


Figure 6.53. Change in GW–SW exchange classification for wetlands in three DMUs (4–6 of 12), length (km)





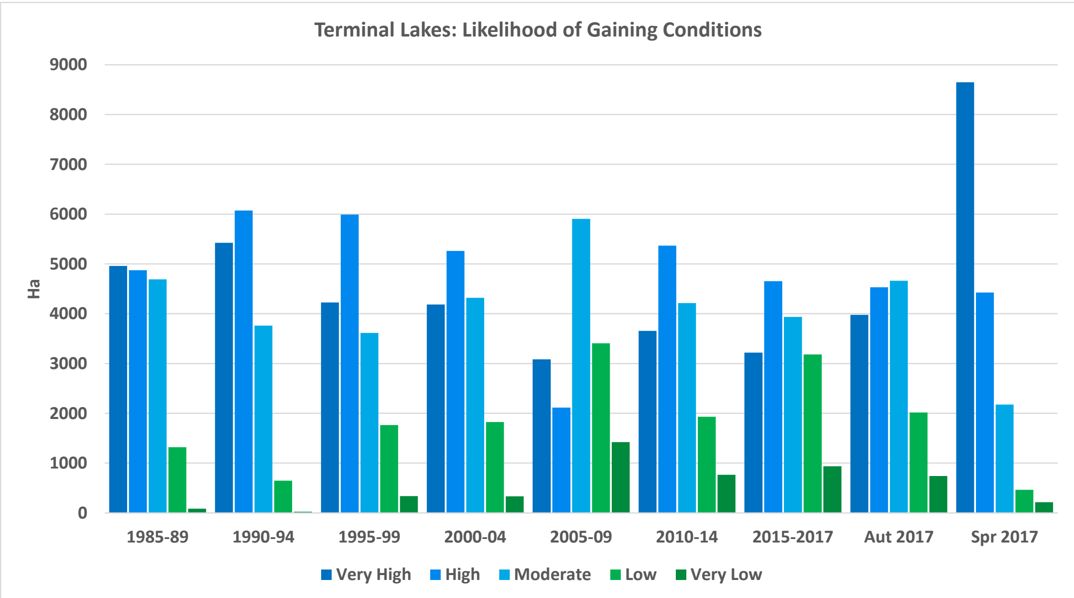
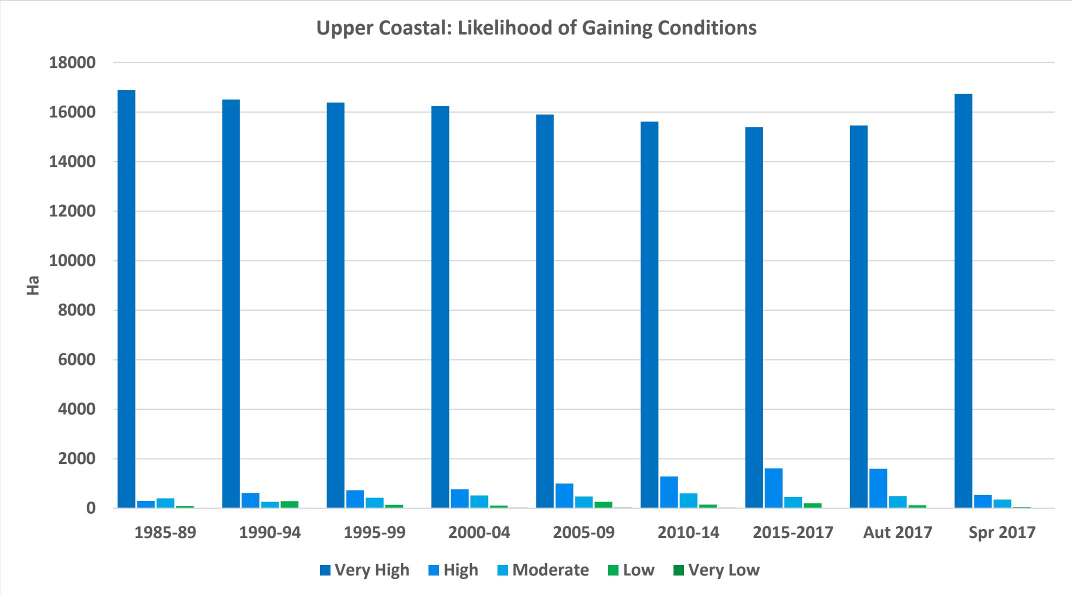
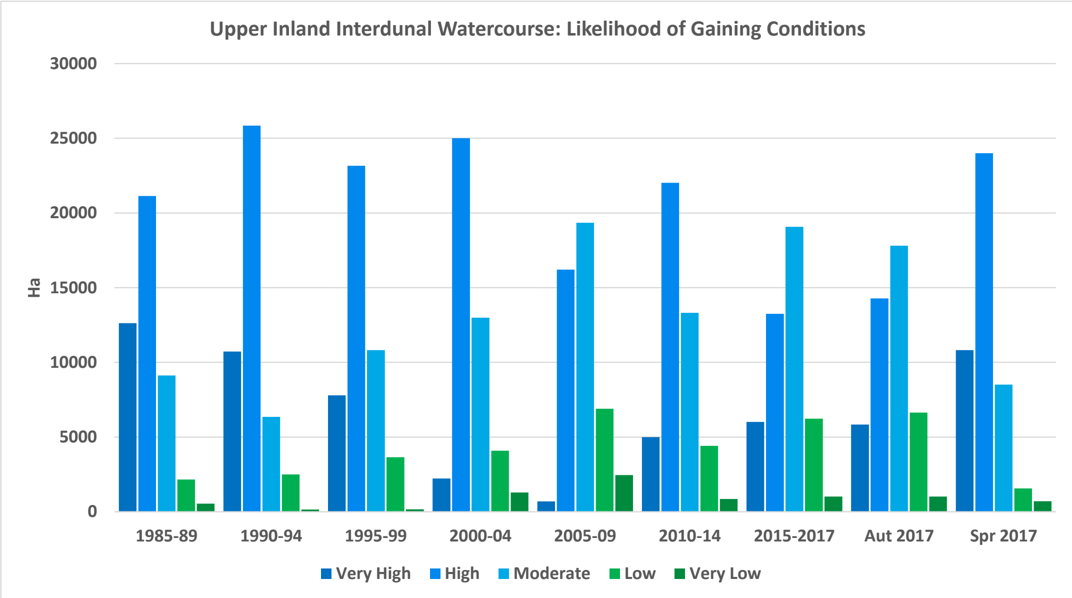


Figure 6.54. Change in GW–SW exchange classification for wetlands in three DMUs (7–9 of 12), length (km)





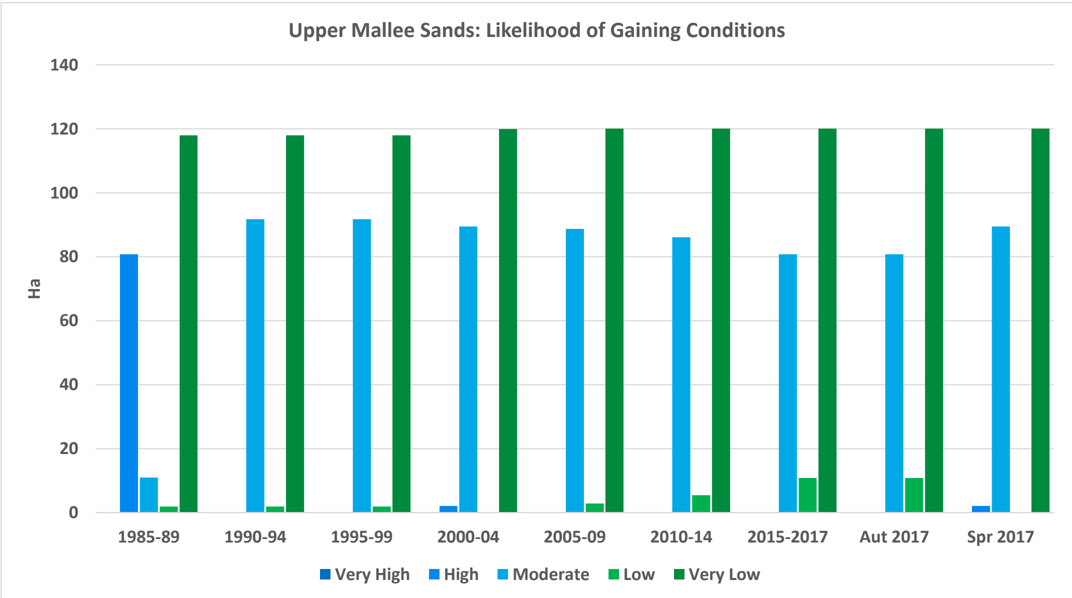
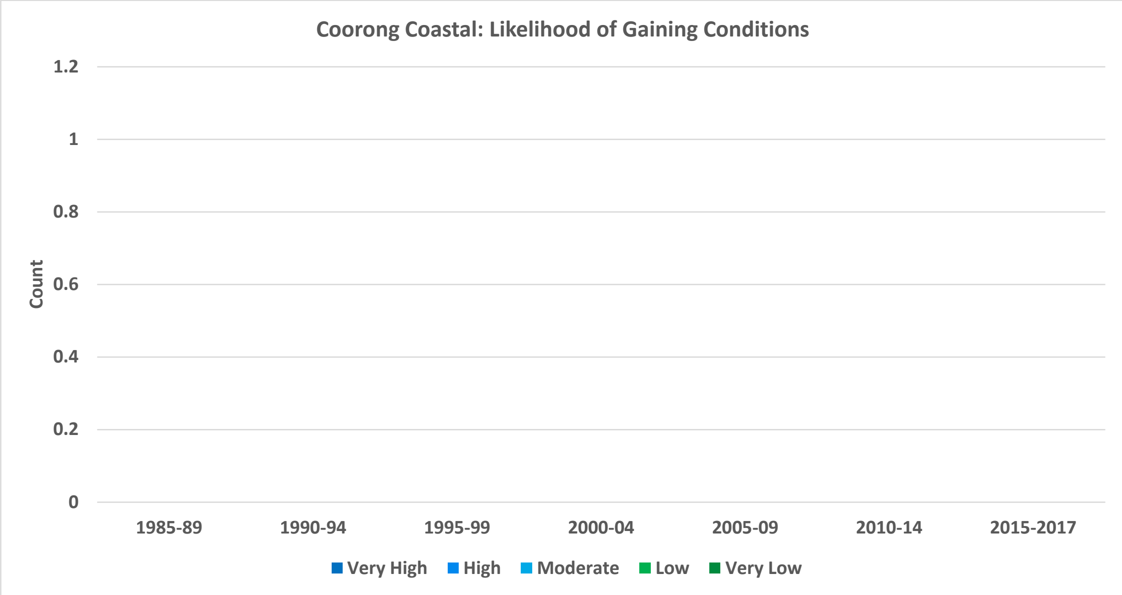
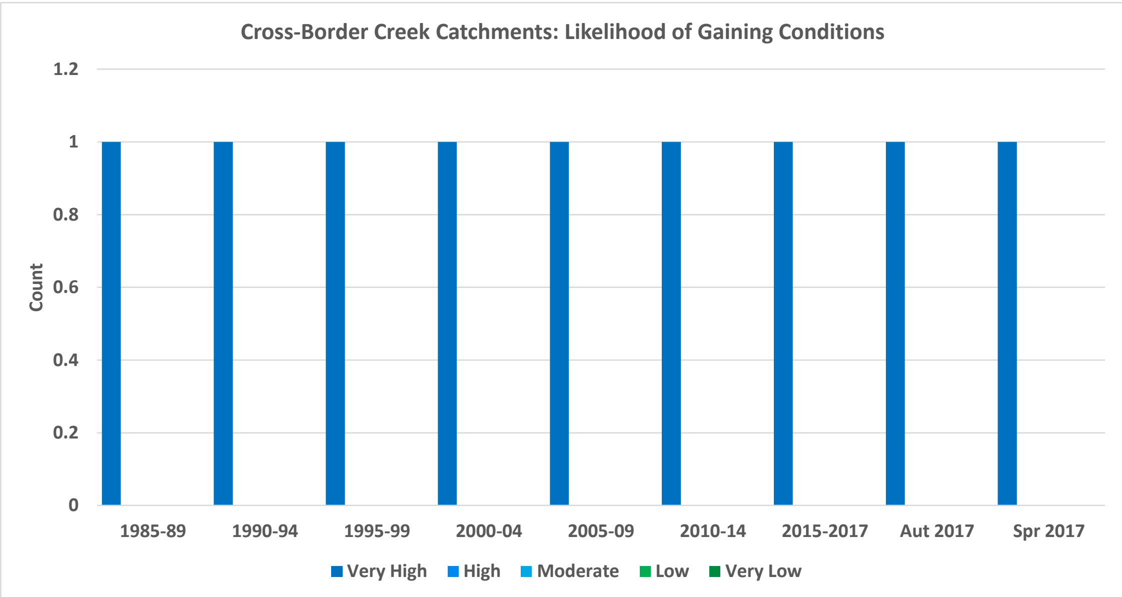


Figure 6.55. Change in GW–SW exchange classification for wetlands in three DMUs (10–12 of 12), length (km)





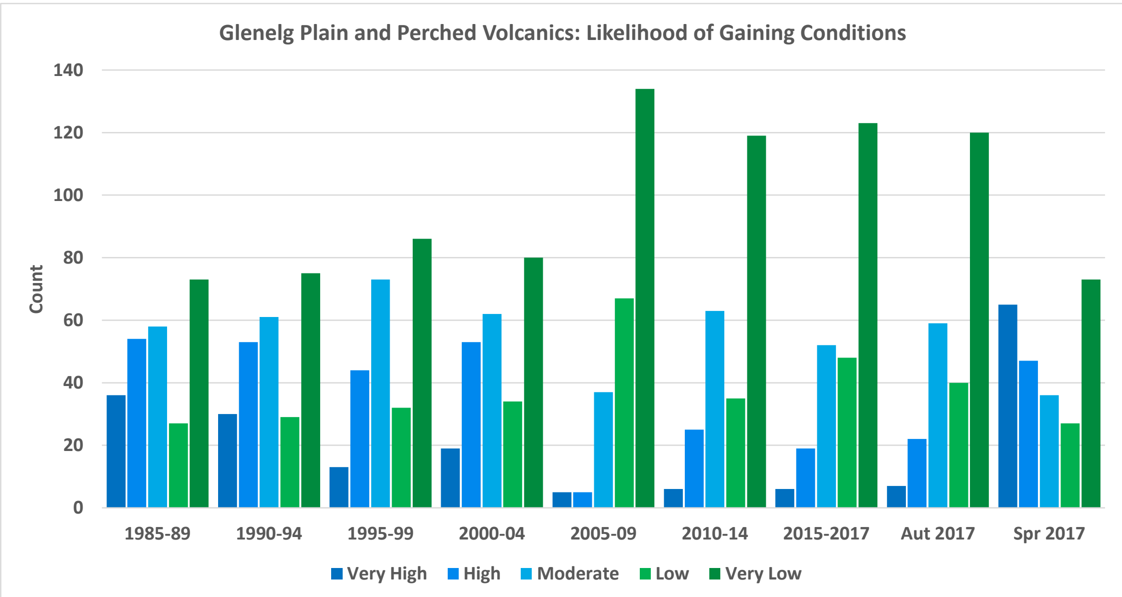
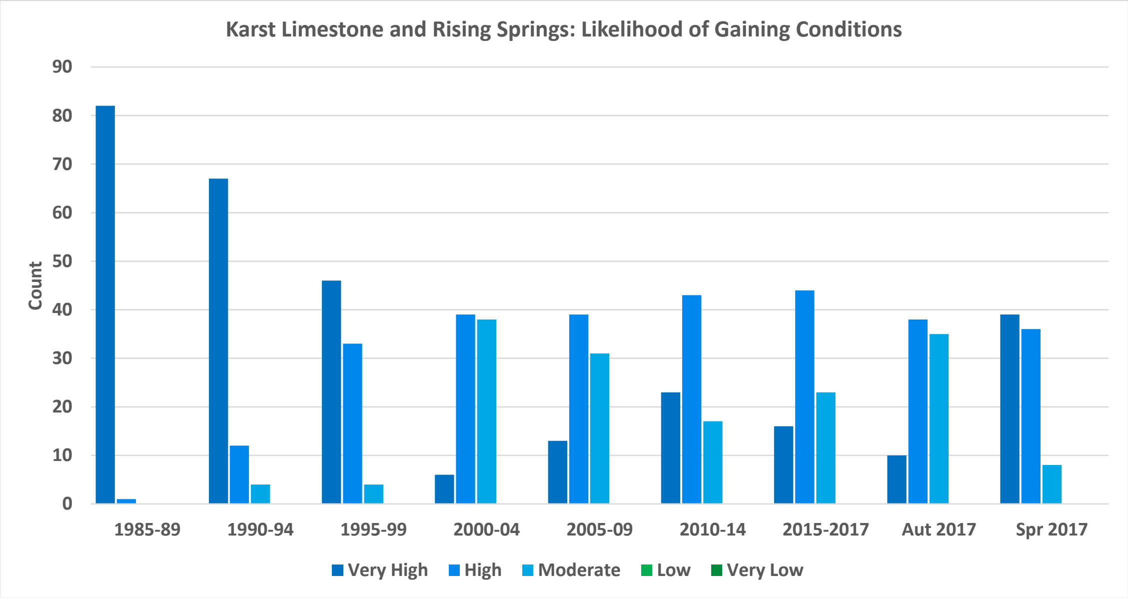
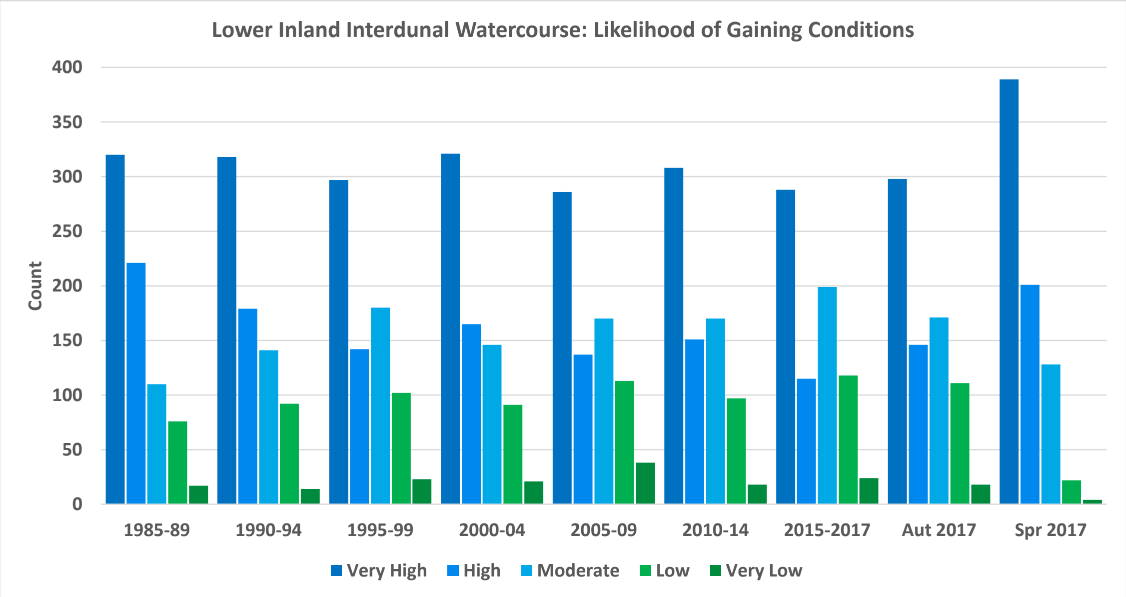


Figure 6.56. Change in GW–SW exchange classification for drains in three DMUs (0–3 of 12), count





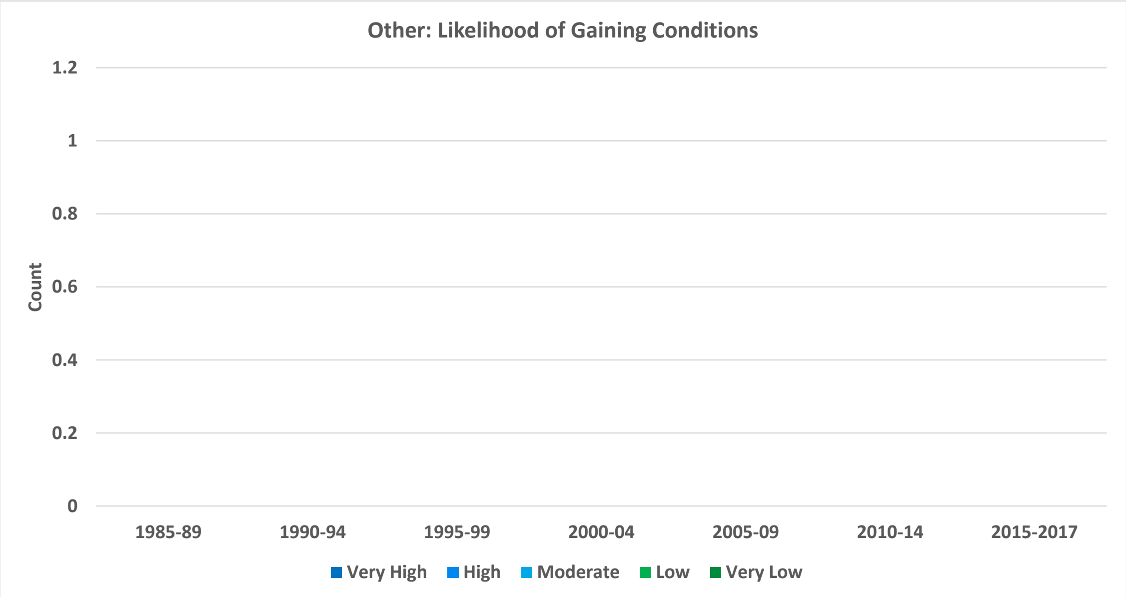
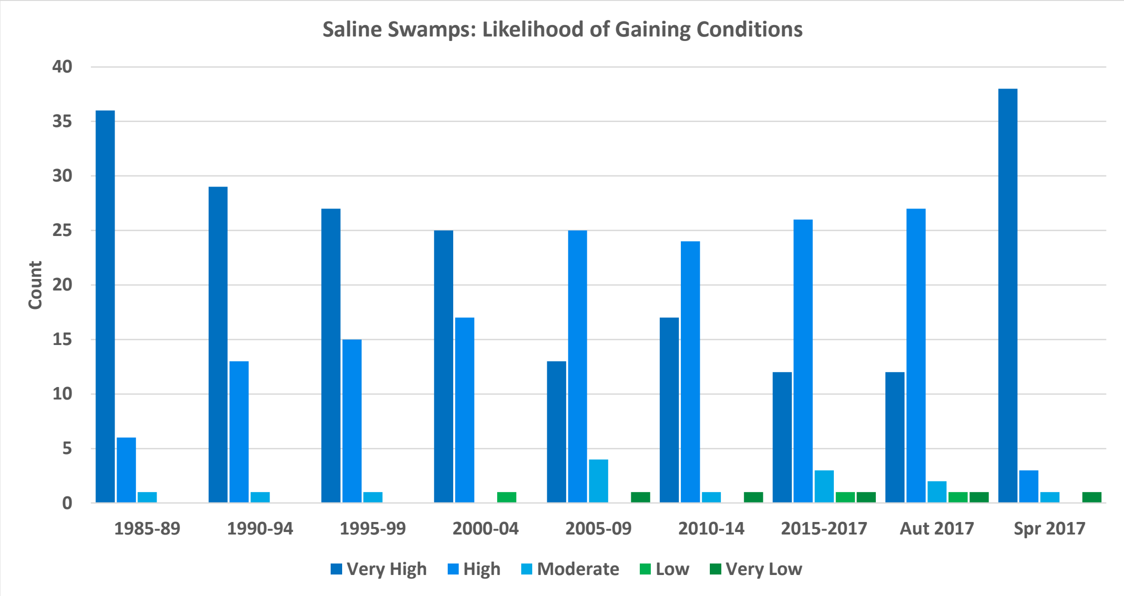
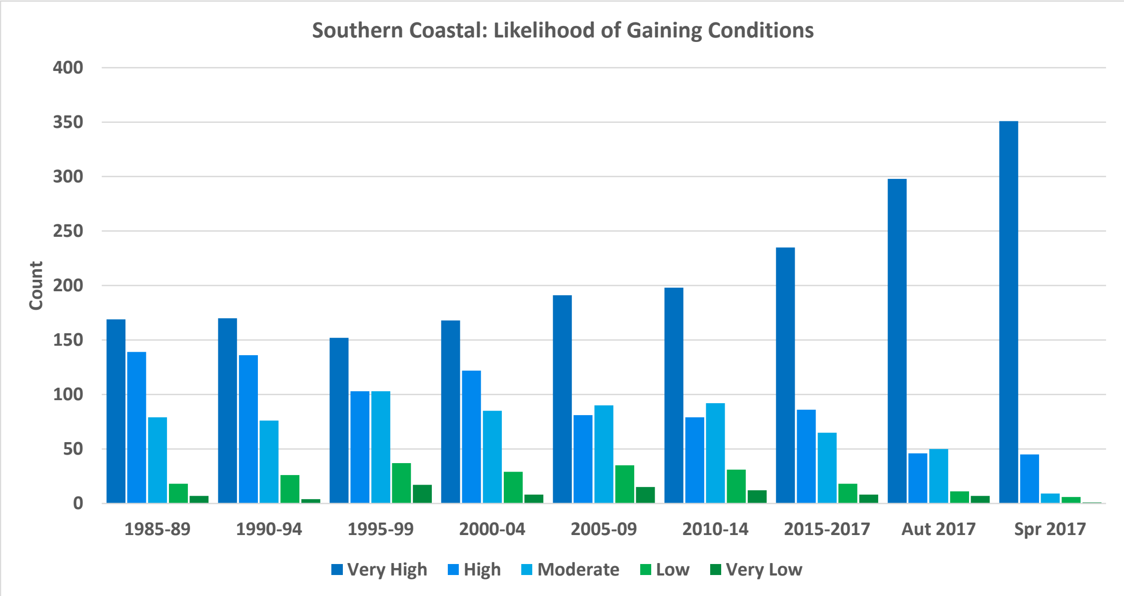


Figure 6.57. Change in GW–SW exchange classification for drains in three DMUs (4–6 of 12), count





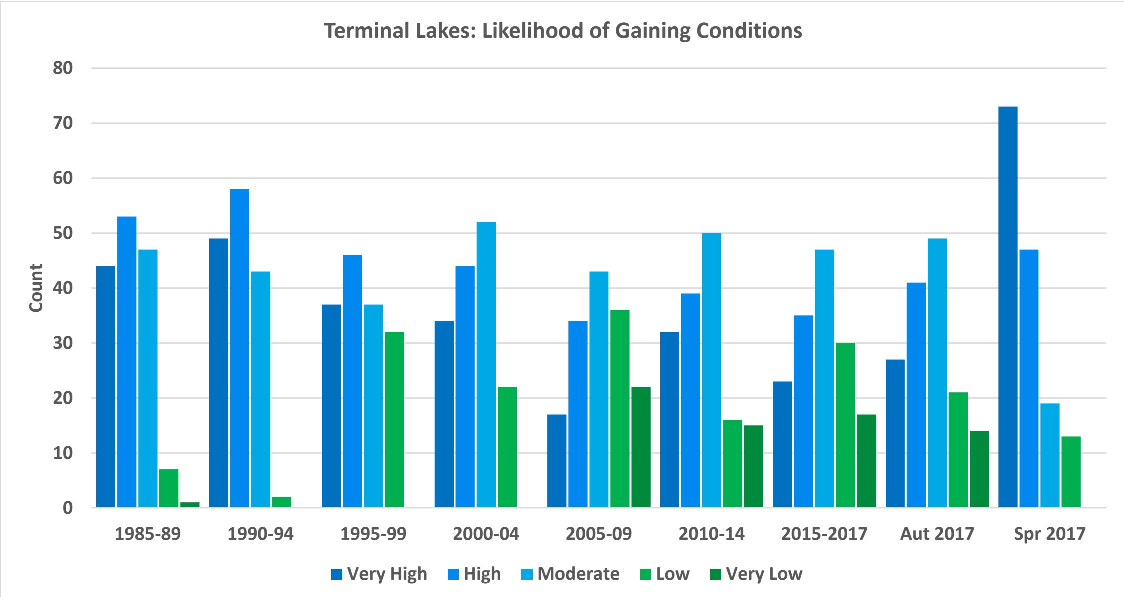
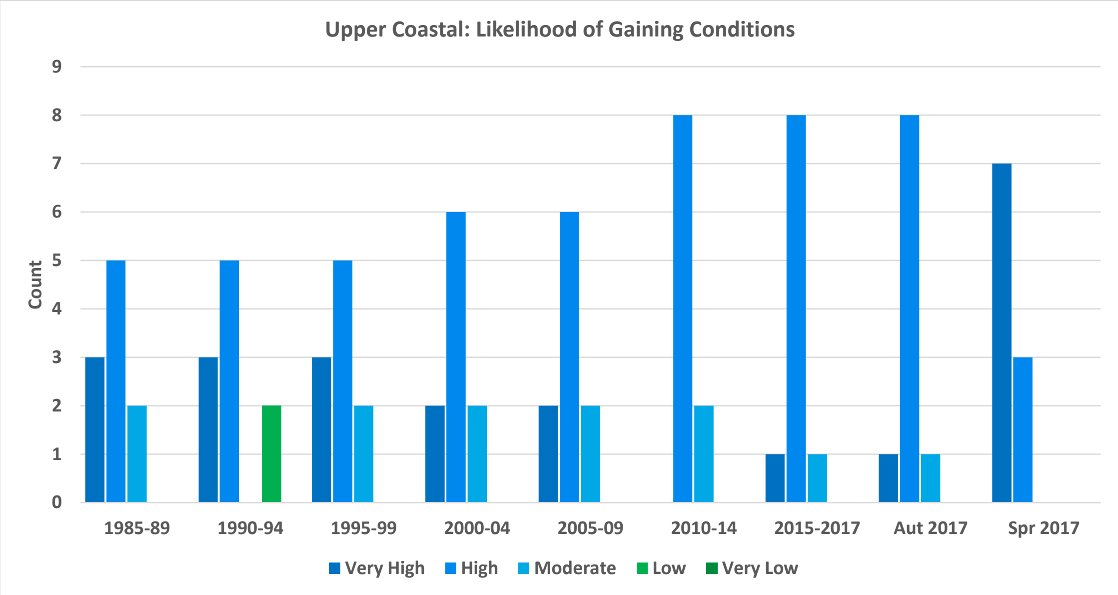
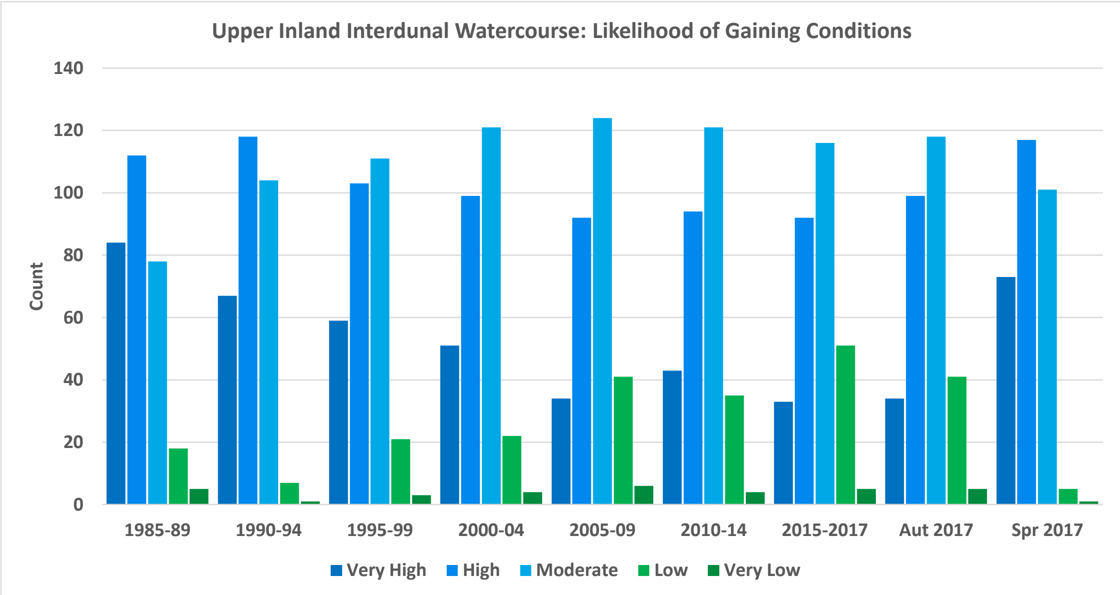


Figure 6.58. Change in GW–SW exchange classification for drains in three DMUs (7–9 of 12), count





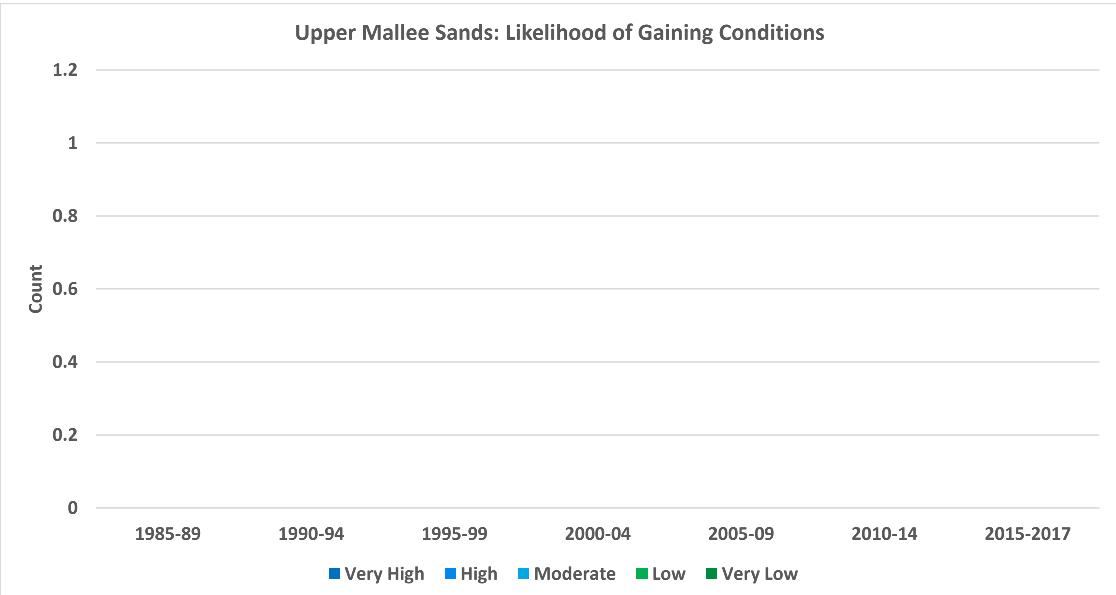
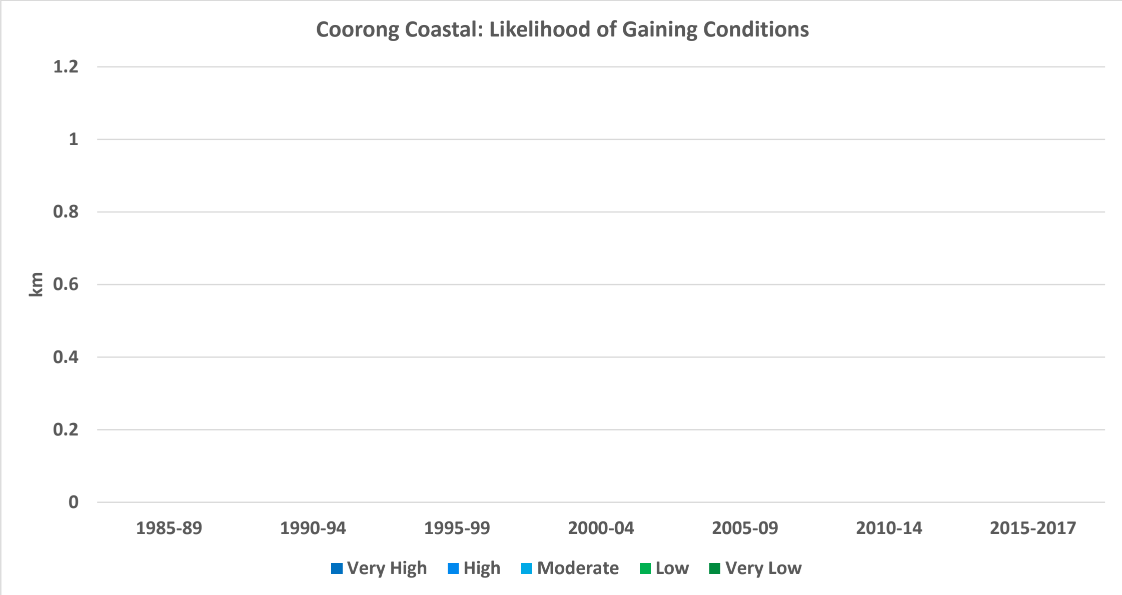
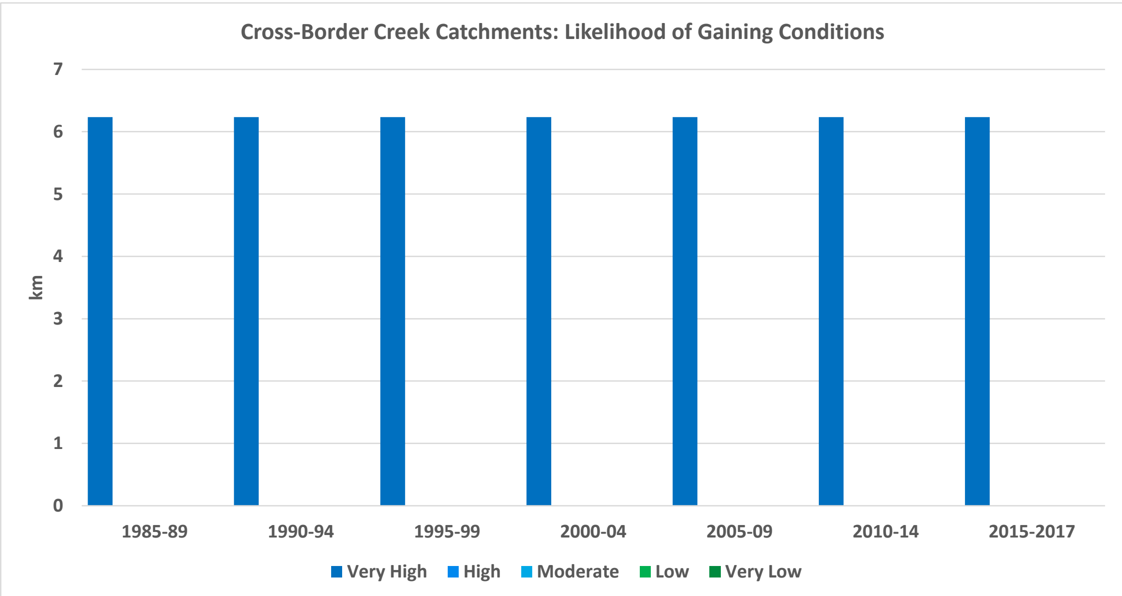


Figure 6.59. Change in GW–SW exchange classification for drains in three DMUs (10–12 of 12), count





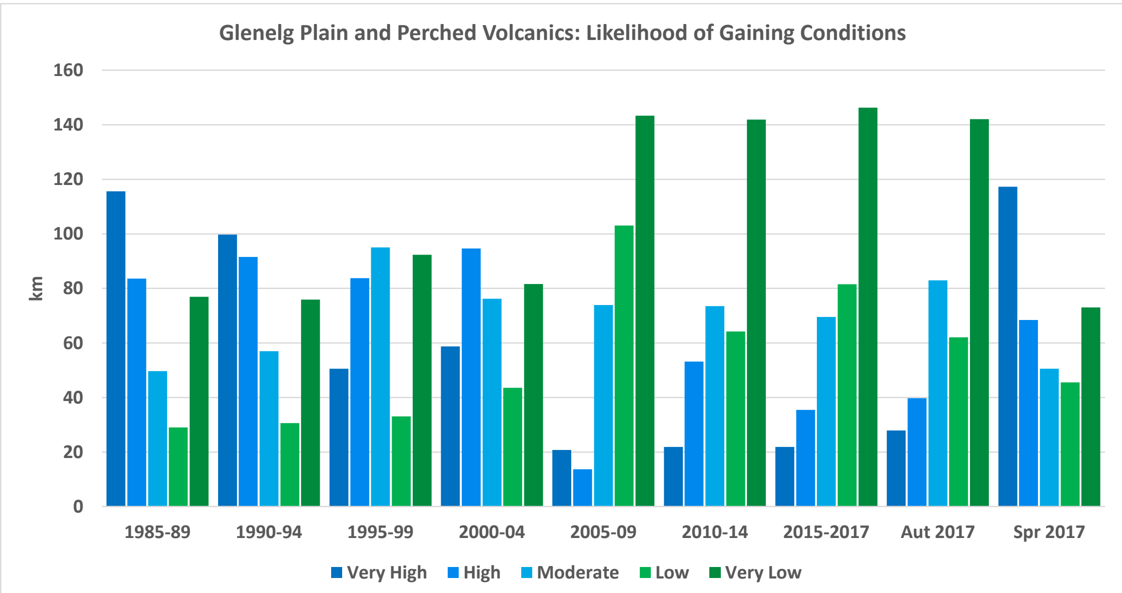
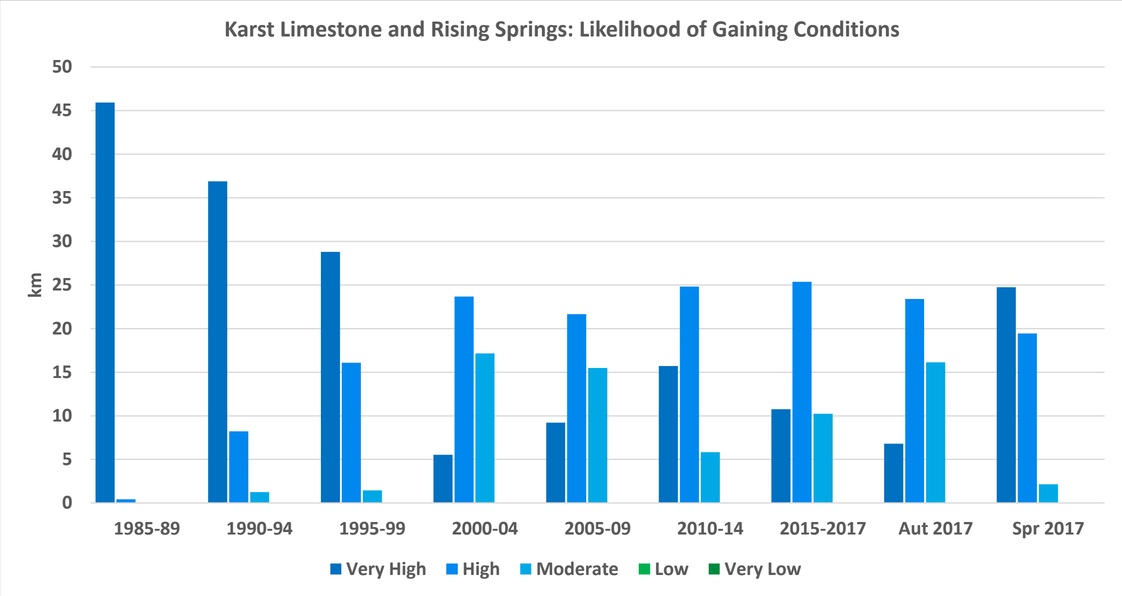
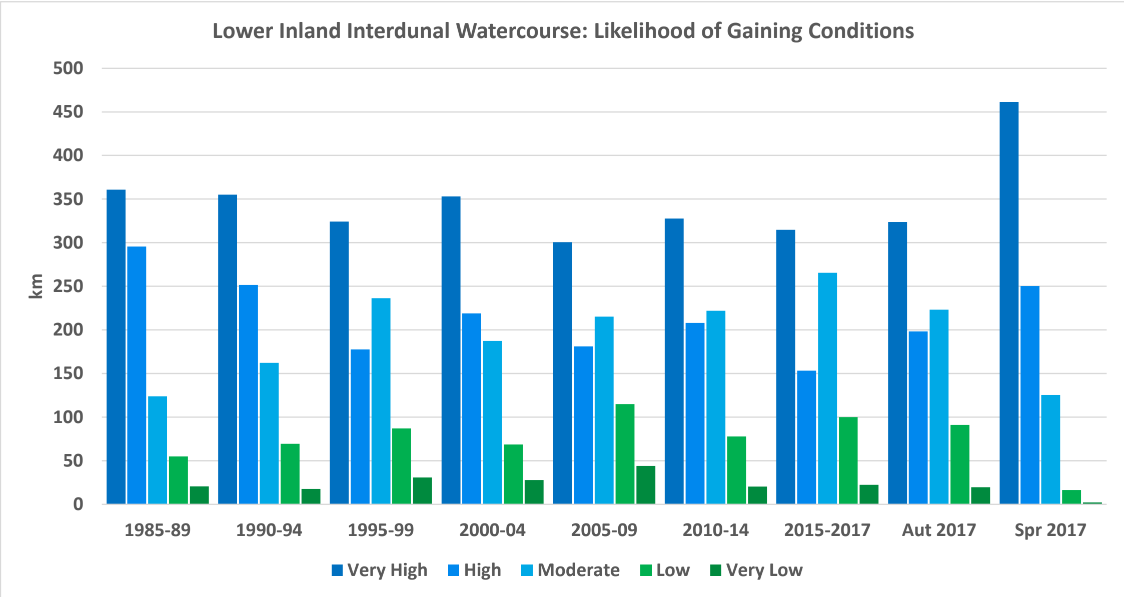


Figure 6.60. Change in GW–SW exchange classification for drains in three DMUs (0–3 of 12), area (Ha)





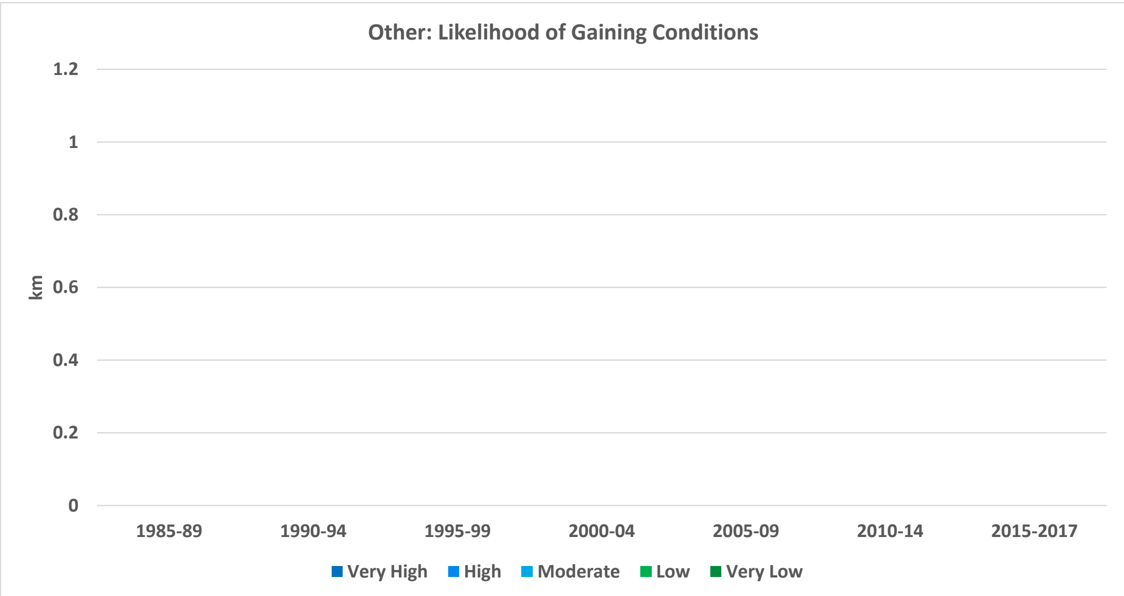
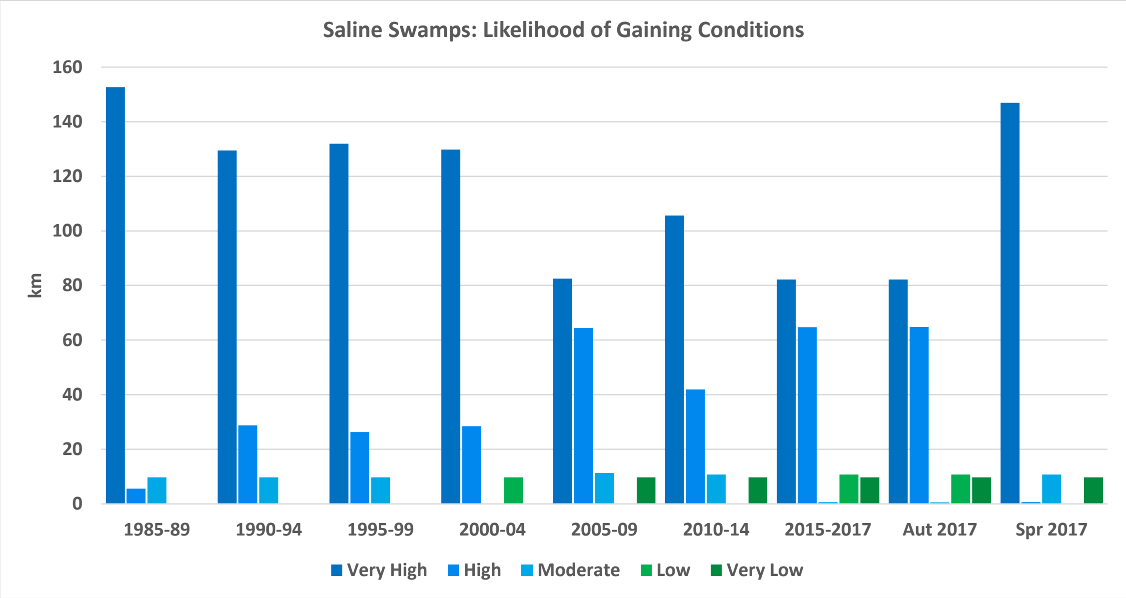
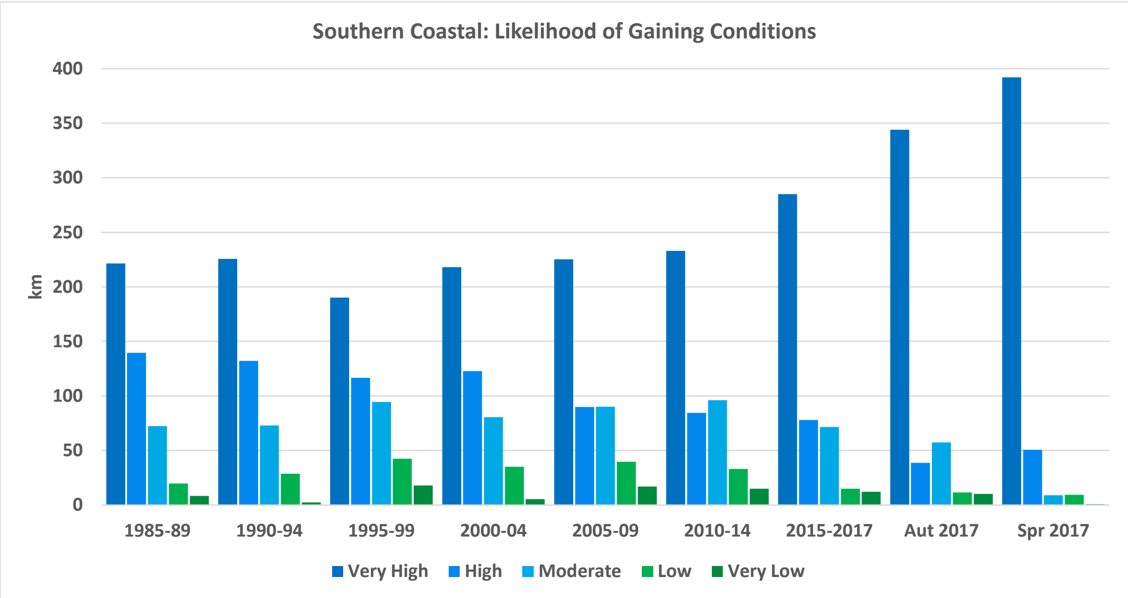


Figure 6.61. Change in GW–SW exchange classification for drains in three DMUs (4–6 of 12), area (Ha)





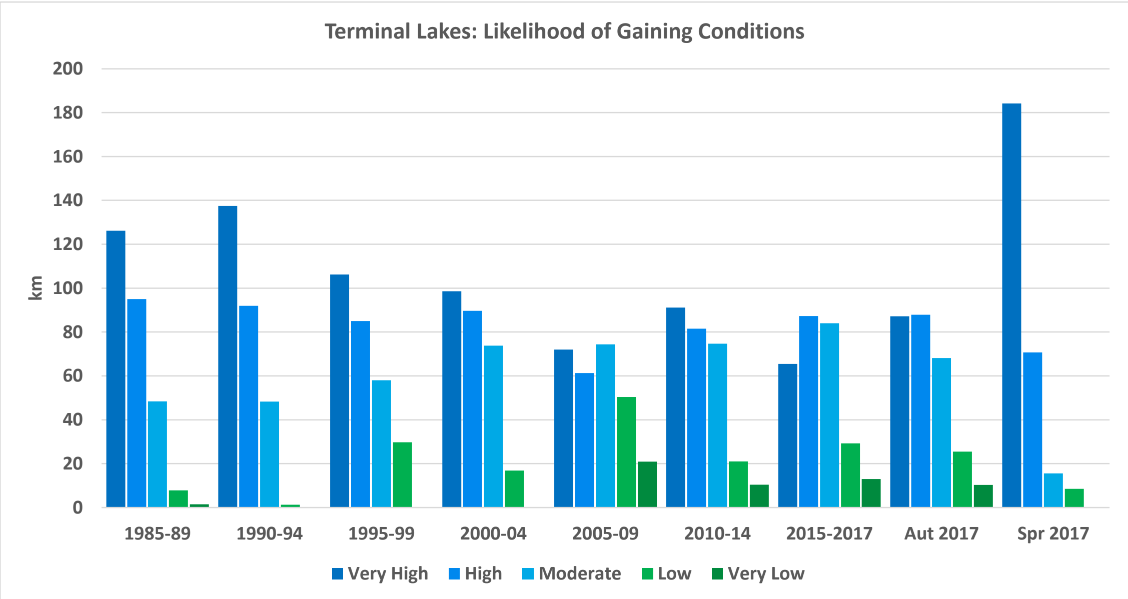


Figure 6.62. Change in GW–SW exchange classification for drains in three DMUs (7–9 of 12), area (Ha)

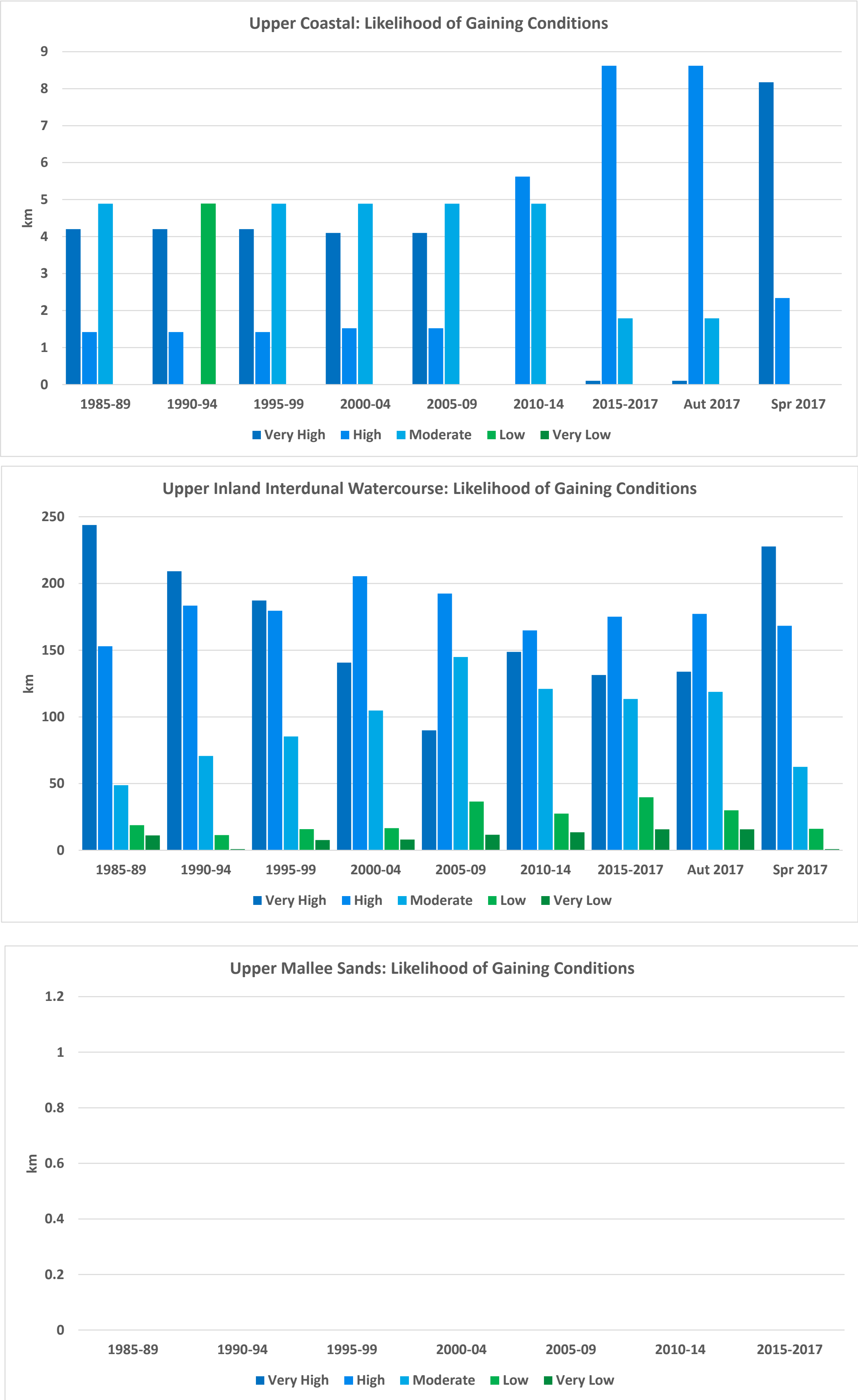


Figure 6.63. Change in GW–SW exchange classification for drains in three DMUs (10–12 of 12), area (Ha)

F. Comparison of autumn and spring 2017 classifications for each DMU

Below are figures comparing the likelihood of gaining conditions for wetlands, drains and watercourses for each of the DMUs in the autumn and spring of 2017.

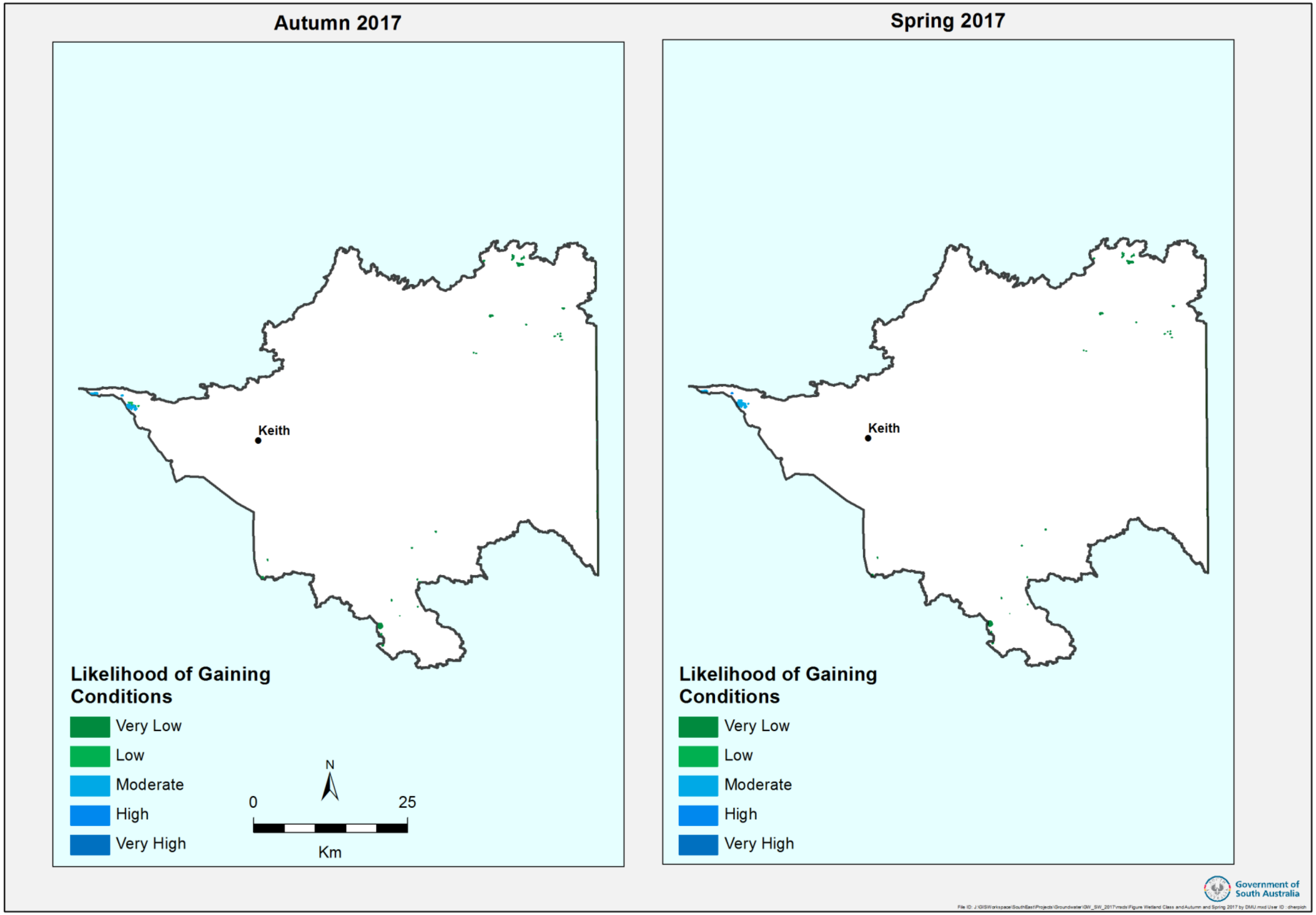


Figure 6.64. Autumn and spring 2017 GW–SW exchange classification in the Upper Mallee Sands DMU

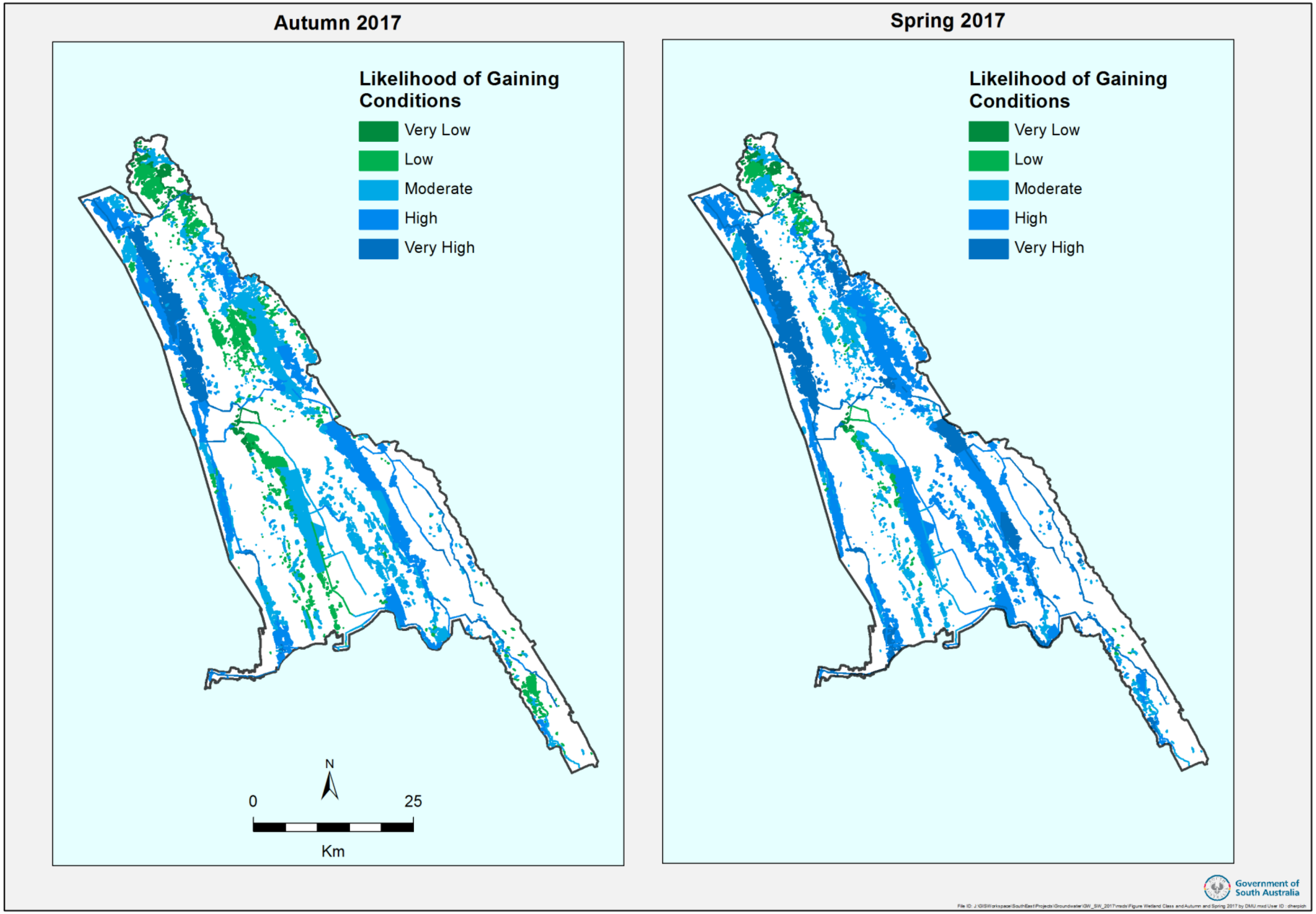


Figure 6.65. Autumn and spring 2017 GW–SW exchange classification in the Upper Interdunal Watercourses DMU

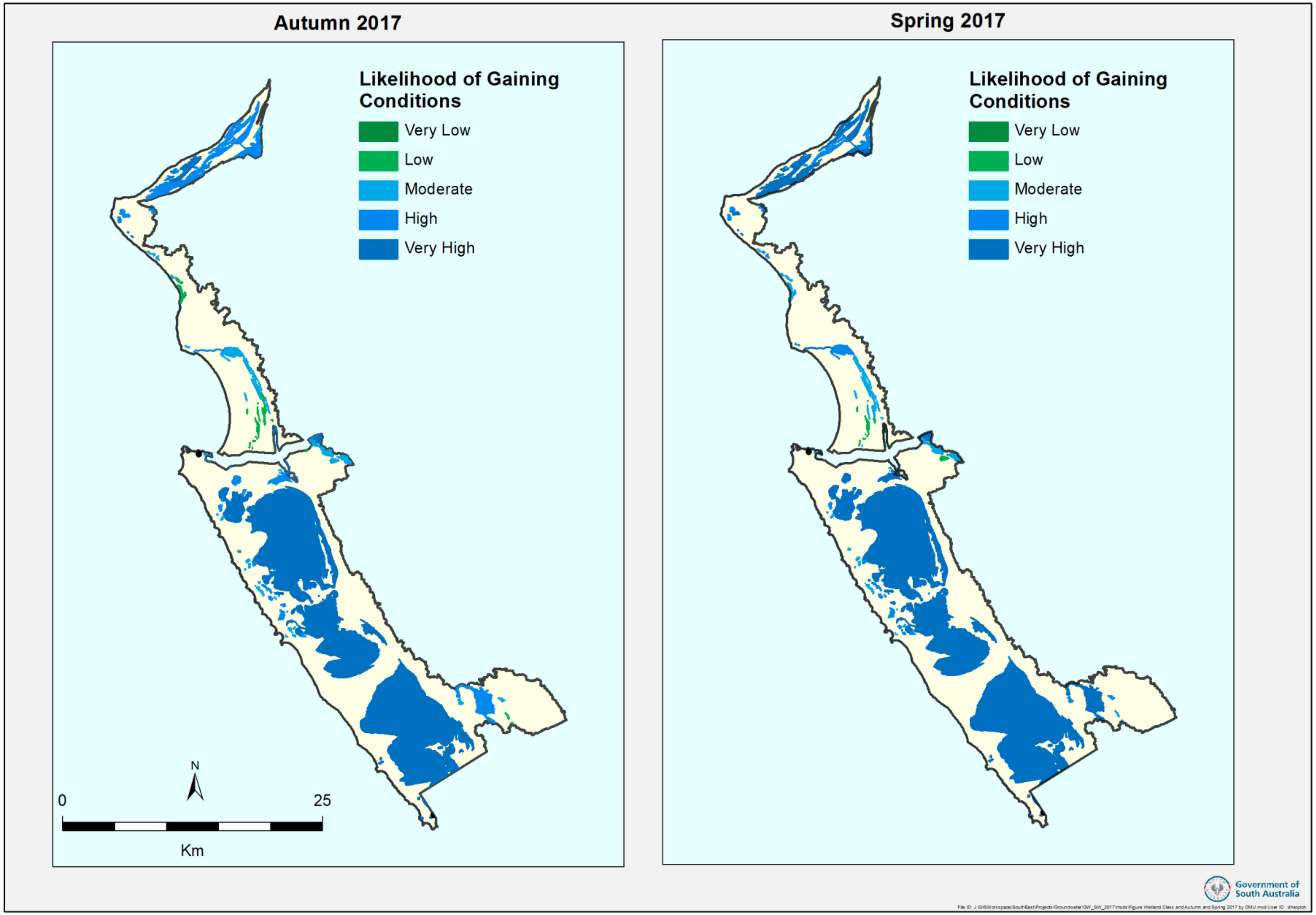


Figure 6.66. Autumn and spring 2017 GW–SW exchange classification in the Upper Coastal DMU

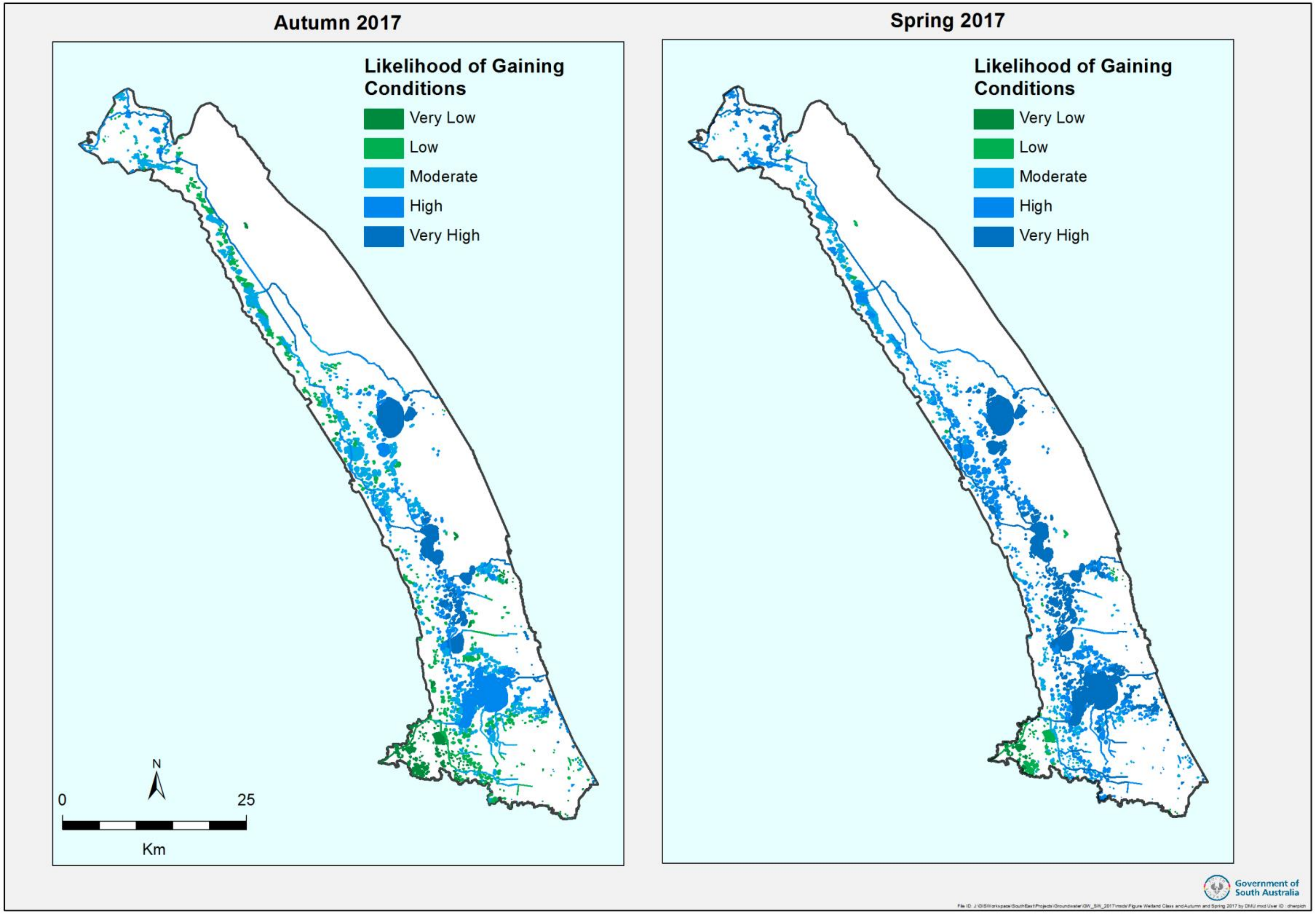


Figure 6.67. Autumn and spring 2017 GW–SW exchange classification in the Terminal Lakes DMU

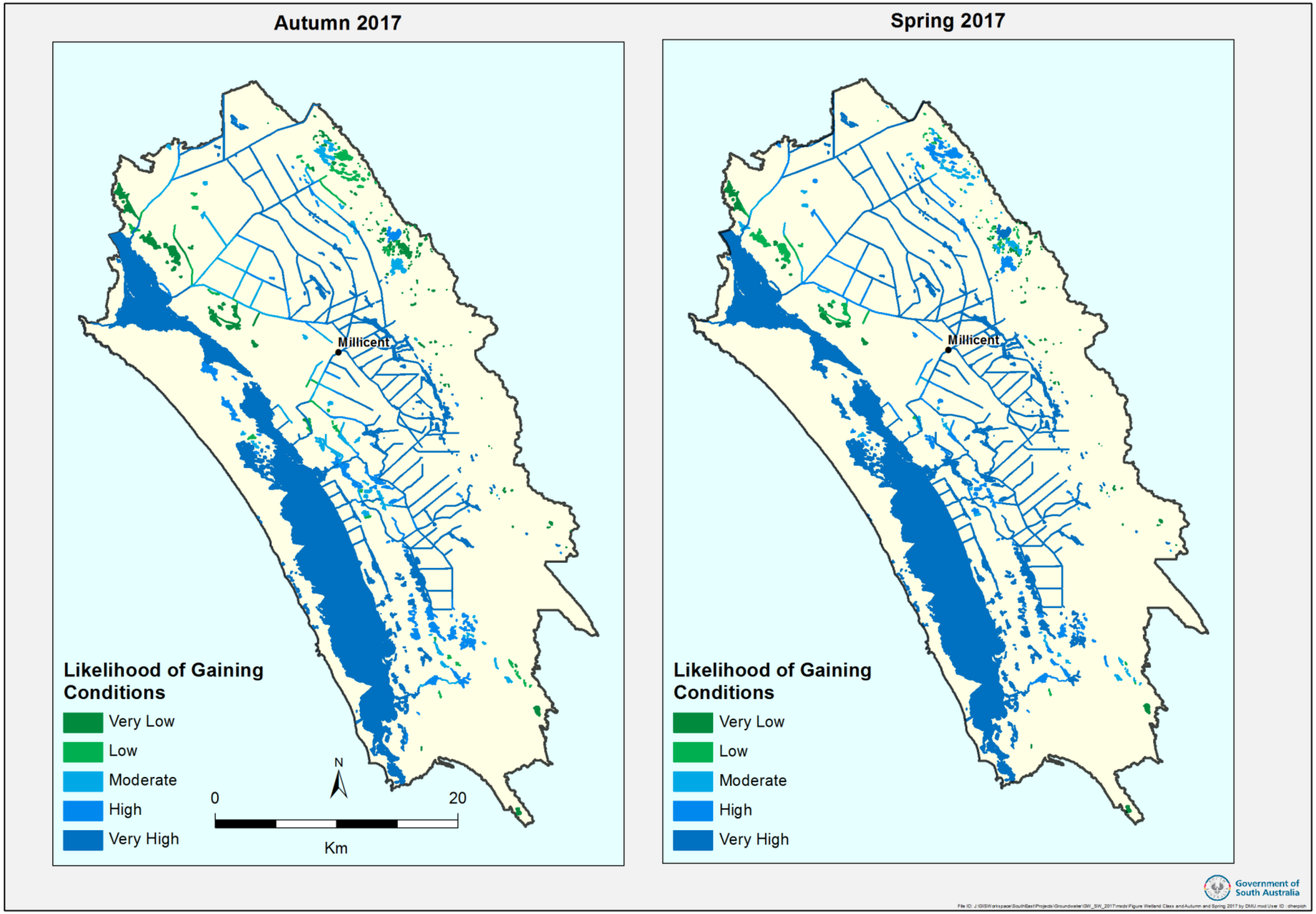


Figure 6.68. Autumn and spring 2017 GW–SW exchange classification in the Southern Coastal DMU

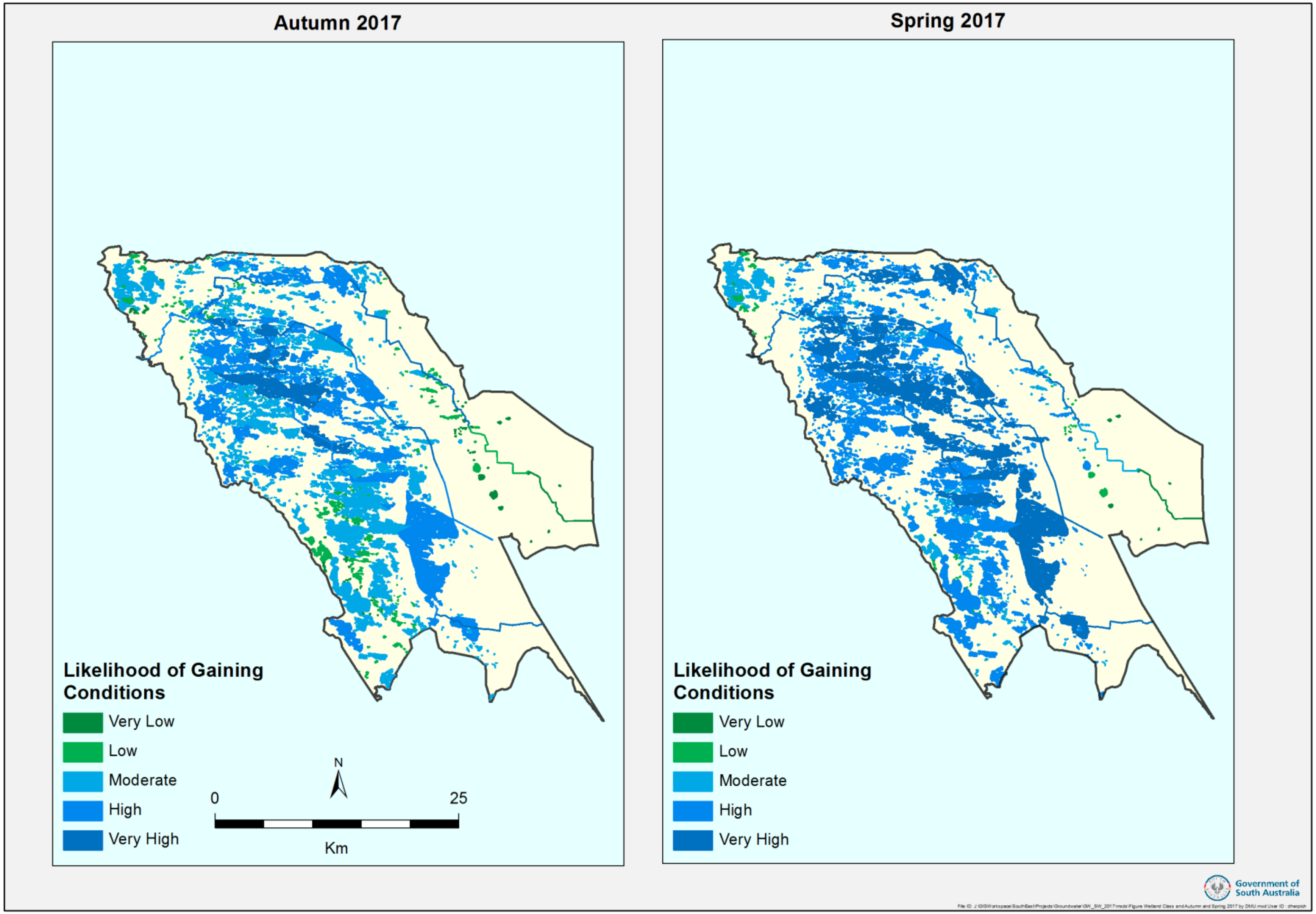


Figure 6.69. Autumn and spring 2017 GW–SW exchange classification in the Saline Swamps DMU

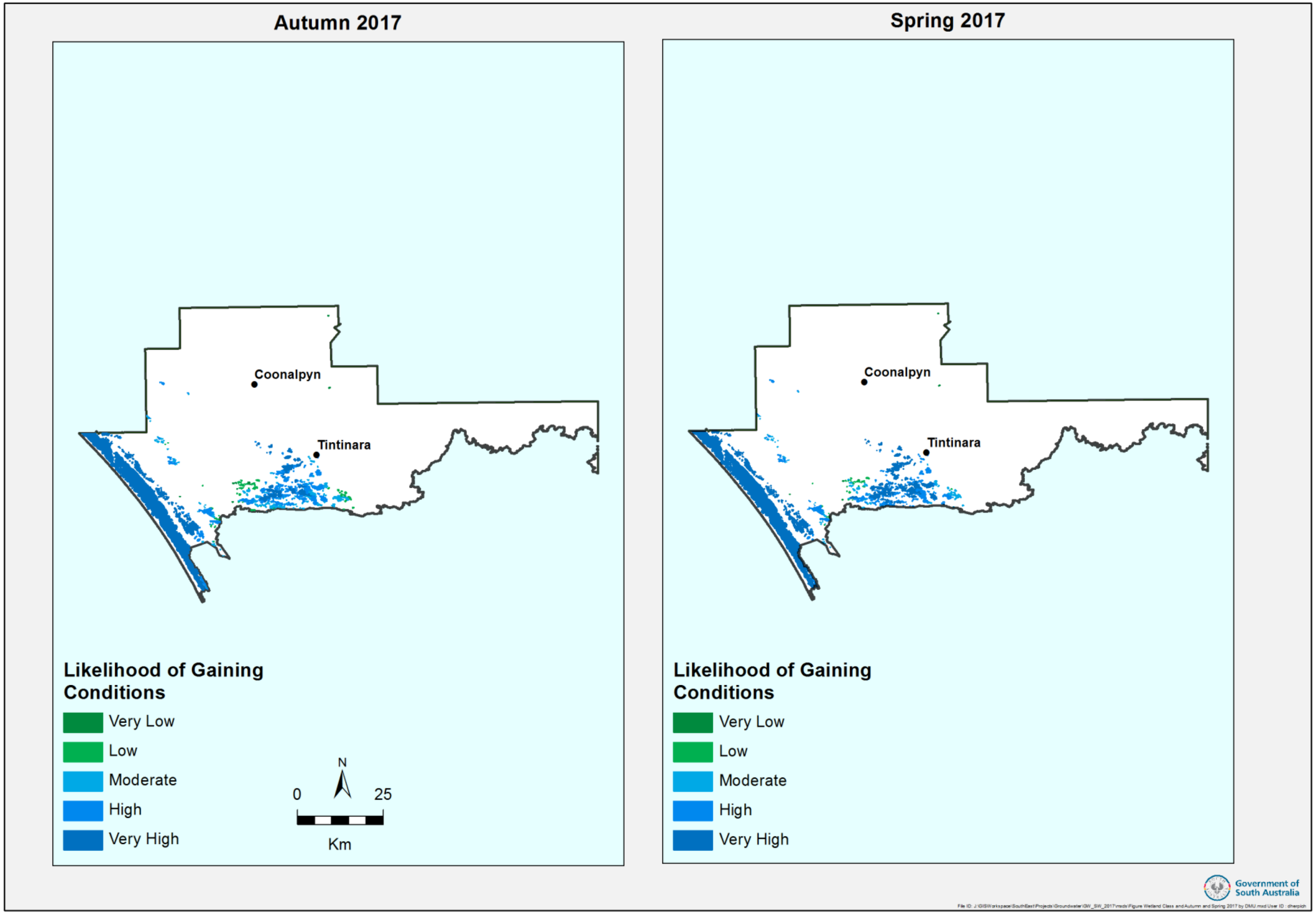


Figure 6.70. Autumn and spring 2017 GW–SW exchange classification in the Other DMU

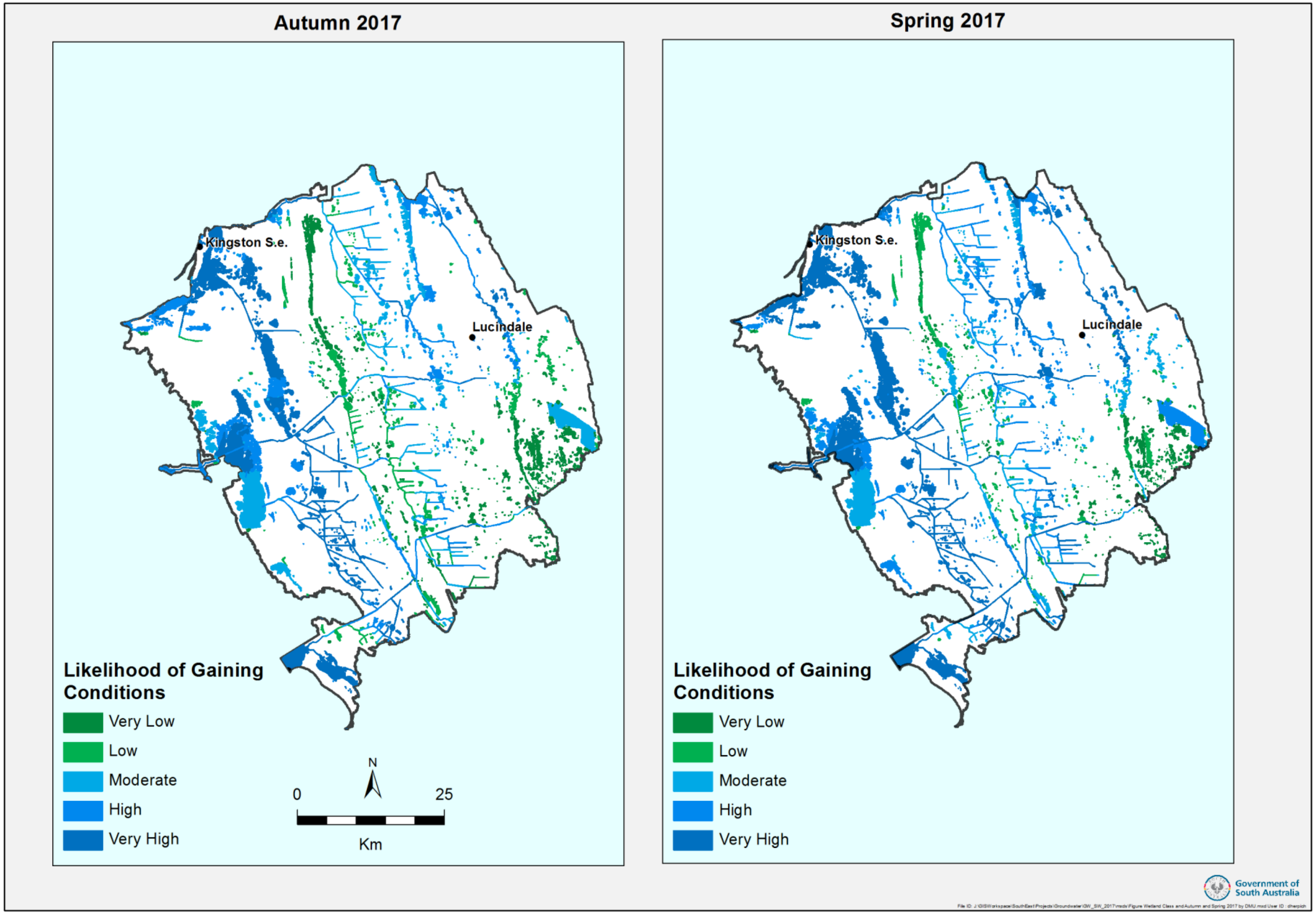


Figure 6.71. Autumn and spring 2017 GW–SW exchange classification in the Lower Interdunal Watercourses DMU

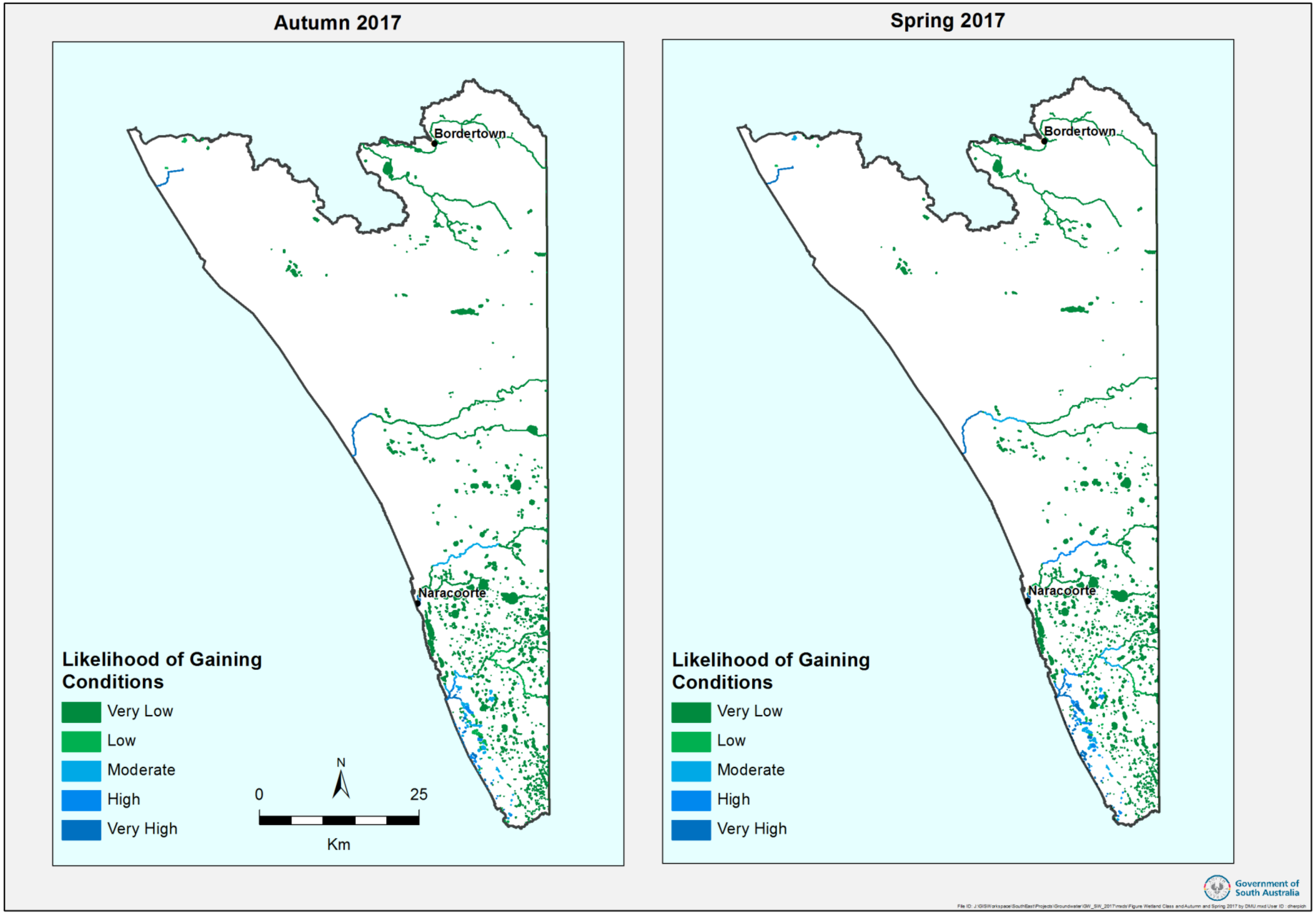


Figure 6.72. Autumn and spring 2017 GW–SW exchange classification in the Cross-Border Creek Catchments DMU

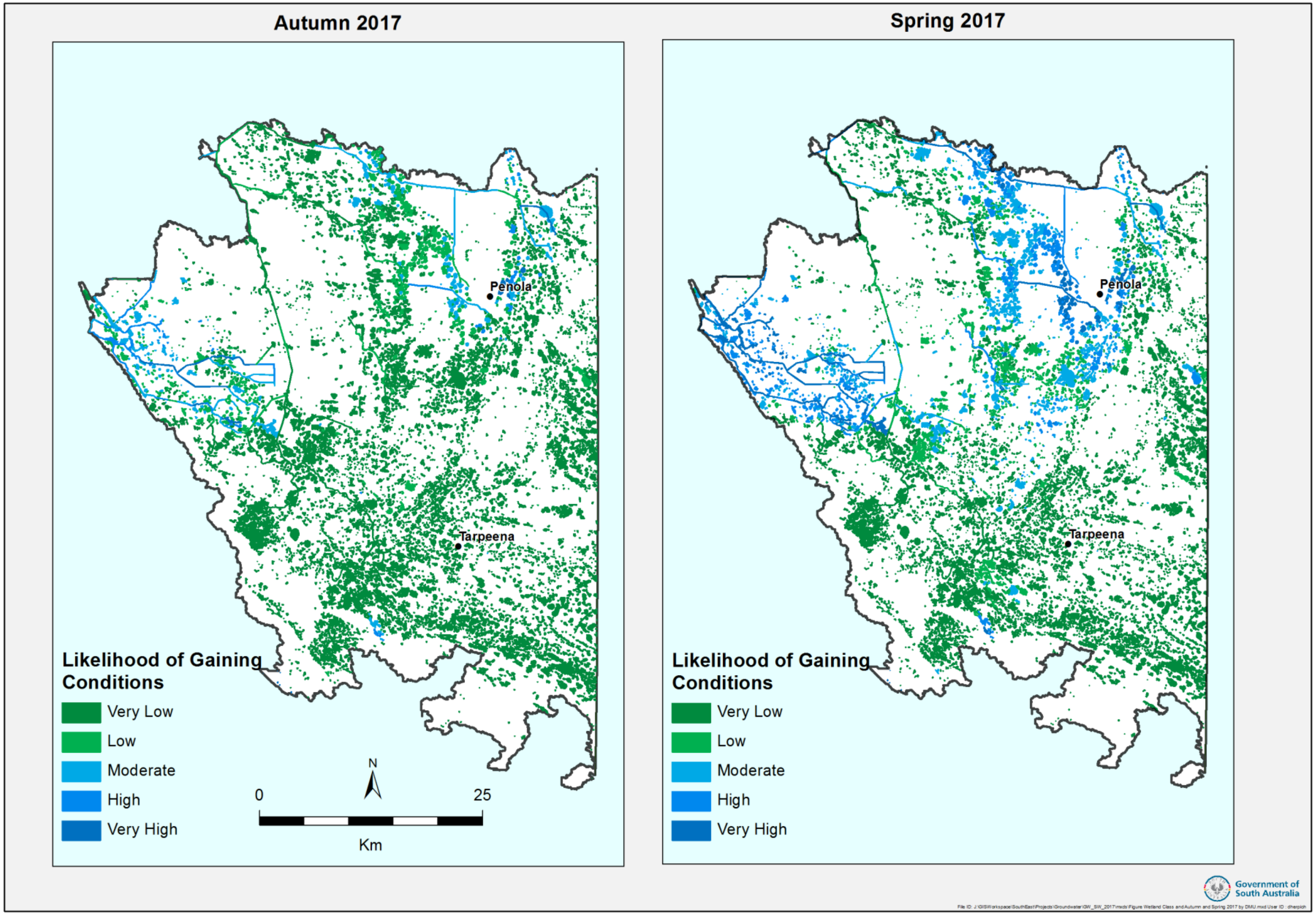


Figure 6.73. Autumn and spring 2017 GW–SW exchange classification in the Glenelg Plain and Perched Volcanics DMU

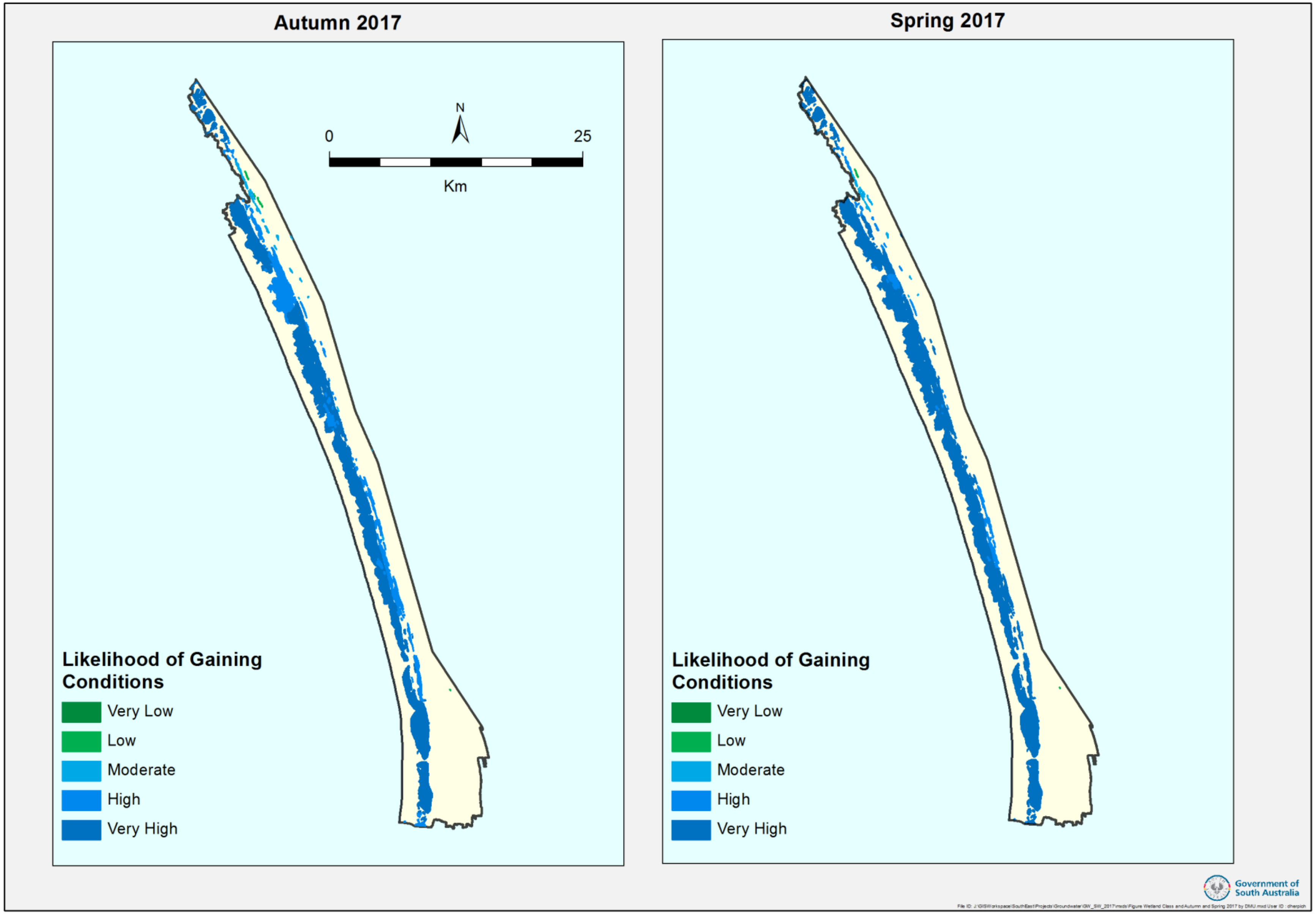


Figure 6.74. Autumn and spring 2017 GW–SW exchange classification in the Coorong Coastal DMU

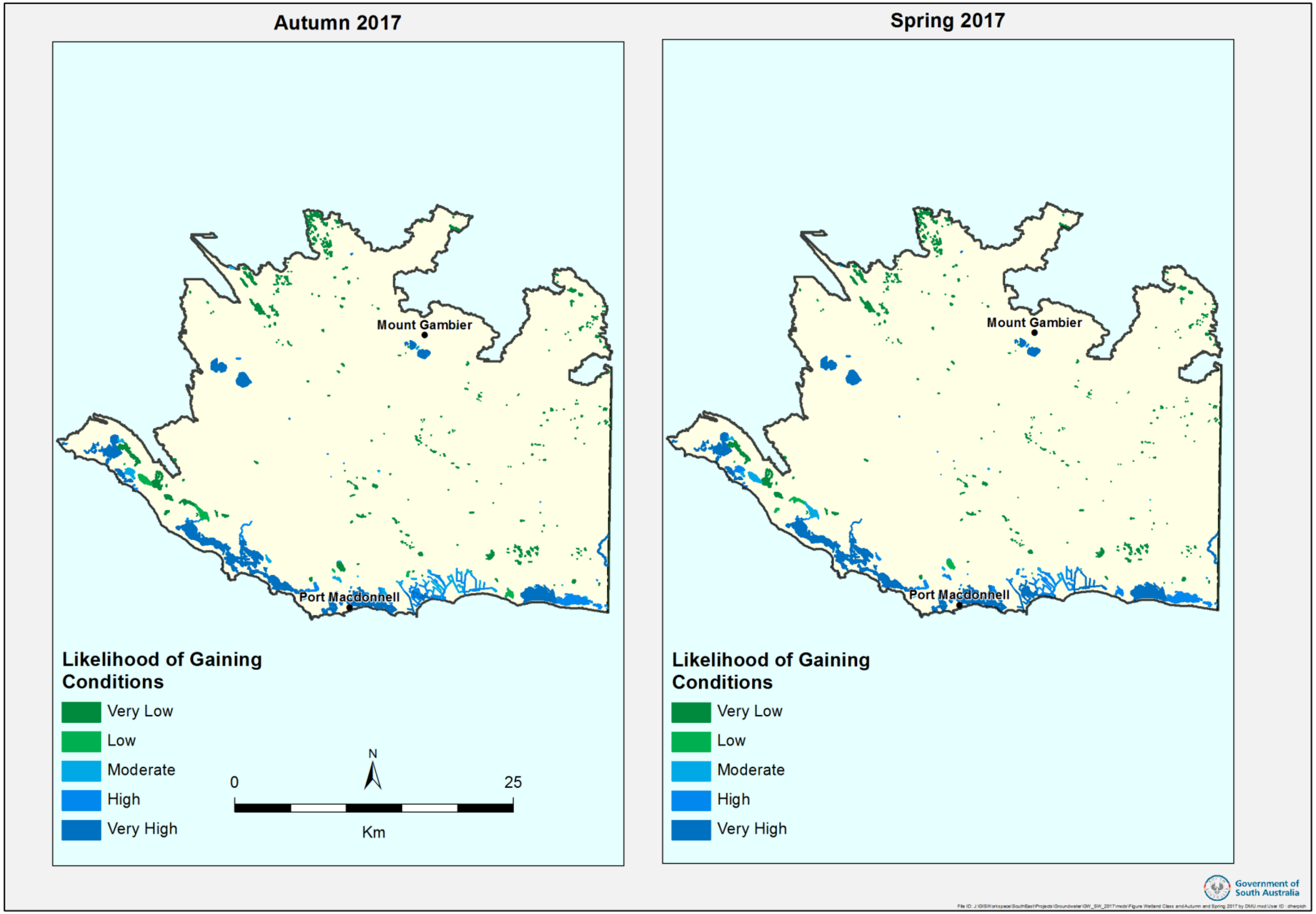


Figure 6.75. Autumn and spring 2017 GW–SW exchange classification in the Karst and Rising Springs DMU

7 Units of measurement

7.1 Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microliter	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

7.2 Shortened forms

bgs below ground surface

EC electrical conductivity (µS/cm)

m AHD metres Australian Height Datum (approximately sea level)

8 Glossary

Adaptive management — A management approach often used in natural resource management where there is little information and/or a lot of complexity, and there is a need to implement some management changes sooner rather than later. The approach is to use the best available information for the first actions, implement the changes, monitor the outcomes, investigate the assumptions, and regularly evaluate and review the actions required. Consideration must be given to the temporal and spatial scale of monitoring and the evaluation processes appropriate to the ecosystem being managed.

Aquatic ecosystem — The stream channel, lake, wetland, or estuary bed, water, and/or biotic communities, and the habitat features that occur therein

Aquifer — An underground layer of rock or sediment that both stores and transmits water

Aquifer, confined — An aquifer that is overlain in part or wholly by an aquitard (see also 'confining layer') and the water is held at greater than atmospheric pressure; water in a penetrating well will rise above the surface of the aquifer unless seriously impacted by groundwater extraction

Aquifer, unconfined — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure

Aquitard — A layer in the geological profile that separates two aquifers and restricts the flow between them

Baseline – a reference period of time against which projections of future climate are compared

Climate futures analysis — a method for the grouping of multiple 'GCM' climate projections according to the amount of change they project in two or more climate variables (e.g. average projected future change in temperature and rainfall compared to a baseline period). This may be undertaken to determine where there is the most agreement between models in relation to the likely future change in primary climate variables

Climate projection — a scenario of future climate, generally resulting from running a GCM with a specified greenhouse gas concentration scenario (or RCP). A projection differs from a prediction in that it is conditional on the representation of a particular model (GCM) and the uncertain assumptions of the model inputs (primarily the greenhouse gas concentration scenario, or RCP)

Climate scenario — description of the possible future climate according to a particular GCM and influenced by a specific RCP

Cone of depression — An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction that exceeds the rate of recharge; continuing extraction of water can extend the area and may affect the viability of adjacent wells, due to declining groundwater levels or water quality

Confining layer — A geological unit which has low permeability that restricts the flow of water and forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also 'aquifer, confined'

DEWNR — Department of Environment, Water and Natural Resources (Government of South Australia)

Downscaling – The process of deriving local climate change impacts from large scale global climate models

Ecosystem — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment

Environmental water requirements — The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk

Evapotranspiration — The total loss of water as a result of transpiration from plants and evaporation from land, and surface water bodies

GCM — global climate model, sometimes also referred to as generalised circulation model. These are mathematical models that integrate systems of differential equations describing the dynamic processes and interaction between the atmosphere, land and ocean. GCMs typically have a grid resolution on the order of 150 x 250 km and require downscaling for local-scale applications; see also 'statistical downscaling'

GDE — Groundwater dependent ecosystem

GMA — Groundwater Management Area

Groundwater — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also 'underground water'

Hydraulic conductivity (K) — A measure of the ease of flow through aquifer material: high K indicates low resistance, or potential high flow conditions; measured in metres per day

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers; see also 'hydrology'

Impact — A change in the chemical, physical, or biological quality or condition of a water body caused by external sources

IPCC – Intergovernmental Panel on Climate Change

Irrigation — Watering land by any means for the purpose of growing plants

LEACHM — Leaching Estimation and Chemistry Model

LiDAR — Light Detecting and Ranging; can be used to develop digital elevation models of the land surface

Model — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm run-off, assessing the impacts of dams, groundwater flow or predicting ecological response to environmental change

Monitoring — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things

Natural recharge — The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc). See also recharge area, artificial recharge

Observation well — A narrow well or piezometer whose sole function is to permit groundwater level measurements

Phreatophytic vegetation — Vegetation (plants) with deep root systems that obtain a significant portion of the water that it needs from groundwater

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer, measured in metres (m); also known as piezometric surface

Prescribed water resource — A water resource declared by the Governor to be prescribed under the Act, and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Prescribed well — A well declared to be a prescribed well under the Act

PWA — Prescribed Wells Area

RCP — representative concentration pathway, a scenario of possible future global atmospheric greenhouse gas and aerosol concentrations, applied in GCMs when projecting future climate change.

Recharge area — The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. See also artificial recharge, natural recharge

Recommended extraction limit (REL) — The volume of extraction for consumptive use that can be sustained over time while keeping the groundwater system from exceeding relevant resource condition limits

Resource condition indicator (RCI) — with respect to groundwater resources, a parameter that can be directly monitored such as groundwater levels or groundwater salinity which gives an indication of the state of the resource; can be derived from other field observations such as the groundwater discharge (baseflow) component of river flow or estimates of aquifer storage.

Resource condition limit (RCL) — with respect to groundwater resources, a selected resource condition indicator beyond which there is an unacceptable risk to the economic, social and environmental values associated with the resource

Resource condition trigger (RCT) — with respect to groundwater resources, a specified level or metric of a resource condition indicator that is breached warning that there is an increased risk to a resource condition limit being reached. The trigger is intended to initiate a management response which may be further investigation or more swift action related to licensed allocations.

SA Geodata — A collection of linked databases storing geological and hydrogeological data, which the public can access through the offices of PIRSA. Custodianship of data related to minerals and petroleum, and groundwater, is vested in PIRSA and DWLBC, respectively. DWLBC should be contacted for database extracts related to groundwater

Salinity — The concentration of dissolved salts in water or soil, expressed in terms of concentration (mg/L) or electrical conductivity (EC)

Spatial variability — where the value of a parameter is changes across some distance or area

Statistical downscaling — a process of inferring high-resolution information from low-resolution information (e.g. developing local-scale weather information from regional-scale generalised circulation model outputs that are statistically consistent with historical observed data)

TDS — Total dissolved solids, measured in milligrams per litre (mg/L); a measure of water salinity

Temporal variability — when the value of a parameter changes in time

Threshold level — See 'Resource condition threshold level'

Timelag — broadly refers to the an interval of time between two related phenomena (such as cause and its effect); more specifically for the Upper South East it may refer to the period of time between rainfall and subsequent recharge

TLA — Tertiary Limestone aquifer

Transmissivity (T) — A measure of the ease of flow through aquifer material: high T indicates low resistance, or potential high flow conditions; measured in metres squared per day and can calculated by multiplying the hydraulic conductivity by the saturated thickness of the aquifer or by conducting aquifer tests

Underground water (groundwater) — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground

Water allocation — (1) In respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence. (2) In respect of water taken pursuant to an authorisation under s.11 means the maximum quantity of water that can be taken and used pursuant to the authorisation

WAP — Water Allocation Plan; a plan prepared by a water resources planning committee and adopted by the Minister in accordance with the Act

Water body — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers

Watercourse — A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse

Water quality monitoring — An integrated activity for evaluating the physical, chemical, and biological character of water in relation to human health, ecological conditions, and designated water uses

Well — A well (also known as a 'bore', or 'borehole') is usually a drilled hole constructed by a licensed driller for the purposes of obtaining or monitoring groundwater, but may also include an artificial excavation used for the purpose of collecting, storing or taking groundwater

Wetlands — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceed six metres

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