Hunter & Central Coast
Regional Environmental
Management Strategy

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Regional Climate Projections: Hunter, Central and Lower North Coast Region of New South Wales

Hunter & Central Coast
Regional Environmental
Management Strategy

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1. Executive summary

In 2009 the Hunter and Central Coast Regional Environmental Management Strategy (HCCREMS) released research identifying historic and projected climate variability for the Hunter, Central and Lower North Coast region of NSW (Blackmore & Goodwin 2009). This research was completed for HCCREMS by the University of Newcastle and Macquarie University and utilised a weather typing approach to statistical downscaling.

In 2014 HCCREMS commissioned the University of Newcastle to review these 2009 climate projections utilising more recently available climatic data. This aimed to identify the on-going veracity of the methodology and to identify if there were any likely variations from the original climate projections. Key outputs from this review are provided in this report and include:

1.1. Review of historical climate data and reference periods

The review has assessed for completeness recent Bureau of Meteorology (BOM) data (1 March 2007 to 1 October 2014) from across the region, and joined this to previous data to produce historic trend graphs.

Outcomes show no significant variation in the extended data, indicating no major shift in conditions in the region since the development of regional downscaled climate projections by Blackmore and Goodwin (2008, 2009). The climate reference periods (1948–1976 and 1977–2007) used as the basis for the synoptic typing process to develop the projections also remain valid.

1.2. Review and validation of 2009 regional climate projections

The review has confirmed that seasonal minimum temperature and precipitation projections from the 2009 research remain valid across all climate zones, with the projections following a similar trend to those evident in the historic record and aligning to broader scale model projections from the Office of Environment and Heritage (OEH) based on recent ensemble Global Climate Model output produced through the NSW and ACT Regional Climate Modelling (NARCliM) Project.

However maximum temperature projections for the western zone, and spring maximum temperature projections in all zones were found to be a poor fit with the historic trend, and do not reflect broader scale model projections. As a result, OEH projections have been used instead in this report, to inform the climate projections for these variables. Tables 1 and 2 identify the source of climate data that underpin each of the climate projections that are provided.

1.3. Climate grid layers

Twenty-four gridded spatial datasets reflecting historic (1990) and current (2015) climate for the region, and thirty six layers depicting seasonal future climate conditions (2040, 2060 and 2080) have been created as part of the review process. The climate variables for which these gridded datasets are provided include:

- Maximum Temperature
- Minimum Temperature
- Precipitation

These datasets integrate information collected from individual BOM stations to provide a spatial representation of the variation that is evident across the region for each climate variable. Providing spatial datasets for historic, current and projected climate conditions visually illustrates historic and projected climate variation over time.

Table 1. Data underpinning climate projections – coastal and central climate zones

CLIMATE VARIABLE	SEASON	UNDERPINNING CLIMATE DATA	
		HCCREMS	OEH
Maximum temperature	Summer	X	
	Autumn	X	
	Winter	X	
	Spring		X
Minimum temperature	All	X	
Precipitation	All	X	

Table 2. Data underpinning climate projections – western climate zone

CLIMATE VARIABLE	SEASON	UNDERPINNING CLIMATE DATA	
		HCCREMS	OEH
Maximum temperature	Summer	X	
	Autumn		X
	Winter	X	
	Spring		X
Minimum temperature	All	X	
Precipitation	All	X	

2. Introduction

In 2009 the Hunter and Central Coast Regional Environmental Management Strategy (HCCREMS) released research identifying historic and projected climate variability for the Hunter, Central and Lower North Coast region of NSW (Blackmore & Goodwin 2009). This research was completed for HCCREMS by the University of Newcastle and Macquarie University and utilised a weather typing approach to statistical downscaling. In summary, this included:

1. Identifying the key Synoptic Types (STs) that drive climate variability in the region.
2. Identifying the relationships between these STs and Bureau of Meteorology (BOM) historical records for key climate variables.
3. Using the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Mk3.5 Global Climate Model (GCM) to identify projected changes in the frequency of occurrence of these key STs based on sea level pressure (SLP) output data generated by the GCM
4. Combining our understanding of how the regions weather is impacted by these key STs with projected changes in their frequency to project likely changes in key climate variables across the region.

This approach enabled both an analysis of historical climate variability and future climate projections to be provided at both seasonal and sub regional (Coastal, Central and Western) scales. Average projections were provided for each of the time periods 2020–2040, 2040–2060 and 2060–2080. Both historical analysis and projections were provided for a range of climate variables including:

- rainfall
- temperature (minimum, maximum and average annual)
- humidity
- pan evaporation
- water balance
- wind

In 2014 HCCREMS commissioned the University of Newcastle to review these 2009 climate projections utilising more recently available climatic data. This aimed to identify the on-going veracity of the methodology and to identify any likely variations from the original climate projections. This report:

1. Describes the methodology employed to undertake the review, including the production of individual interpolated surfaces (spatial gridded datasets) for key climate variables for the 1990, 2015, 2040, 2060 and 2080 time horizons. These depict seasonal climate conditions for maximum temperature, minimum temperature and precipitation for each time horizon.
2. Presents the results of the evaluation and analysis of current Bureau of Meteorology (BOM) data for key climate variables for the Hunter, Central and Lower North Coast region of NSW. These results extend on previous work (Verdon & Goodwin, 2007; Blackmore & Goodwin, 2008 & 2009) to consider trends in observed climate data from 1 March 2007 to 1 October 2014.
3. Presents the outcomes of updated climate projections that draw upon the evaluation and analysis of the more recent BOM data that has been completed. Projections have been downscaled to selected BOM stations within the region. These projections are provided

as spatial grid datasets that reflect the linear trends that have been developed via this methodology.

3. The study region

The study region includes the 14 Local Government Areas (LGAs) of the Hunter, Central and Lower North Coast region of New South Wales. For the purposes of data selection and developing gridded spatial datasets, a buffer of 50 km was placed around the study boundary to ensure layers adequately cover the entire region. The study region and 50 km buffer zone used for data selection is shown in Figure 1.

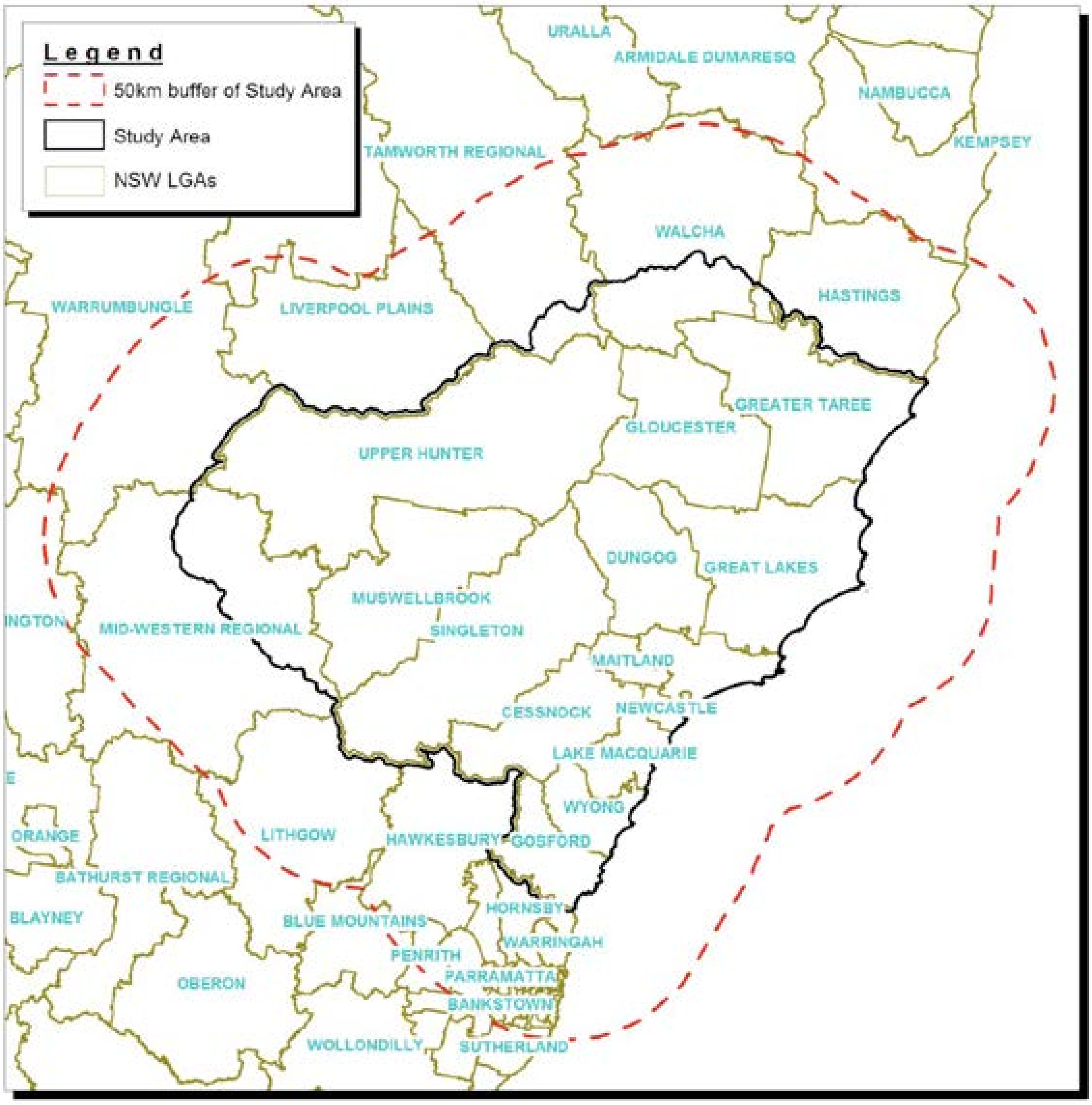

Figure 1. Study region and buffer zone used in climate data selection

4. Climate zones

To facilitate the sub-regional analysis and interpretation of projected climate change impacts, three sub-regional climate zones (coastal, central and western) were established for the region during the 2009 research (refer Figure 2). These zones were identified through a process known as climate zonation, which divides a region into distinct sub-regions or zones where climatic similarity is maximised within zones and minimised between zones. This purely statistical process was based upon key seasonal climate variables including summer, autumn, winter and spring precipitation and average minimum and maximum temperature.

The 2009 research also derived statistically downscaled regional climate change projections for each of these climate zones. Under this process the average change in a given climate variable was considered to apply uniformly within an individual climate zone. The work presented in this report extends this downscaling process to individual BOM stations across the study region. Data is therefore presented in this report for individual BOM stations that are considered representative of each climate zone.

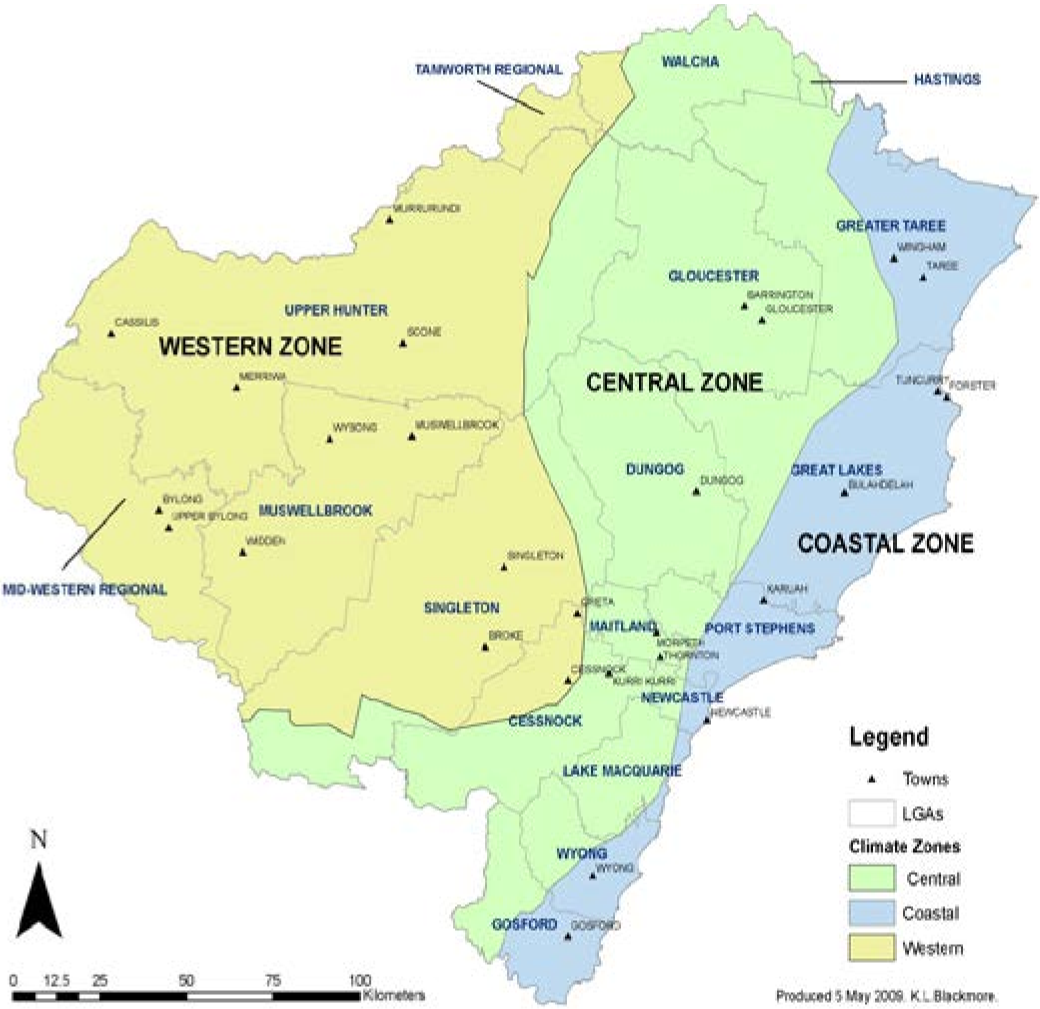

Figure 2. coastal, central and western climate zones

5. Methodology

The methodology for reviewing the 2009 climate projections comprised three implementation stages:

1. Update and analysis of historic climate data
2. Evaluation of 2009 climate projections
3. Generating interpolated surfaces (gridded spatial datasets) representing historic, current and projected climate conditions.

Activities completed within each stage are identified in Figure 3, where Stage 1 is represented as green, Stage 2 as orange and Stage 3 as red.

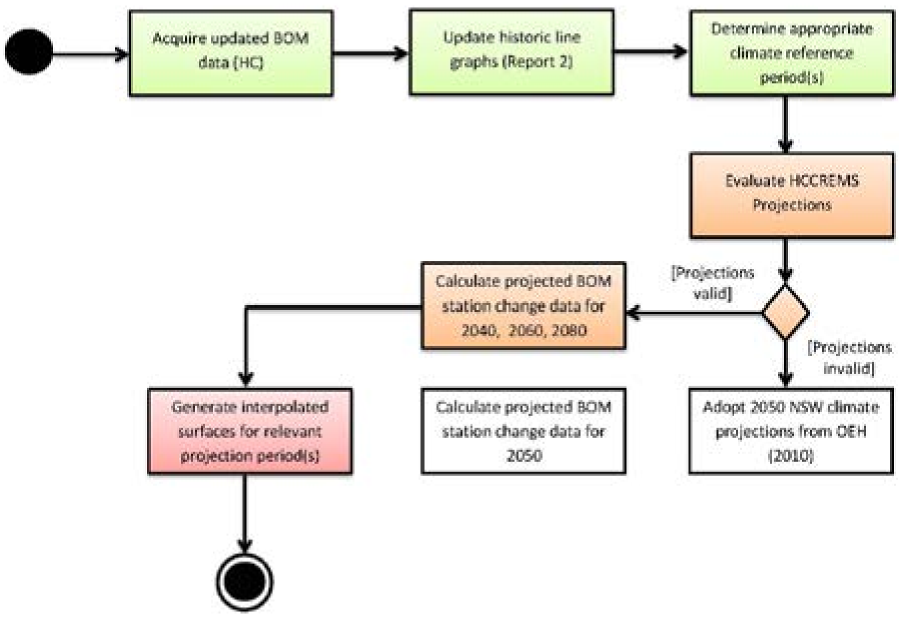

Figure 3. Methodology for reviewing regional climate change projections

5.1. Update and analysis of historic climate data

5.1.1. ACQUISITION AND REVIEW OF RECENT CLIMATE DATA

Data from all BOM weather stations within the study region for the period 1 March 2007 to 1 October 2014 were obtained from the Bureau of Meteorology and an evaluation of the completeness of data for each of these stations undertaken. This aimed to determine if all stations used in the previous climate studies for the region remained valid. This process included determining if stations provided data of sufficient length, covered a common time span and were reasonably complete. It was also important to ensure that the selected stations provided adequate spatial coverage of the study zone to support development of interpolated climate surfaces (gridded spatial datasets) for the region. Outcomes from the evaluation process are provided below.

5.1.2. DAILY PRECIPITATION

The 80 relevant stations identified in the previous regional climate change study were re-evaluated for completeness. Eight of these stations were found to have fallen below the 90% completeness threshold. A further eighteen stations had no available data beyond 01 January 2014. A summary of data for these 80 stations is provided in Table 3.

Table 3. Summary of data available for BOM daily precipitation stations

STATION ID	NAME	START DATE	END DATE	COMPLETENESS
055006	Blackville Post Office	22 February 1886	30 September 2014	96%
055017	Premer (Eden Moor)	19 March 1887	31 July 2014	91%
055037	Pine Ridge (Mooki Springs)	01 January 1886	31 January 2012	99%
055039	Spring Ridge	01 January 1922	31 July 2014	100%
055041	Nundle Post Office	01 July 1890	26 September 2014	89%
055043	Willow Tree (Parraweena)	01 March 1934	31 December 2013	96%
055049	Quirindi Post Office	01 January 1882	01 October 2014	97%
055057	Willow Tree (Valais)	01 May 1881	31 August 2014	99%
055062	Werris Creek Post Office	01 March 1889	31 August 2014	95%
055064	Pine Ridge (Windy)	01 July 1915	30 June 2013	100%
055066	Wallabadah (Woodton)	01 June 1892	26 September 2014	95%
055069	Yannergee (Dobroyd)	01 July 1927	31 August 2014	89%
055164	Weabonga (Stoneleigh)	01 January 1913	26 September 2014	85%
056010	Walcha (Emu Creek)	01 May 1940	31 August 2014	95%
056083	Glen Morrison (Branga Plains)	01 January 1940	31 May 2014	99%
060002	Buladelah Post Office	09 November 1905	26 September 2014	94%
060005	Comboyne Post Office	12 October 1905	18 February 2014	95%
060013	Forster – Tuncurry Marine Rescue	14 July 1896	01 October 2014	97%
060015	Gloucester Post Office	01 May 1888	29 September 2014	94%
060017	Hannam Vale (Hannam Vale Road)	01 February 1926	31 August 2014	97%
060020	Kendall Post Office	01 September 1899	31 March 2012	95%
060021	Krambach Post Office	01 January 1910	01 October 2014	94%

STATION ID	NAME	START DATE	END DATE	COMPLETENESS
060023	Harrington (Oxley Anchorage Caravan Park)	15 May 1887	31 January 2008	96%
060026	Port Macquarie (Hill St)	07 January 1841	31 July 2010	84%
060027	Lorne (Lorne Road)	01 January 1938	31 August 2014	98%
060028	Seal Rocks Camping Reserve	07 September 1897	02 September 2012	98%
060031	Telegraph Point (Farrawells Road)	01 March 1910	31 August 2014	99%
060035	Wauchope (Avondale Street)	19 September 1890	31 March 2012	99%
060036	Wingham (Lanark Close)	01 August 1888	01 October 2014	98%
061000	Aberdeen (Main Rd)	01 June 1894	31 May 2013	93%
061002	Blackville (Krui Vale)	01 January 1885	31 May 2014	99%
061007	Bunnan (Milhaven)	01 November 1900	31 August 2014	98%
061010	Clarence Town (Prince St)	01 September 1895	31 August 2014	99%
061012	Cooranbong (Avondale)	01 November 1903	01 October 2014	86%
061014	Branxton (Dalwood Vineyard)	01 May 1863	26 September 2014	82%
061016	Denman (Palace Street)	01 January 1883	26 September 2014	99%
061017	Dungog Post Office	14 August 1897	31 August 2014	95%
061024	Gresford Post Office	01 October 1895	29 August 2014	97%
061026	Gundy (Miller St)	01 June 1887	31 August 2014	92%
061031	Raymond Terrace (Kinross)	01 April 1894	31 August 2014	100%
061040	Merriwa (Gummun Place)	01 January 1882	31 May 2011	95%
061048	Mulbring (Vincent Street)	01 December 1932	31 August 2007	92%
061050	Sedgefield (Bundajon)	01 May 1903	31 August 2014	97%
061051	Murrurundi Post Office	01 October 1870	01 October 2014	98%
061055	Newcastle Nobbys Signal Station Aws	01 January 1862	01 October 2014	98%
061056	Pokolbin (Ben Ean)	09 July 1905	10 February 2014	90%
061065	Aberdeen (Rossgole)	01 January 1926	31 July 2014	100%
061071	Stroud Post Office	01 May 1889	31 August 2014	97%
061072	Tahlee (Carrington (Church St))	01 April 1887	30 June 2014	99%
061074	The Entrance (Eloora Street)	15 March 1943	31 August 2014	93%
061075	Merriwa (Bowglen)	01 January 1926	31 August 2014	98%
061079	Wingen (Murrulla)	01 May 1887	31 May 2007	98%
061082	Wyee (Wyee Farms Rd)	01 March 1899	30 September 2014	99%
061083	Wyong (Wyong Golf Club)	01 January 1885	31 March 2010	94%
061086	Jerrys Plains Post Office	01 June 1884	17 April 2014	99%
061087	Gosford (Narara Research Station) Aws	01 July 1917	30 May 2013	95%
061095	Rouchel Brook (Albano)	01 October 1932	31 August 2014	99%
061096	Paterson Post Office	01 June 1901	22 September 2014	94%
061151	Chichester Dam	01 January 1942	31 August 2014	99%
062009	Cassilis (Dalkeith)	01 January 1874	31 August 2014	93%

STATION ID	NAME	START DATE	END DATE	COMPLETENESS
062013	Gulgong Post Office	01 April 1881	01 October 2014	100%
062014	Hargraves (General Store)	01 June 1913	26 September 2014	96%
062015	Merriwa (Merry Vale)	10 April 1890	31 December 2008	99%
062021	Mudgee (George St)	01 August 1870	31 August 2014	99%
062028	Goolma (Brooklyn)	01 January 1919	31 August 2014	99%
062029	Ilford (Tara)	01 July 1928	31 December 2013	99%
062032	Wollar (Barrigan St)	21 January 1901	31 August 2014	98%
062036	Ulan Water	25 March 1906	01 October 2014	80%
063012	Running Stream (Brooklyn)	01 June 1899	31 August 2014	98%
063043	Kurrajong Heights (Bells Line Of Road)	01 September 1866	27 September 2014	91%
063118	Bilpin (Fern Grove)	01 January 1895	31 August 2014	100%
064009	Dunedoo Post Office	01 January 1912	01 October 2014	99%
064025	Coolah (Binnia St)	01 January 1886	01 October 2014	91%
064028	Weetaliba (Weetalabah)	01 January 1884	31 March 2014	85%
066045	Newport Bowling Club	01 July 1931	31 December 2010	97%
066062	Sydney (Observatory Hill)	01 July 1858	01 October 2014	100%
066157	Pymble (Canisius College)	01 December 1947	31 July 2011	98%
067019	Prospect Reservoir	01 February 1887	01 October 2014	100%
067021	Richmond – UWS Hawkesbury	01 January 1881	30 September 2014	96%
067031	Windsor Bowling Club	01 August 1897	31 December 2011	94%

Source: http://www.bom.gov.au/climate/data/stations/ as at 30 October 2014

Despite the identified lapses in completeness, data for all 80 stations were retained for inclusion in further analysis to derive the interpolated climate surfaces.

5.1.3. DAILY MINIMUM / MAXIMUM TEMPERATURE

Sufficient spatial coverage of daily minimum and maximum temperature for the region was obtained from the 17 stations previously determined to be of sufficient completeness. Data for four locations was obtained by joining data from two stations in close geographic proximity to each other. This was necessary where a station had ceased recording data however the location and length of record make the data useful for further analysis. Correlations were used to determine the suitability for joining stations. A summary of the individual stations analysed is provided in Table 4.

Table 4. Summary of data available for BOM daily minimum/maximum temperature stations

				Completeness			
Station ID	Name	Start Date	End Date	Max Temperature	Min Temperature	Joined to Station ID	Date where joined
055049	Quirindi Post Office	05 January 1965	01 October 2014	93%	93%	N/A	N/A
055136	Woolbrook (Danglemah Road)	01 January 1970	01 October 2014	99%	99%	N/A	N/A
060026	Port Macquarie (Hill St)	01 January 1957	27 October 2003	98%	98%	060139	28 October 2003
060030	Taree (Patanga Cl)	01 January 1965	15 March 2005	98%	98%	060141	16 March 2003
060085	Yarras (Mount Seaview)	23 January 1969	01 October 2014	99%	99%	N/A	N/A
060139	Port Macquarie Airport Aws	25 July 1995	01 October 2014	97%	97%	060026	28 October 2003
060141	Taree Airport Aws	10 July 1997	25 September 2014	99%	98%	060030	16 March 2003
061051	Murrurundi Post Office	01 January 1965	01 October 2014	97%	97%	N/A	N/A
061055	Newcastle Nobbys Signal Station Aws	01 January 1957	01 October 2014	98%	98%	N/A	N/A
061078	Williamtown RAAF	10 September 1942	01 October 2014	89%	89%	N/A	N/A
061086	Jerrys Plains Post Office	01 January 1957	17 April 2014	96%	96%	N/A	N/A
061089	Scone Scs	01 January 1965	30 September 2014	92%	91%	N/A	N/A
061250	Paterson (Tocal AWS)	19 November 1967	01 October 2014	92%	93%	N/A	N/A
061288	Lostock Dam	01 November 1969	01 October 2014	94%	94%	N/A	N/A
062013	Gulgong Post Office	01 March 1970	01 October 2014	97%	96%	N/A	N/A
062021	Mudgee (George St)	01 January 1962	31 December 1995	98%	98%	062101	01 January 1996
062101	Mudgee Airport Aws	12 July 1990	01 October 2014	96%	96%	062021	01 January 1996
066062	Sydney (Observatory Hill)	01 January 1859	01 October 2014	100%	100%	N/A	N/A
066124	Parramatta North (Masons Drive)	01 June 1967	01 October 2014	98%	98%	N/A	N/A
067033	Richmond RAAF	01 December 1939	31 October 1994	82%	96%	067105	01 November 2014
067105	Richmond RAAF	21 October 1993	01 October 2014	99%	94%	067033	01 November 2014

Source: http://www.bom.gov.au/climate/data/stations/ as at 27 October 2014

5.1.4. DAILY PAN EVAPORATION

Daily pan evaporation data was available from six suitable stations within the study region (Table 5). The density and spatial distribution of these stations was deemed insufficient to inform detailed regional analysis of pan evaporation variability.

Table 5. Summary of data available for BOM daily pan evaporation stations

Station ID	Name	Start Date	End Date	Completeness
061078	Williamtown RAAF	01 January 1974	01 October 2014	95%
060085	Yarras (Mount Seaview)	23 January 1969	01 October 2014	98%
061089	Scone Scs	01 January 1965	01 October 2014	81%
061242	Cessnock (Nulkaba)	01 June 1973	15 August 2012	98%
061250	Paterson (Tocal AWS)	19 November 1967	01 October 2014	95%
061288	Lostock Dam	01 November 1969	01 October 2014	94%

5.1.5. MAXIMUM WIND GUST

Wind gust data has not been monitored for a long time period, and the majority of stations within the study region do not have continuous data available for this climate variable. Maximum wind gust data from Williamtown remains the only suitable site, and as such, was considered insufficient to inform regional analysis.

5.1.6. UPDATING OF HISTORIC LINE GRAPHS

In light of the review of BOM station data, updated historic line graphs (both annual and seasonal) were developed for climate variables and stations within the region. Historic trends have been considered to determine whether any significant shifts in regional weather patterns have occurred since the previous modeling of climate change scenarios.

5.1.7. DETERMINING APPROPRIATE CLIMATE REFERENCE PERIODS

The previous work to determine regional climate projections (Verdon & Goodwin, 2007; Blackmore & Goodwin, 2008 & 2009) for the Hunter, Central and Lower North Coast region of NSW considered interdecadal variability within the Australasian and South West Pacific regions association with the Interdecadal Pacific Oscillation (IPO). The previous analysis covered the time period from 1948 to 2007, in which there have been two phases of this oscillation: IPO –ve phase (La Nina-like) from 1948 to 1976; and, IPO +ve phase (El Nino-like) from 1977 to 2007. To investigate the climate variability of the region, the Synoptic Type (ST) time series was stratified according to these two time periods, and difference in frequency of synoptic patterns over these period forms the basis for climate projections for the region. Whether a switch in IPO phases has occurred between 2007 and 2014 has not achieved scientific consensus. As such, extending downscaling beyond 2007 was not undertaken as it offers no significant advantages.

5.2. Evaluation of 2009 climate projections

5.2.1. EVALUATING 2009 REGIONAL CLIMATE PROJECTIONS

Previous work by Blackmore and Goodwin (2008, 2009) derived statistically downscaled regional climate change projections for three climate zones (coastal, central and western) within the Hunter, Central and Lower North Coast region of NSW. That is, the average change in a given variable was considered to apply uniformly within an individual climate zone. The work presented in this report extends this downscaling process to the individual stations within the study region that were identified during the first stage of the project, rather than aggregating to the climate zone level.

The 1970–1996 reference period (Blackmore & Goodwin, 2009) was used to evaluate the existing projections. Seasonal averages for each variable, for each of the 12 classified NCEP/NCAR synoptic types, were calculated from BOM data records covering the reference period. Given the seasonal nature of STs (ie. some only occurring in particular seasons during the reference period), not all STs had average data for all seasons. To account for the potential for STs to occur out of season under future climate scenarios, missing average data were interpolated from deviations from seasonal averages, accounting for both station and ST variations.

These station level projections were then plotted with historic data from the BOM, for the period from the start of record until 1 October 2014. A linear trend line was superimposed over both the historic and projected plotted data, and the visual fit of the trend across the two time periods was used to provide an assessment of the validity of the existing projections. The results presented in this report provide a plot for a representative station within the Coastal (Williamtown), Central (Lostock Dam) and Western (Murrurundi) climate zones.

5.2.2. CALCULATING PROJECTED BOM STATION CHANGE DATA FOR 2040, 2060, 2080

Linear regression was used to generate projected individual BOM station values for each climate variable for each of the future time horizons (refer Figure 4). For example, to determine the projected average maximum temperature value for each relevant BOM station for 2040, the b coefficients in linear regression equations, which indicate the rate of change in average maximum temperature over time, were multiplied by 2040. This process was also repeated for 'current' 1990 and 2015 time steps to ensure a consistent modeling approach.

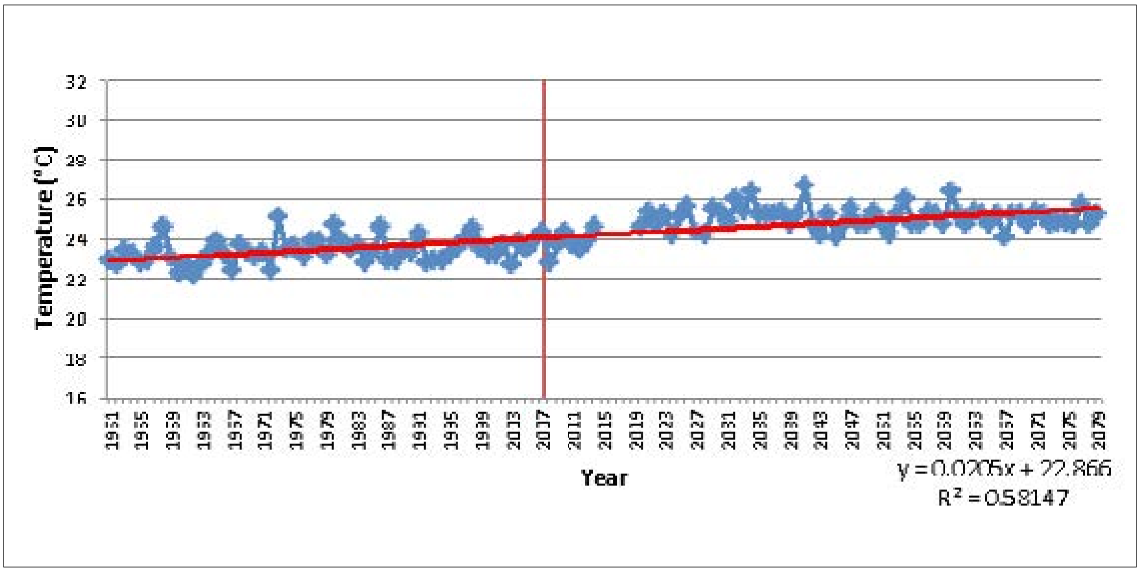

Figure 4. Linear regression example – Average autumn maximum temperature for Williamtown (1951–2080) with linear regression line and regression equation (y = 0.0205). The red vertical line indicates where the time series has been extended.

5.3. Generating interpolated (gridded spatial) surfaces

In the final stage of the review, ArcGIS 10.1 was used to derive raster or gridded surfaces for the 2040, 2060 and 2080 time horizons for the following climate variables:

- average seasonal minimum temperature
- average seasonal maximum temperature
- total seasonal precipitation

These gridded surfaces were obtained using the Kriging interpolation algorithm. The use of this algorithm follows recommendations from relevant literature (Childs, 2004; Earls & Dixon, 2007). Based on the most densely populated point layers (i.e. point locations of precipitation, minimum/maximum temperature stations), the resultant surfaces cover the geographic region from 6576914.34485, 148831.287848 (top, left) to 492722.663408, 6251190.81555 (right, bottom). The cell sizes of the gridded surfaces are:

- 1297.7, 1297.7 (x,y) for precipitation, and
- 1271.2, 1271.2 (x,y) for minimum and maximum temperature.

The slight variation in the cell size occurs as a result of the number, and spatial distribution of, BOM stations used to derive interpolated surfaces. All data are projected to GDA 1994 MGA Zone 56. All layers were saved as ESRI Grid files in a geodatabase.

6. Limitations

Limitations inherent in the original downscaling process are also carried over to this work. Namely, the process of using changes in the estimated frequency of STs to derive projections does not consider the possibility of the emergence of new synoptic patterns. Thus the projections are based on a best-fit approximation of existing patterns only.

Additionally, the projected data reflects overall trends, and does not accurately capture the natural variation evident in the historic record. Thus, projections can be considered to estimate future general trends rather than year to year and seasonal fluctuations.

7. Historic climate analysis

This section of the report presents updated historic line graphs (i.e. beyond the 2009 report Climate Variability of the Hunter, Lower North Coast and Central Coast Region of NSW) for the following climate variables:

1. annual average precipitation
2. seasonal precipitation
3. minimum temperature
4. maximum temperature

Graphs are provided for key BOM weather stations within the study region that are considered indicative for each of the coastal, central and western climate zones. A red vertical line on the graphs is used to indicate where the time series has been extended in this report. A linear trend line is fitted to the data to provide an indication of a general trend, if present, in the data.

7.1. Annual precipitation

7.1.1. COASTAL ZONE

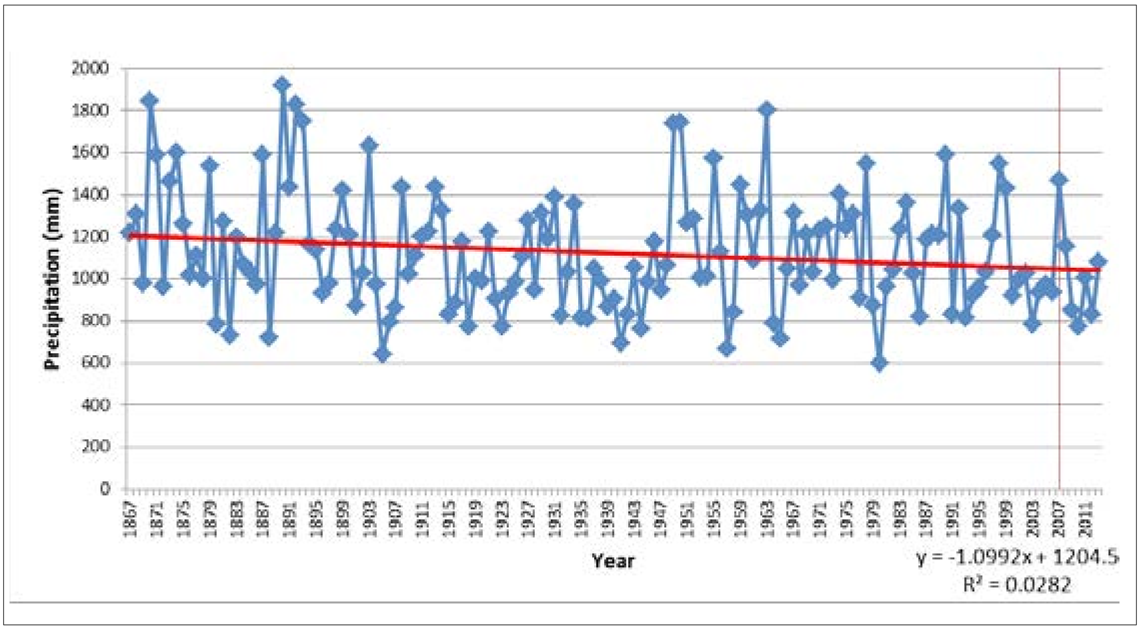

Figure 5. Annual precipitation trends for Newcastle

7.1.2. CENTRAL ZONE

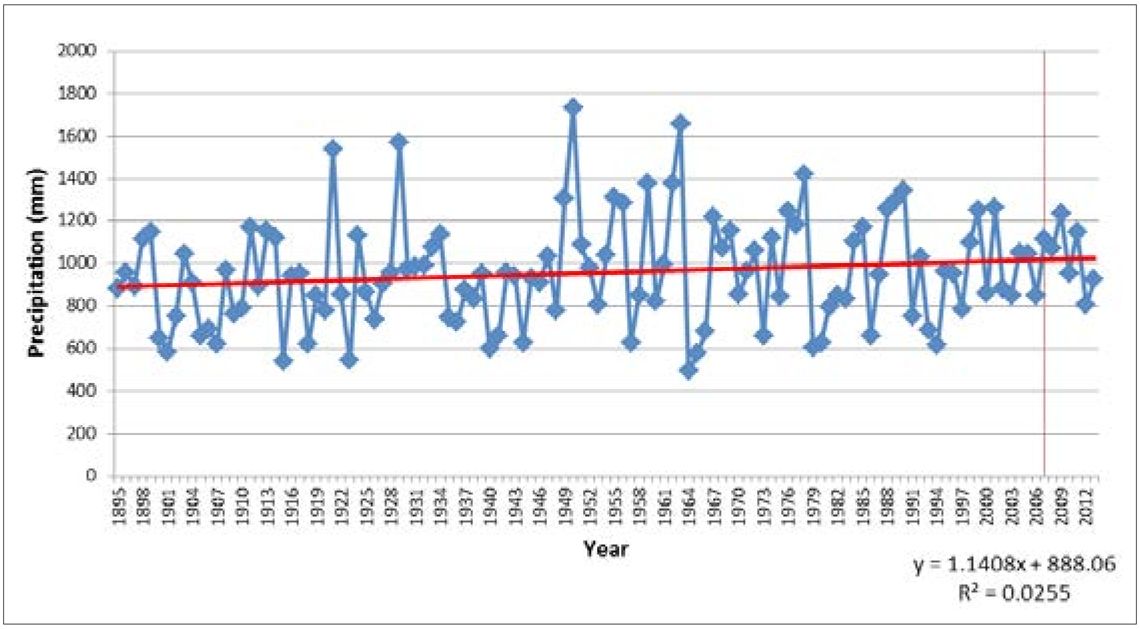

Figure 6. Annual precipitation trends Gloucester

7.1.3. WESTERN ZONE

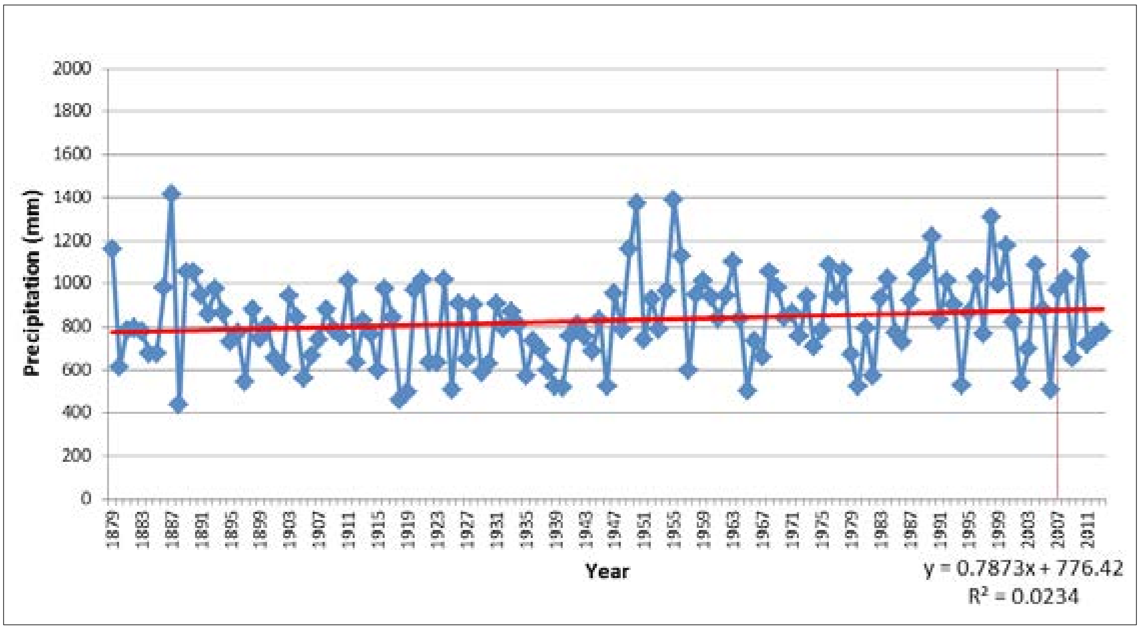

Figure 7. Annual precipitation trends for Murrurndi

7.2. Seasonal precipitation: Coastal Zone

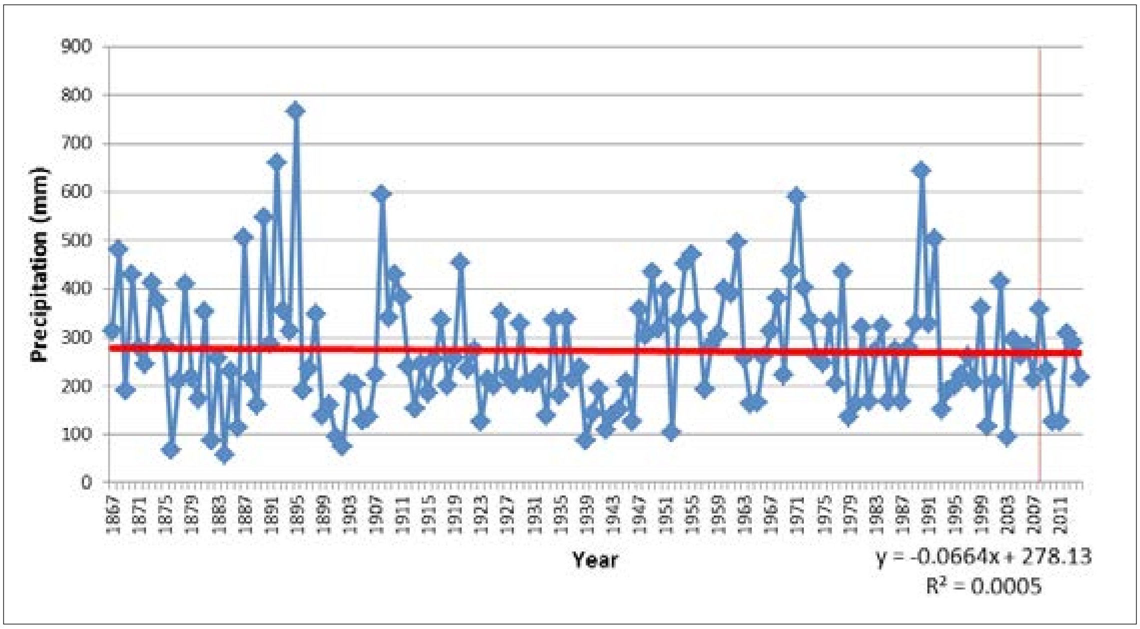

Figure 8. Average summer precipitation trends Newcastle

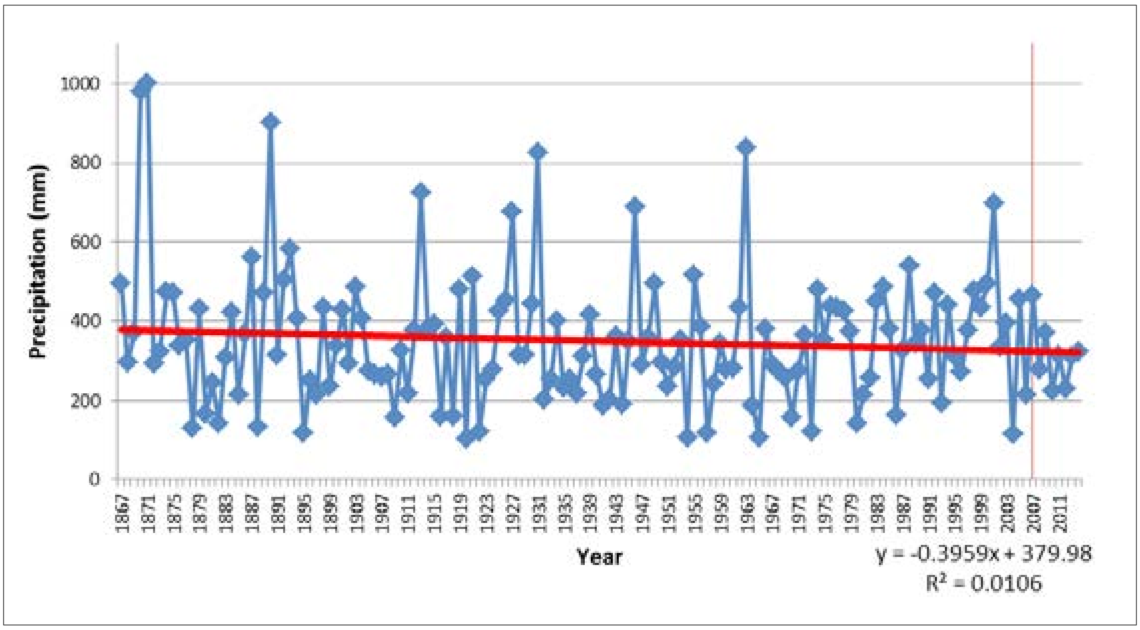

Figure 9. Average autumn precipitation trends Newcastle

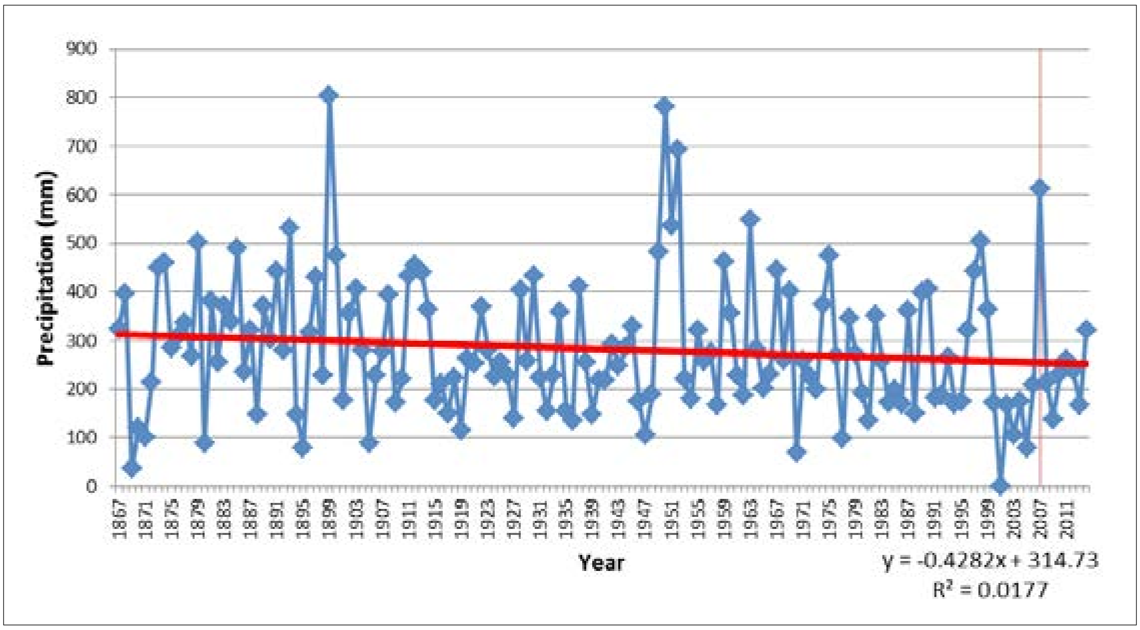

Figure 10. Average winter precipitation trends Newcastle

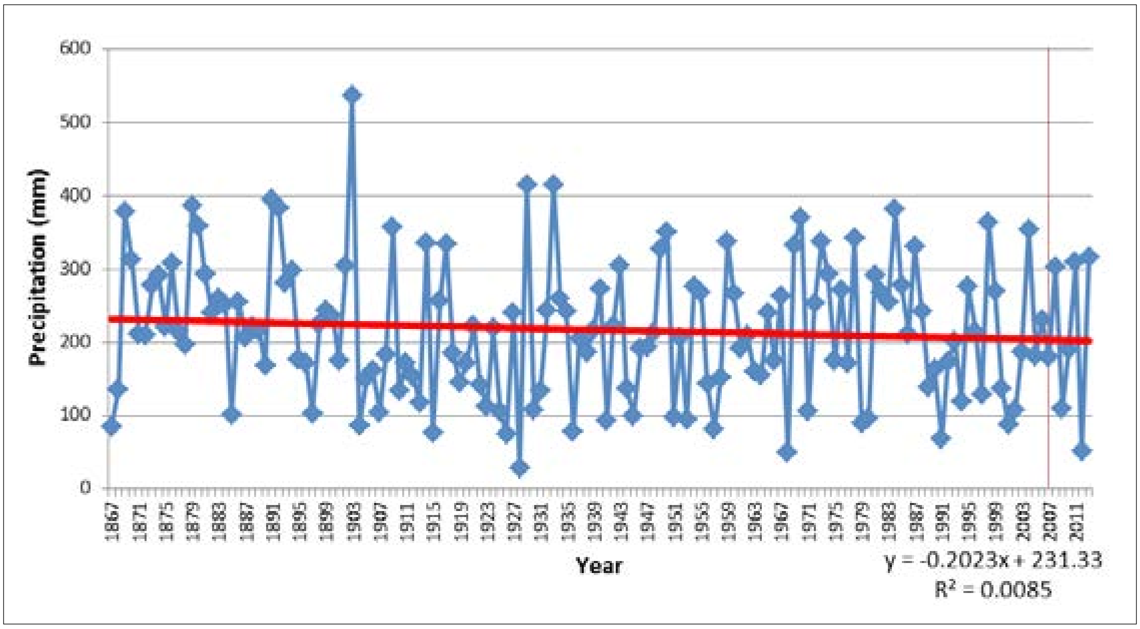

Figure 11. Average spring precipitation trends Newcastle

7.3. Seasonal precipitation: Central Zone

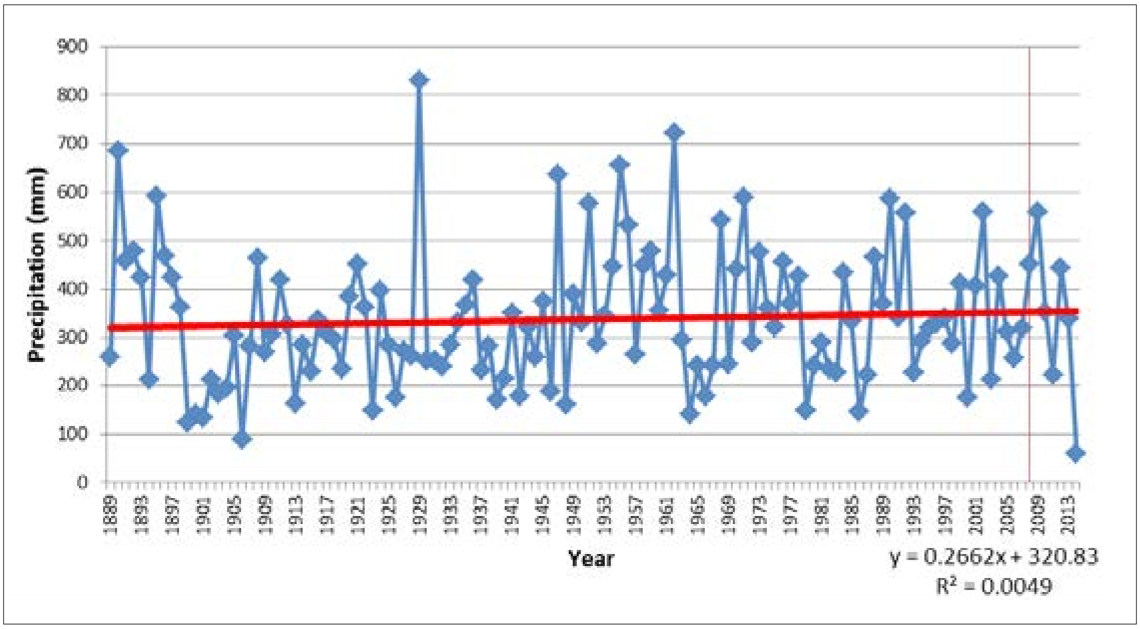

Figure 12. Average summer precipitation trends Gloucester

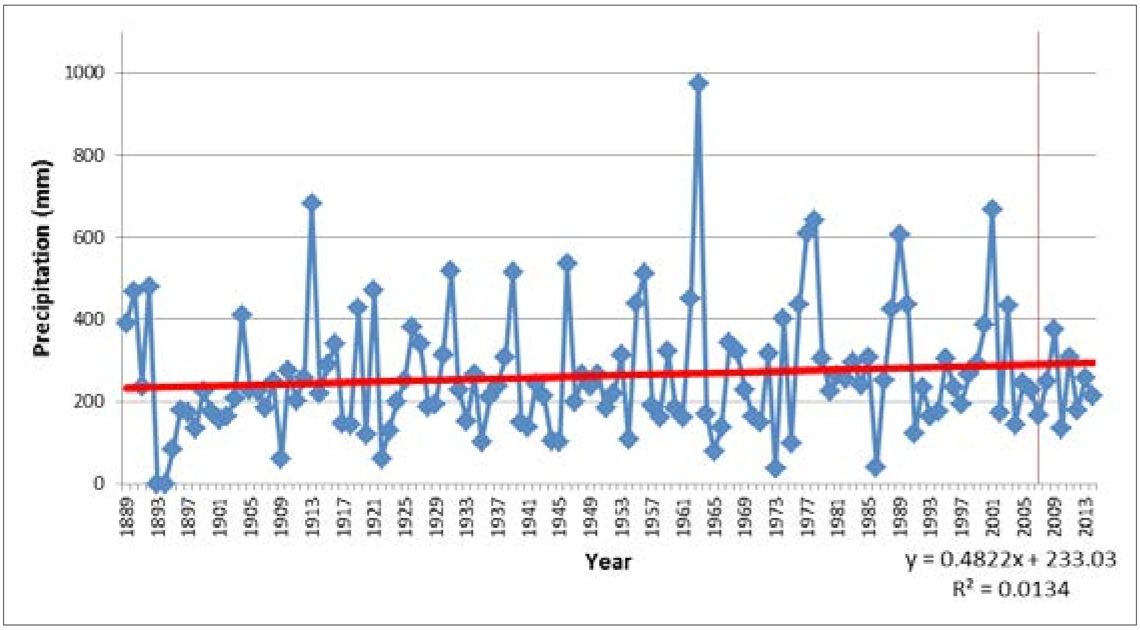

Figure 13. Average autumn precipitation trends Gloucester

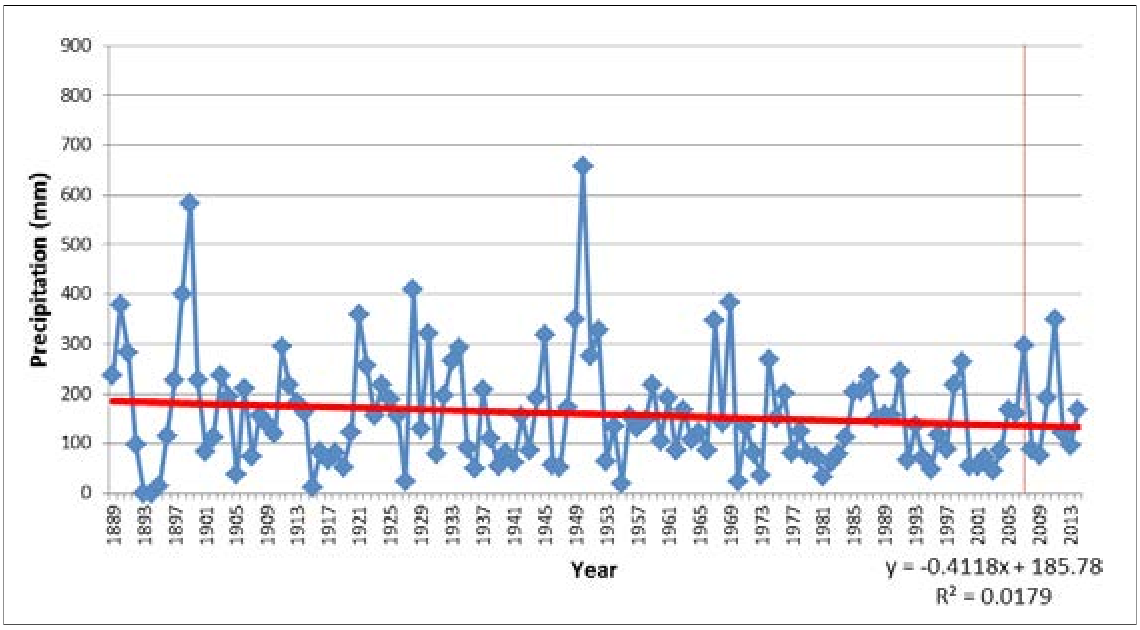

Figure 14. Average winter precipitation trends Gloucester

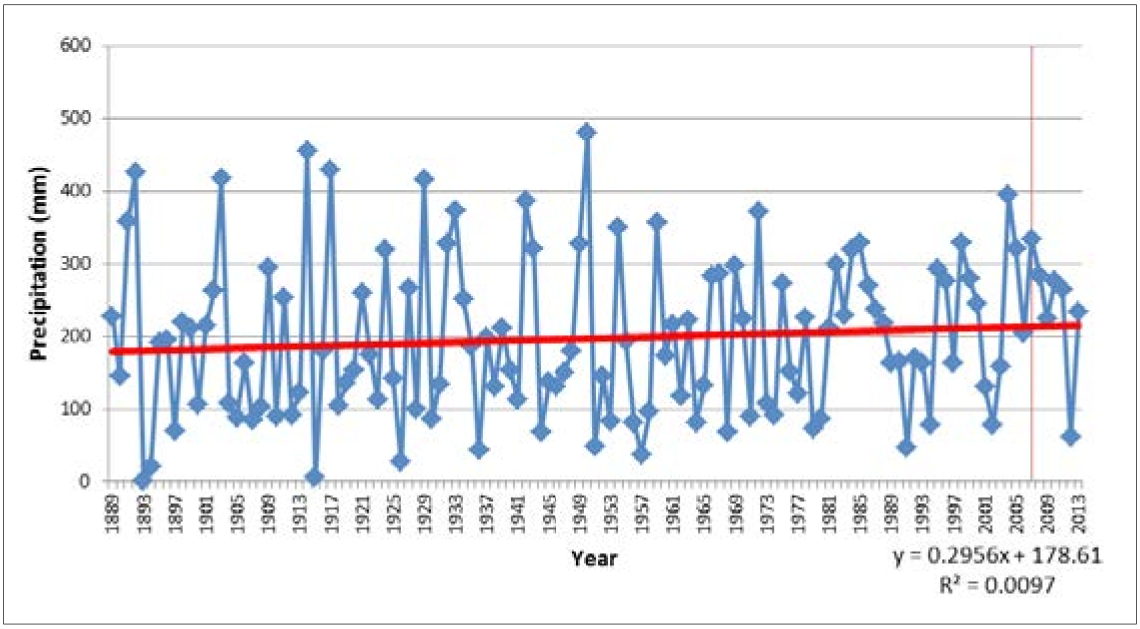

Figure 15. Average spring precipitation trends Gloucester

7.4. Seasonal precipitation: Western Zone

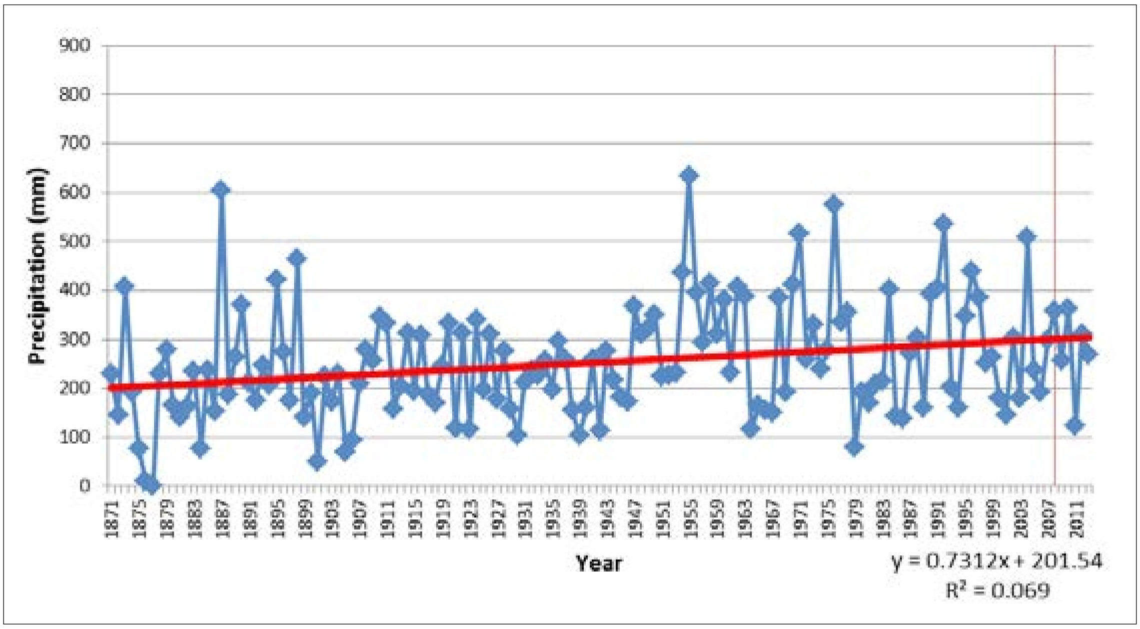

Figure 16. Average summer precipitation trends Murrurundi

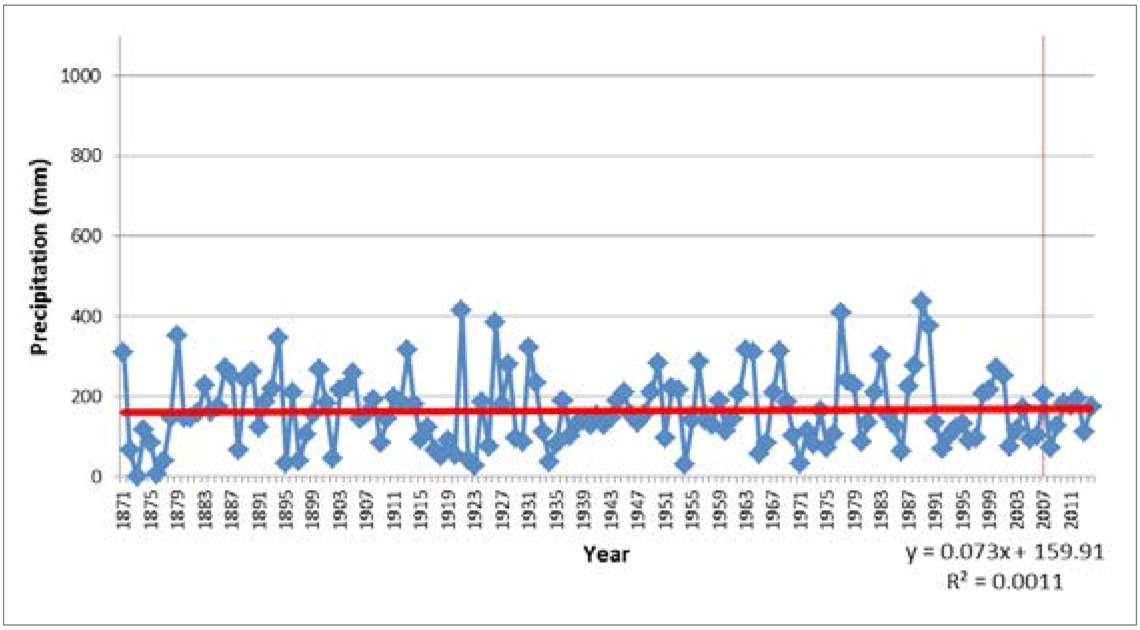

Figure 17. Average autumn precipitation trends Murrurundi

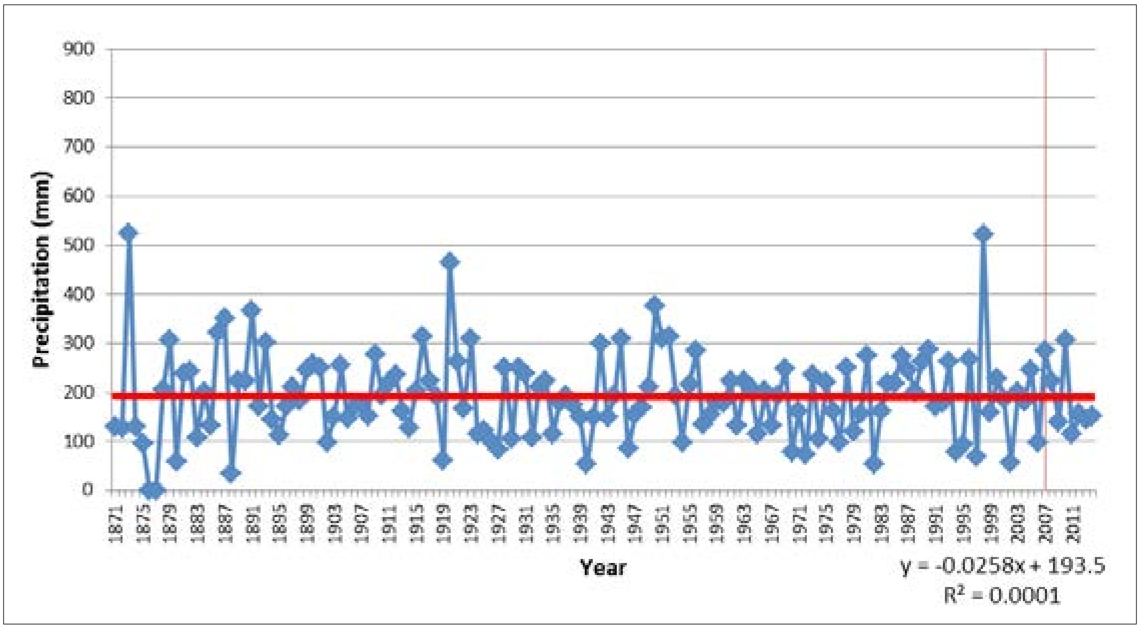

Figure 18. Average winter precipitation trends Murrurundi

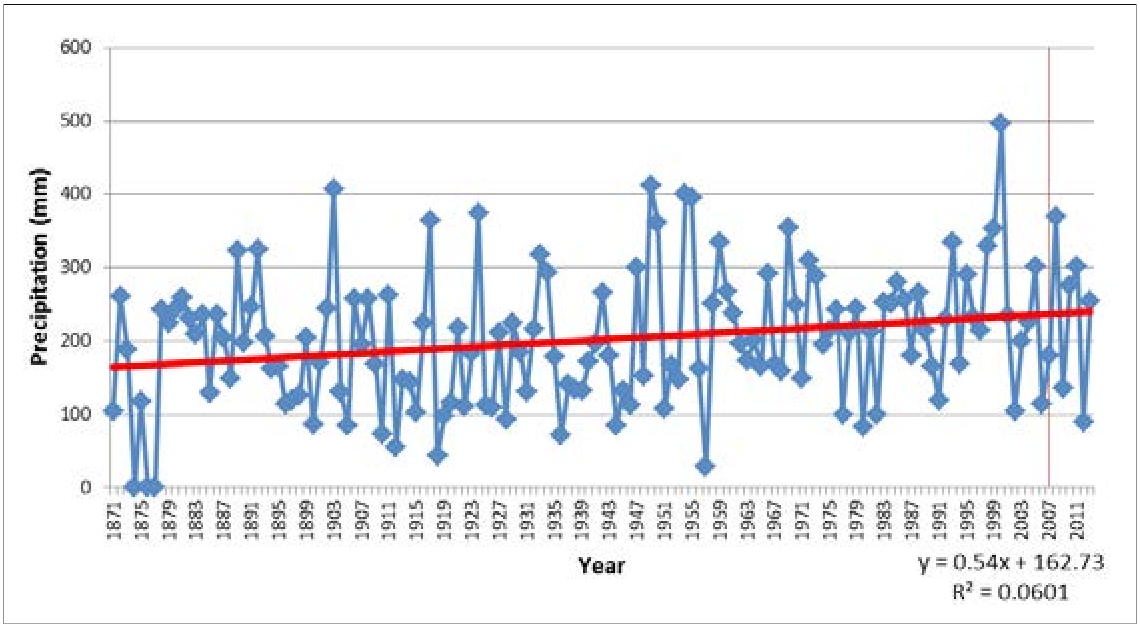

Figure 19. Average spring precipitation trends Murrurundi

7.5. Minimum temperature: Coastal Zone

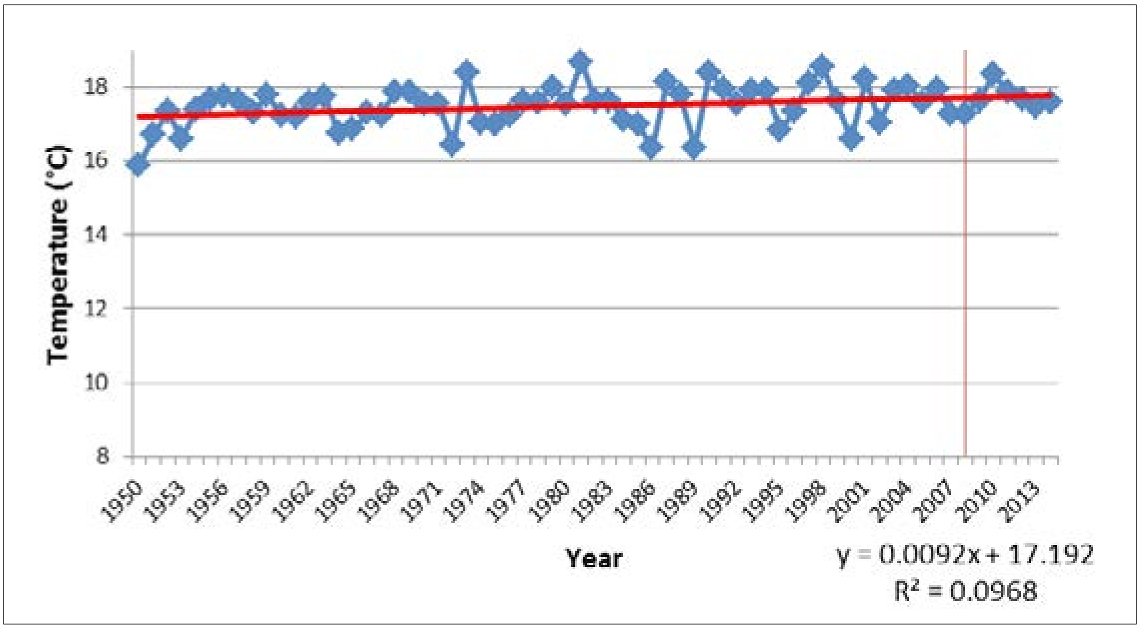

Figure 20. Average summer minimum temperature trends Williamtown

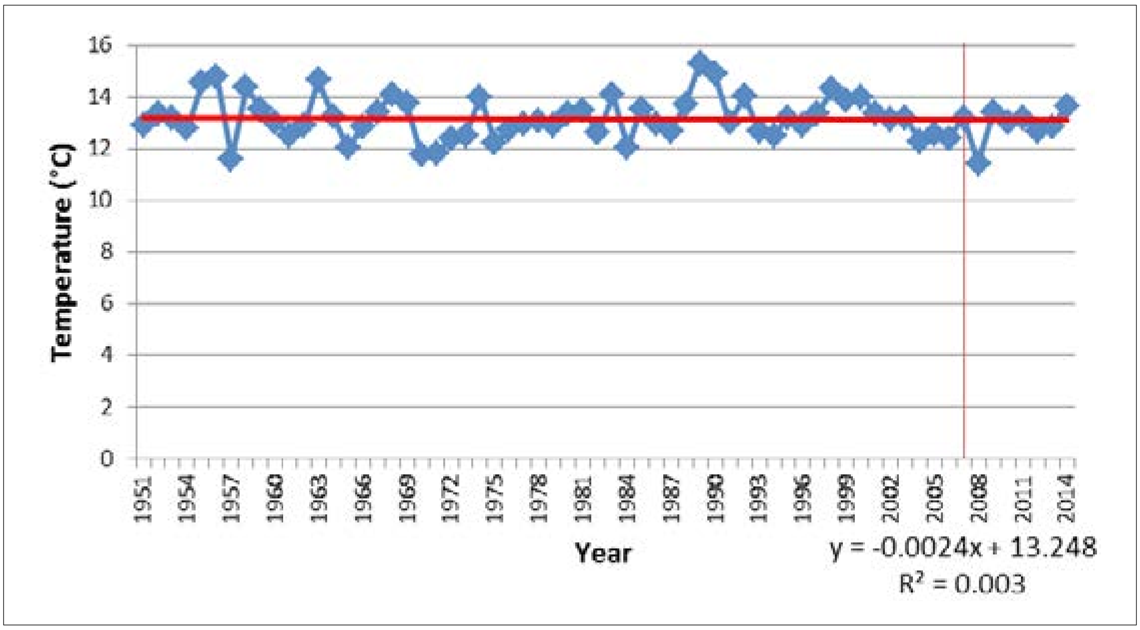

Figure 21. Average autumn minimum temperature trends Williamtown

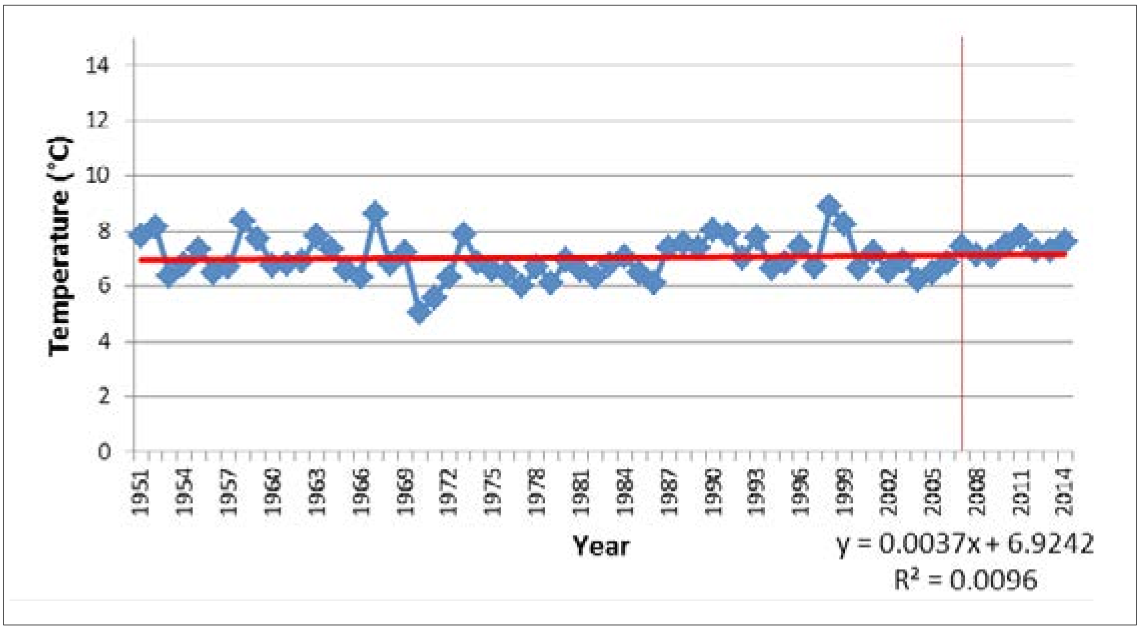

Figure 22. Average winter minimum temperature trends Williamtown

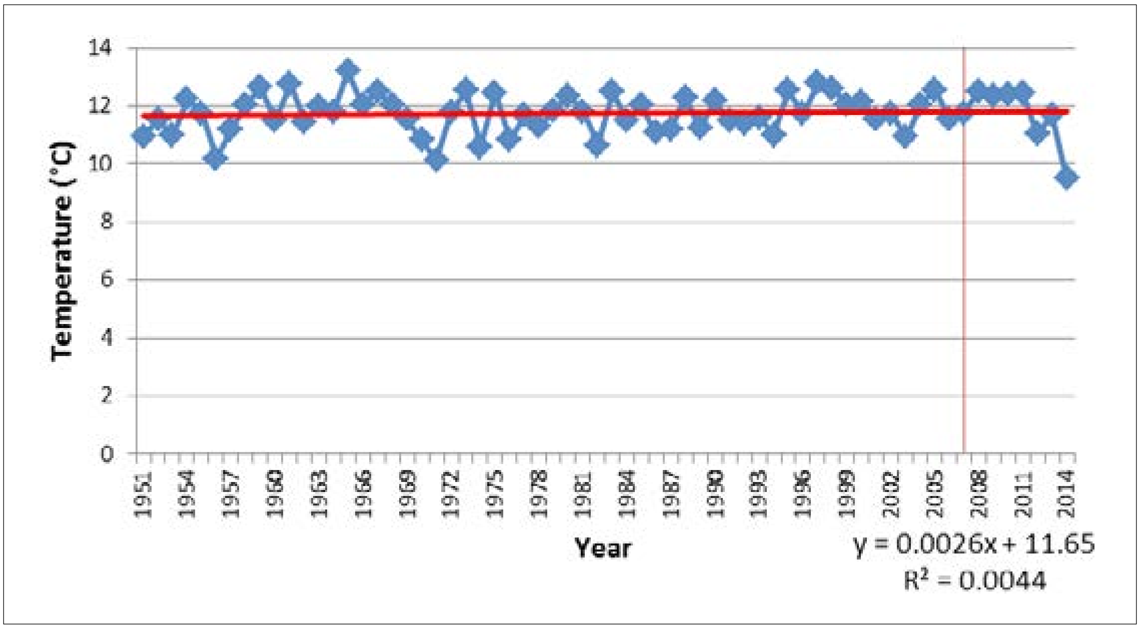

Figure 23. Average spring minimum temperature trends Williamtown

7.6. Minimum temperature: Central Zone

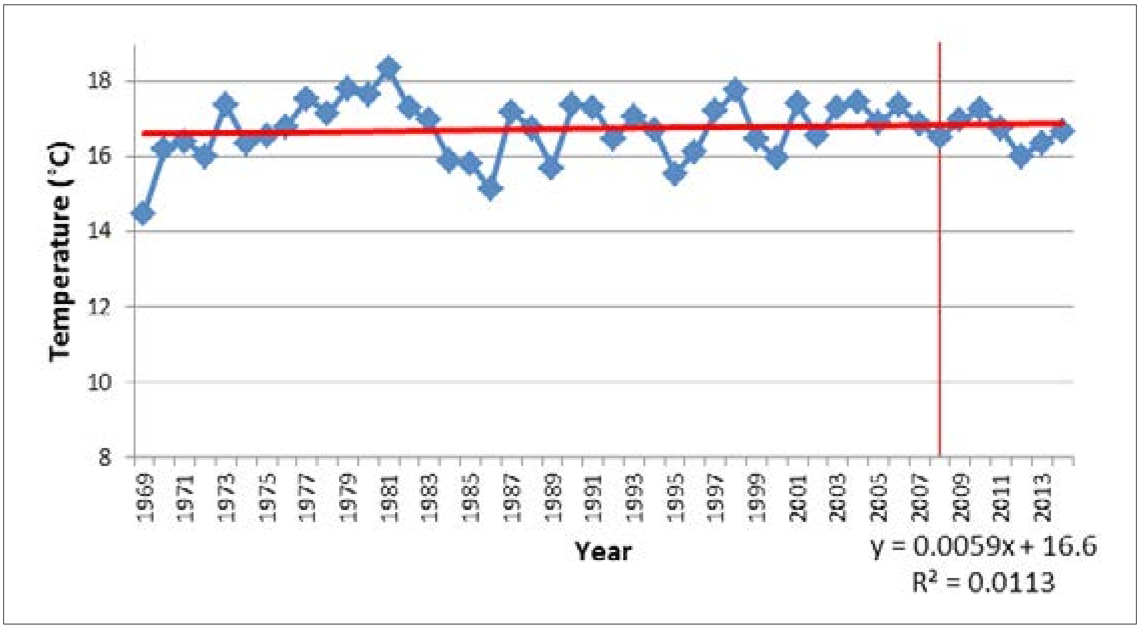

Figure 24. Average summer minimum temperature trends Lostock Dam

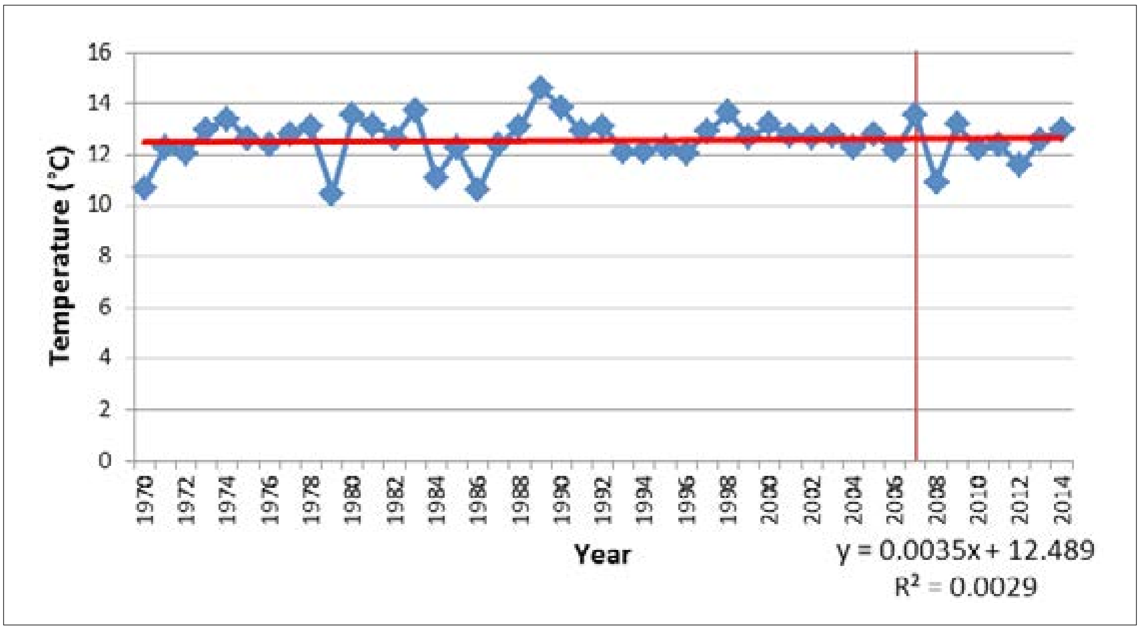

Figure 25. Average autumn minimum temperature trends Lostock Dam

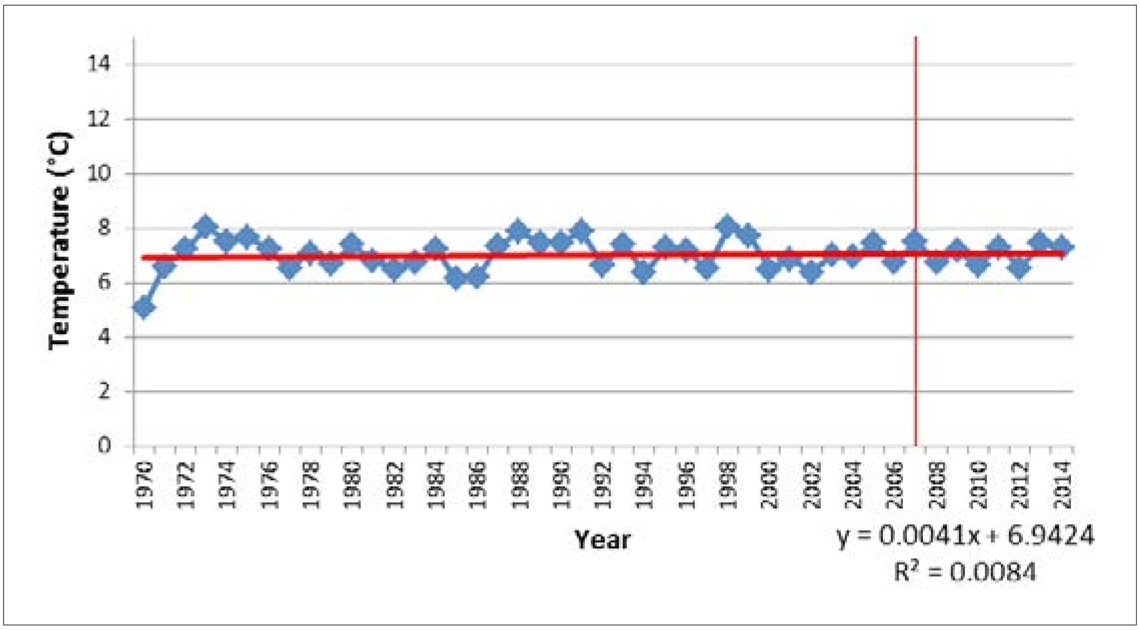

Figure 26. Average winter minimum temperature trends Lostock Dam

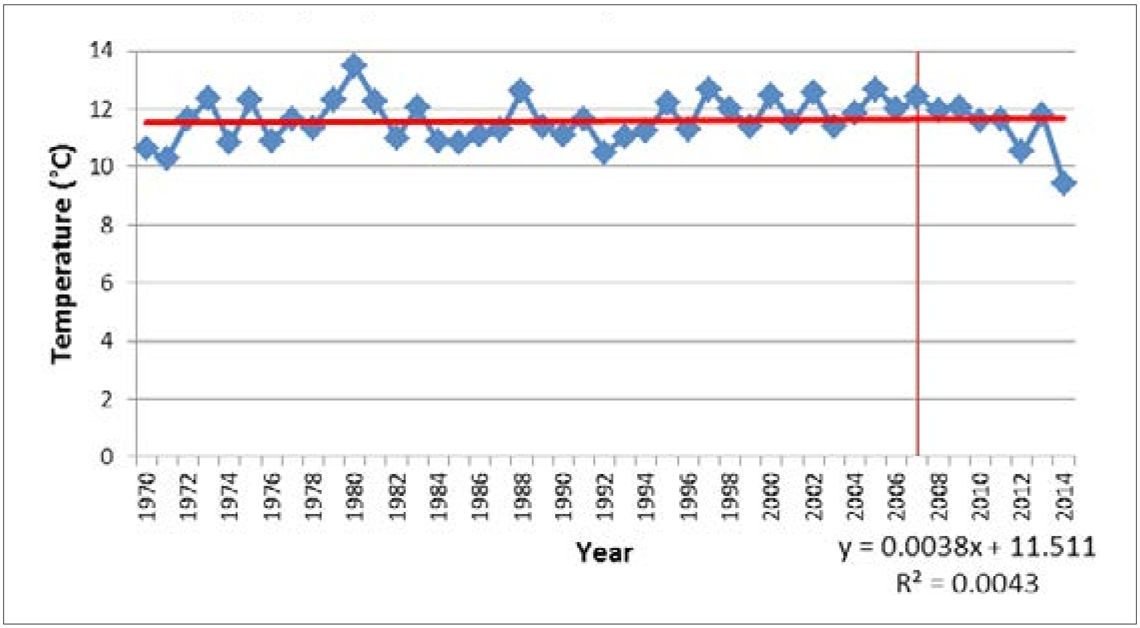

Figure 27. Average spring minimum temperature trends Lostock Dam

7.7. Minimum temperature: Western Zone

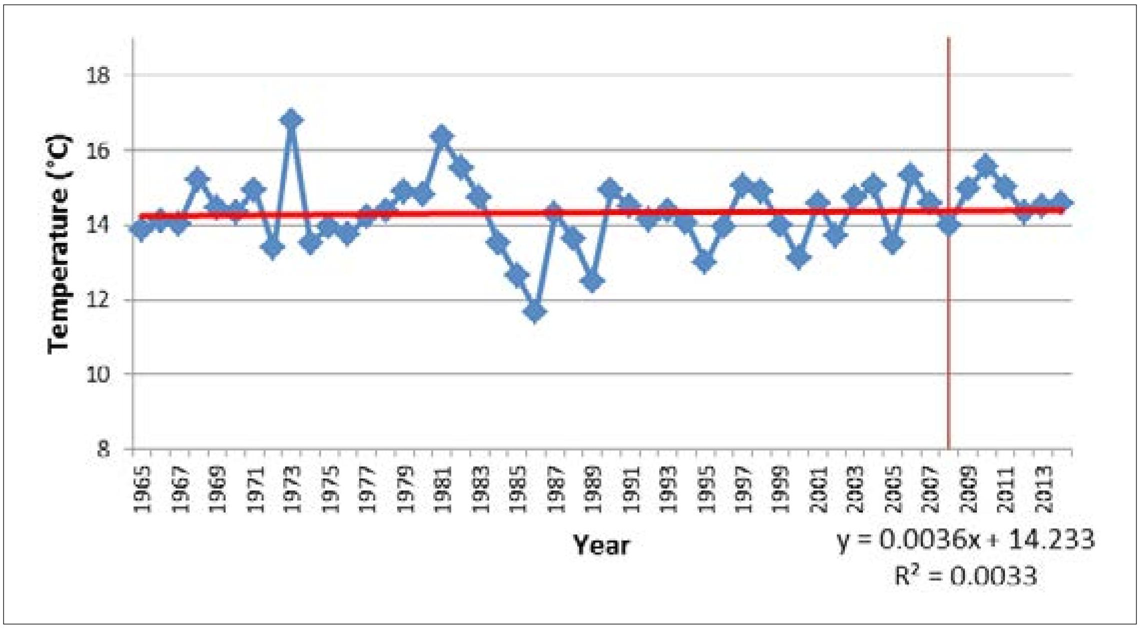

Figure 28. Average summer minimum temperature trends Murrurundi

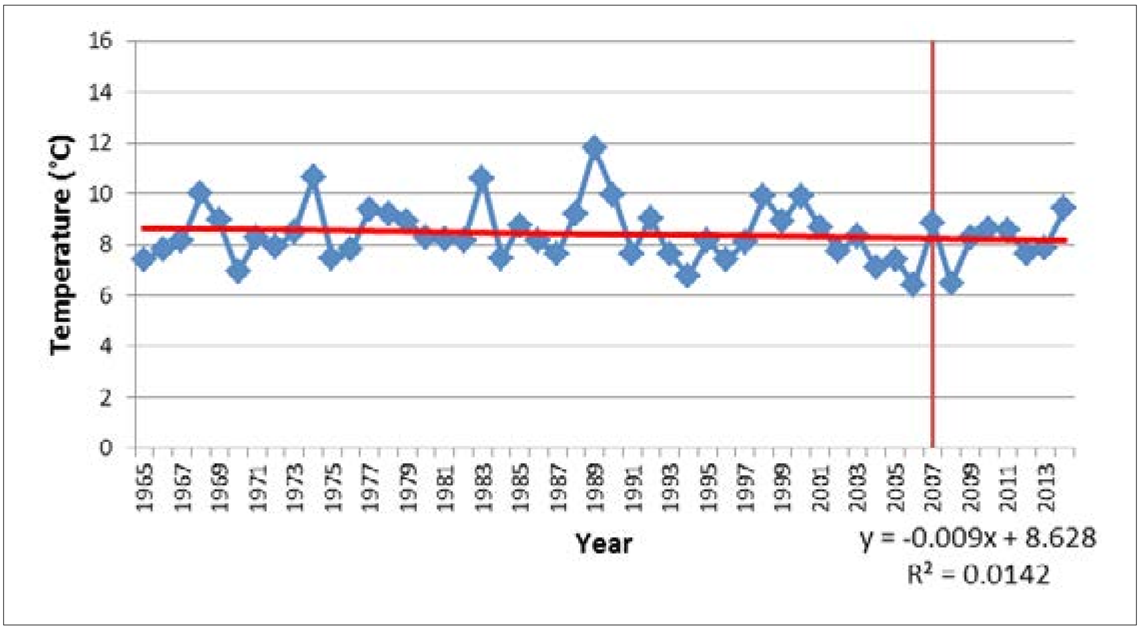

Figure 29. Average autumn minimum temperature trends Murrurundi

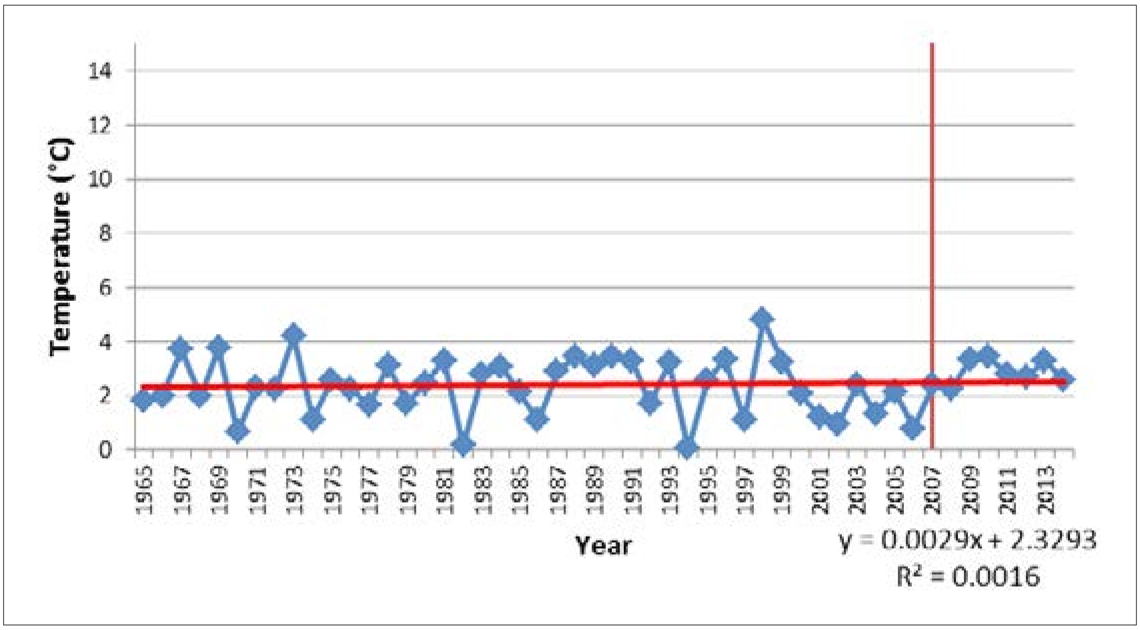

Figure 30. Average winter minimum temperature trends Murrurundi

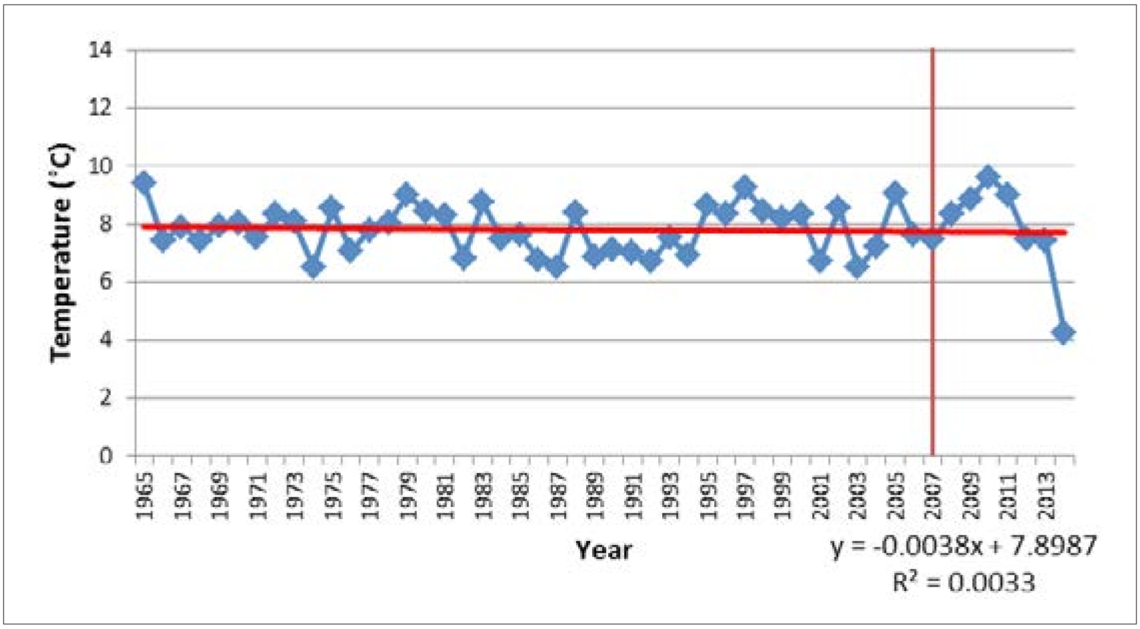

Figure 31. Average spring minimum temperature trends Murrurundi

7.8. Maximum temperature: Coastal Zone

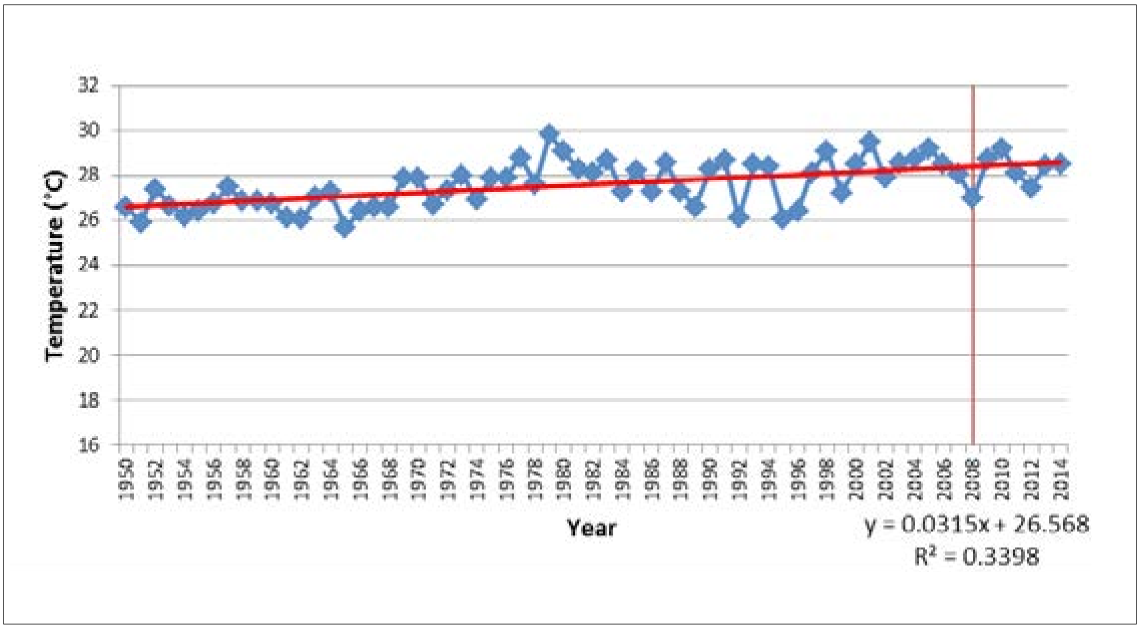

Figure 32. Average summer maximum temperature trends Williamtown

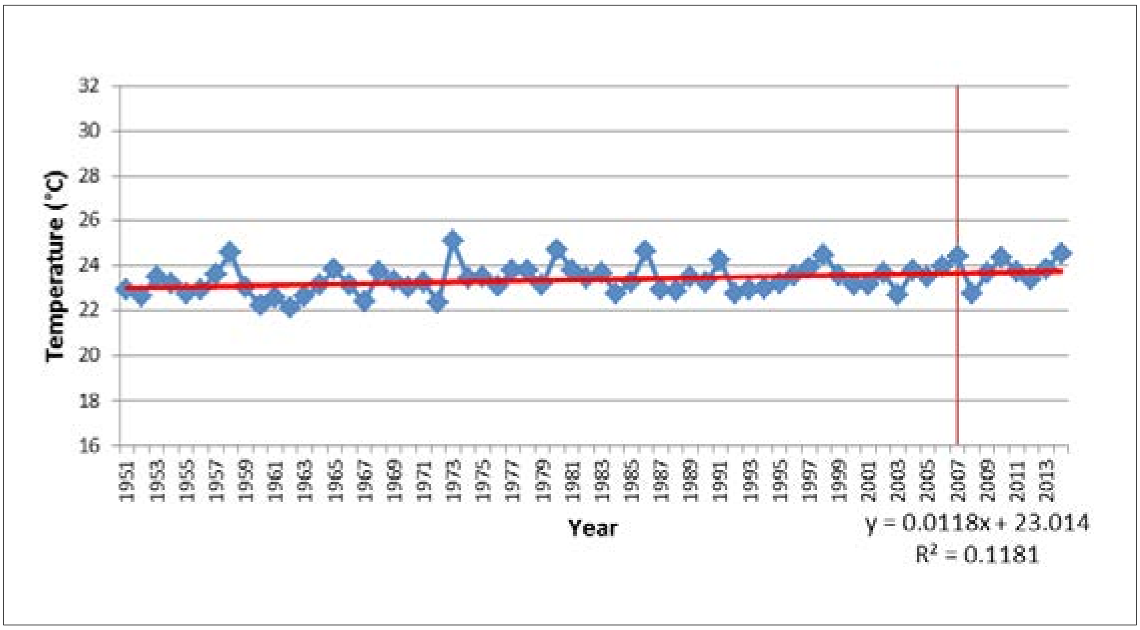

Figure 33. Average autumn maximum temperature trends Williamtown

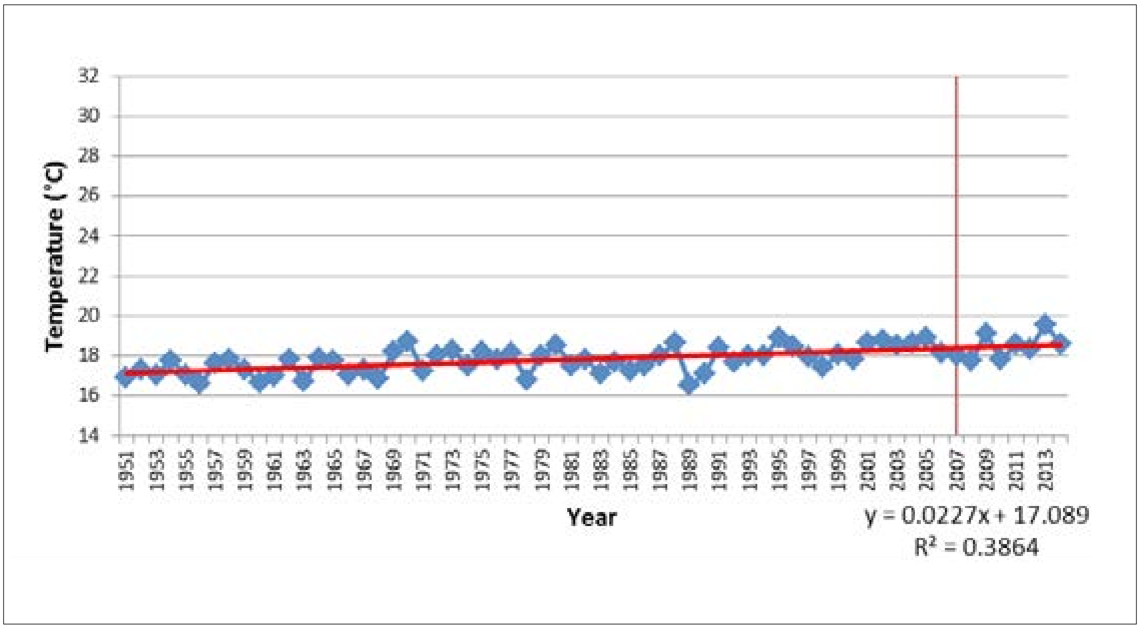

Figure 34. Average winter maximum temperature trends Williamtown

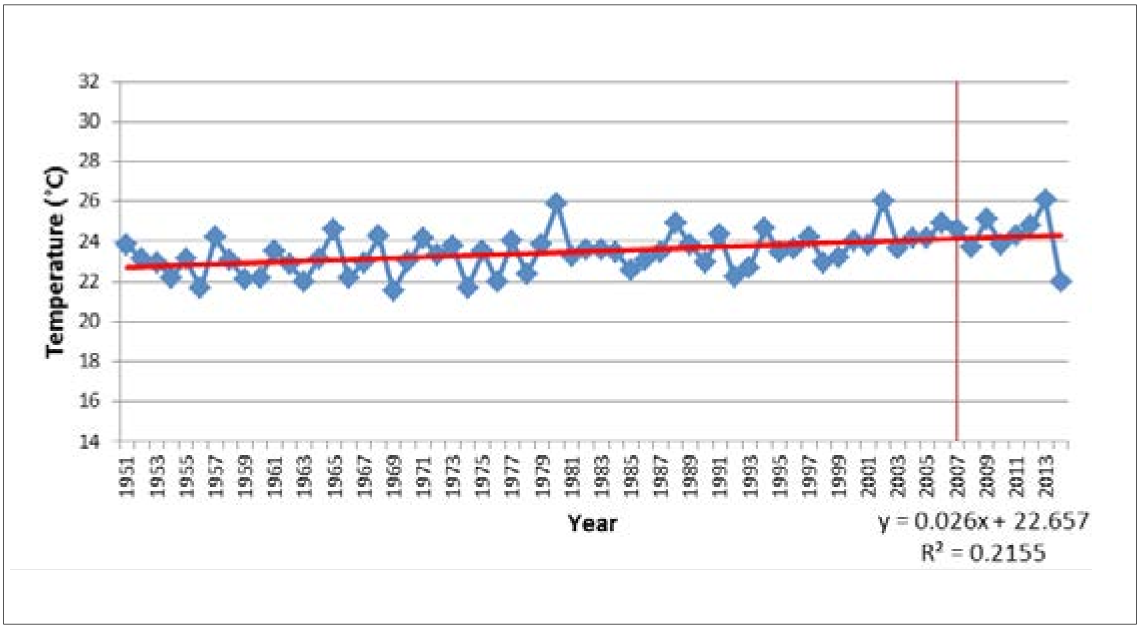

Figure 35. Average spring maximum temperature trends Williamtown

7.9. Maximum temperature: Central Zone

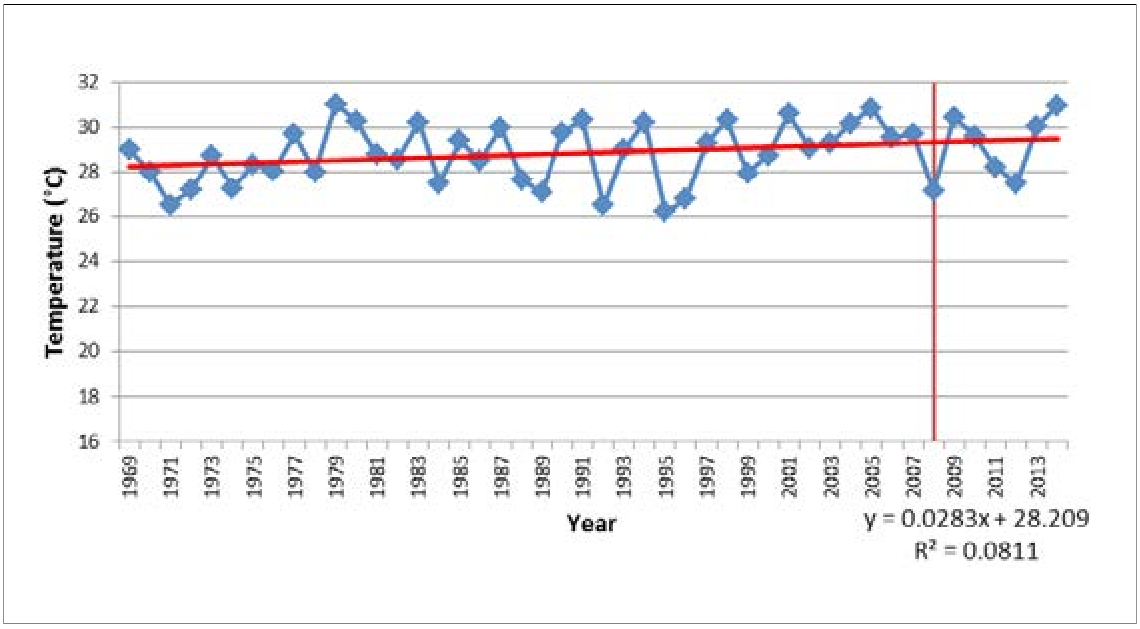

Figure 36. Average summer maximum temperature trends Lostock Dam

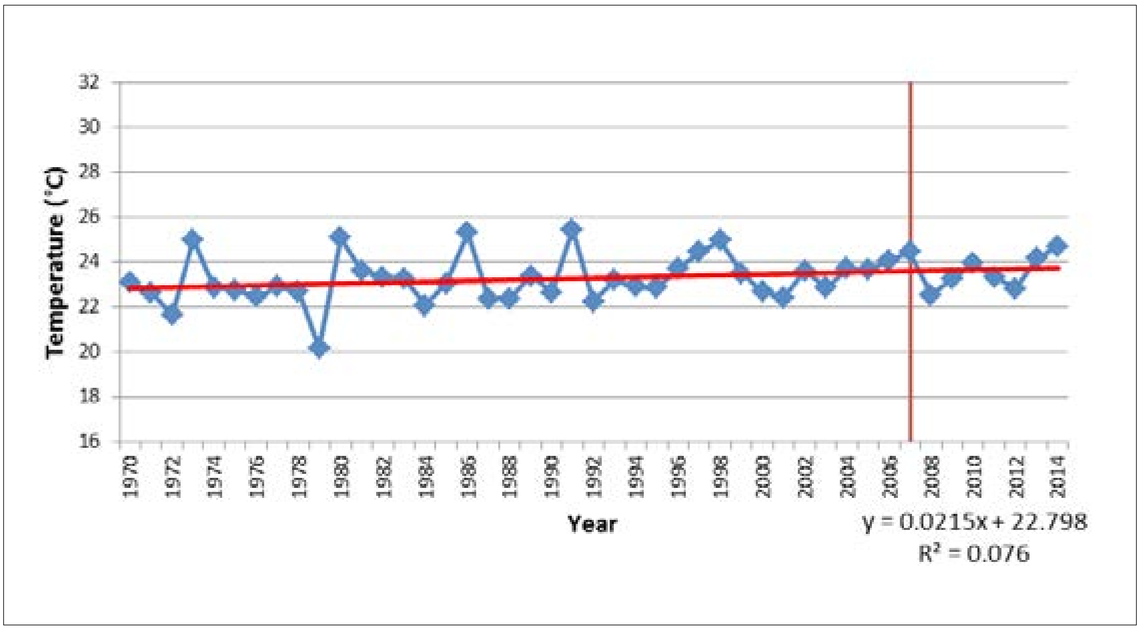

Figure 37. Average autumn maximum temperature trends Lostock Dam

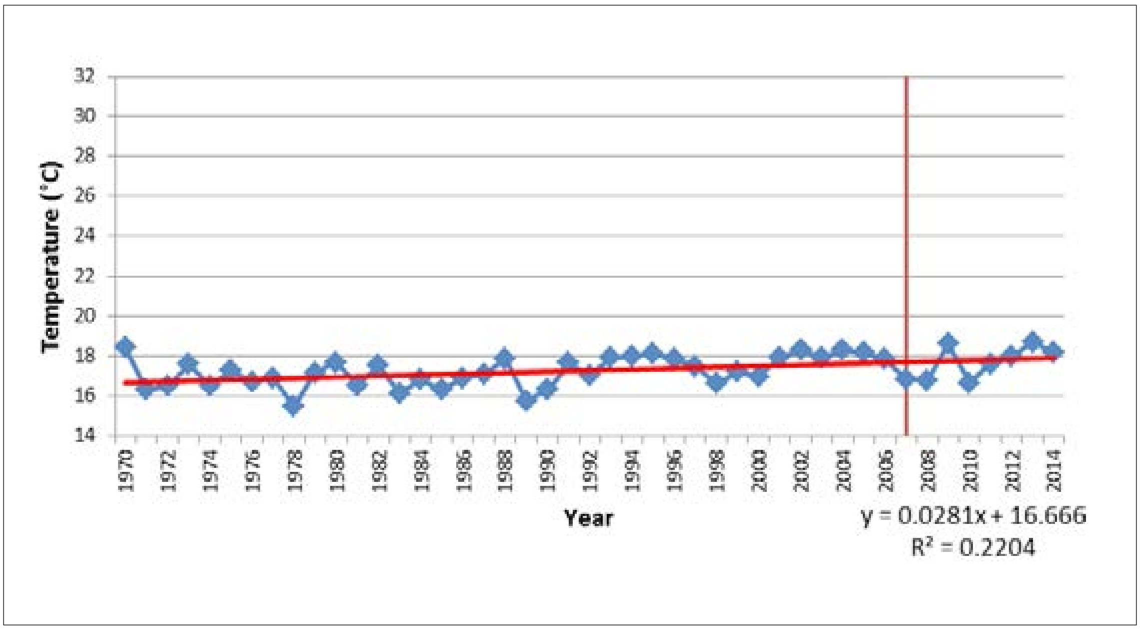

Figure 38. Average winter maximum temperature trends Lostock Dam

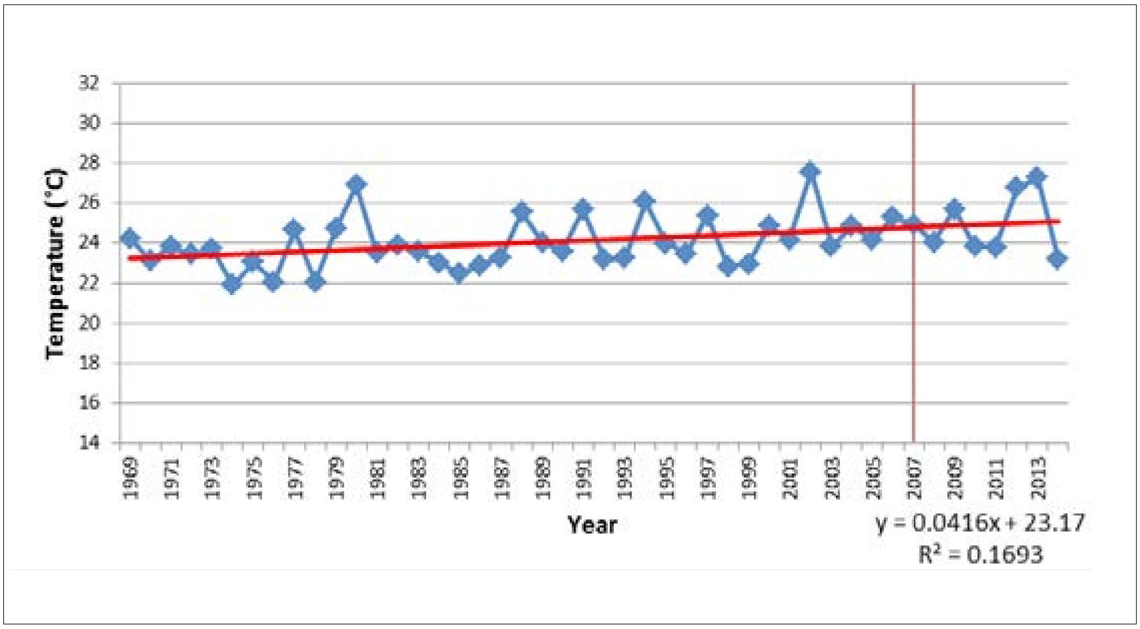

Figure 39. Average spring maximum temperature trends Lostock Dam

7.10. Maximum temperature: Western Zone

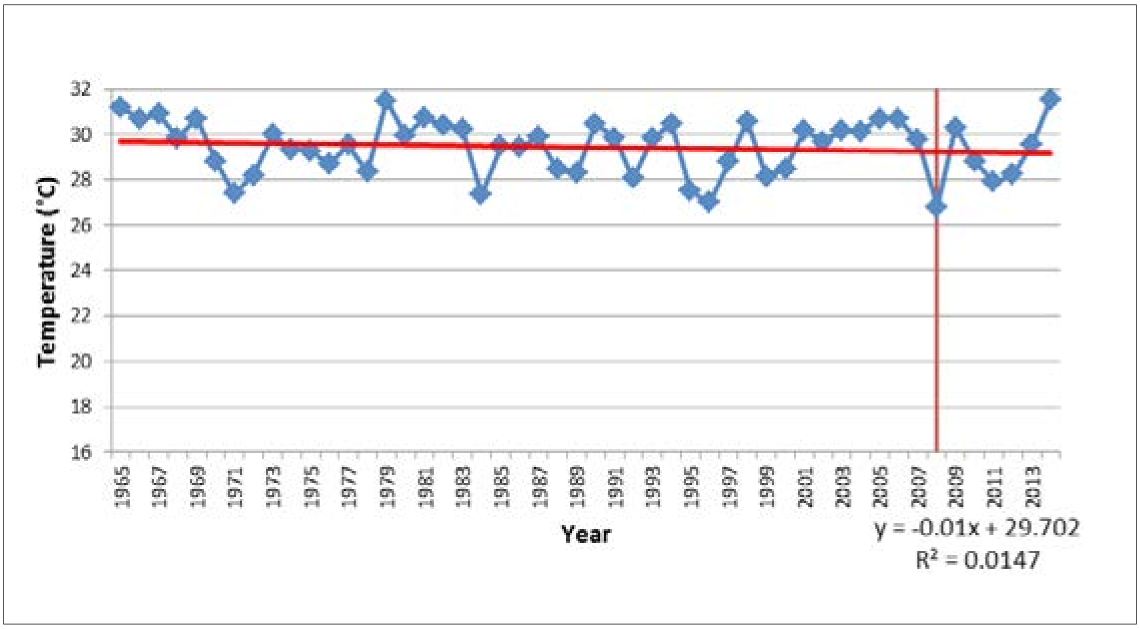

Figure 40. Average summer maximum temperature trends Murrurundi

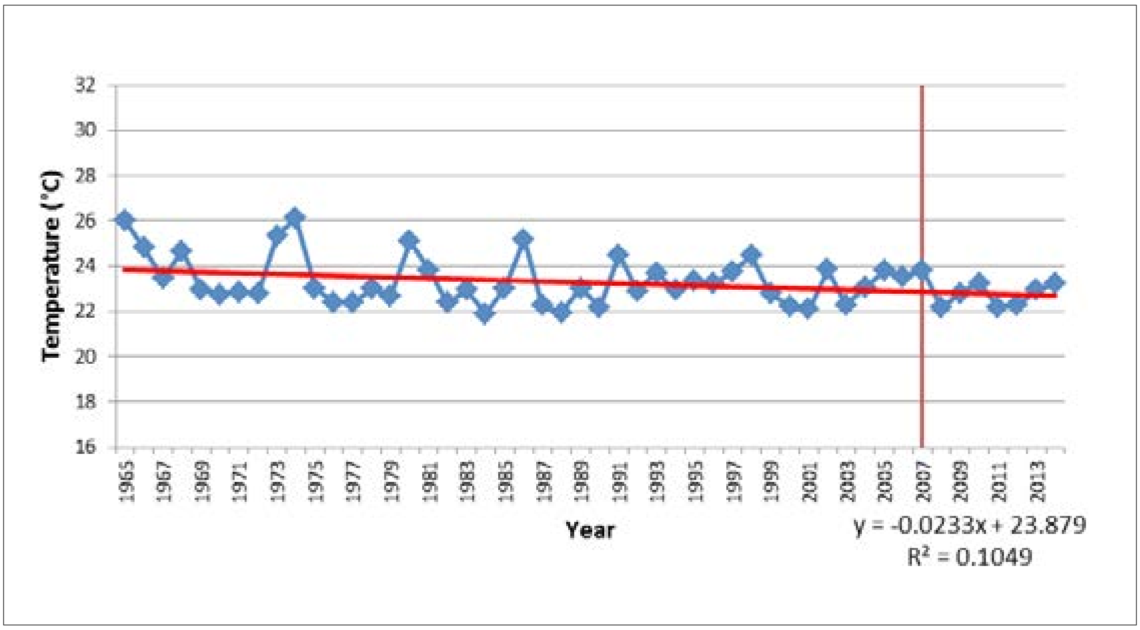

Figure 41. Average autumn maximum temperature trends Murrurundi

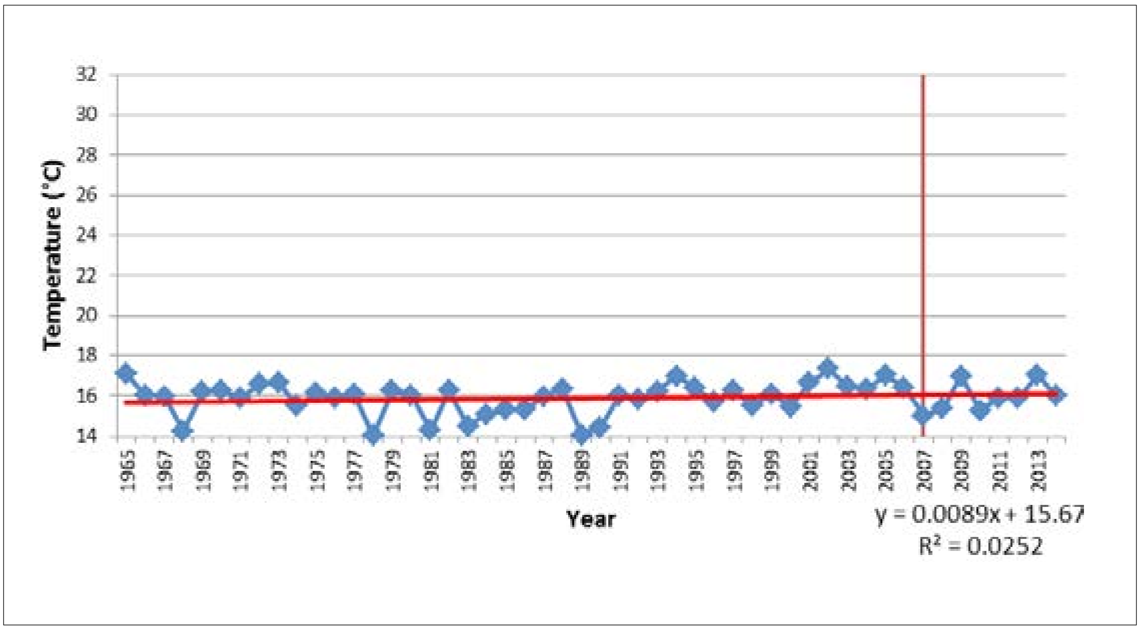

Figure 42. Average winter maximum temperature trends Murrurundi

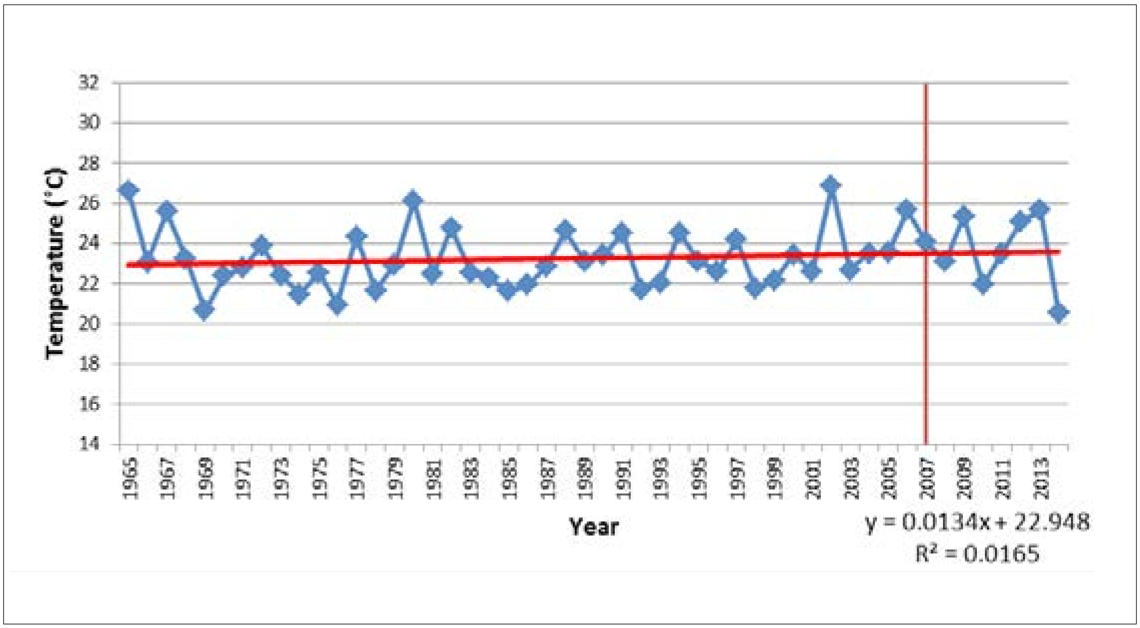

Figure 43. Average spring maximum temperature trends Murrurundi

8. Climate projections

The review process has determined that the seasonal minimum temperature and precipitation projections from the Hunter & Central Coast Regional Environmental Management Strategy (HCCREMS) regional scale climate projections (Blackmore & Goodwin, 2008 & 2009) remain valid across all climate zones, with the projections following a similar trend to those evident in the historic record and aligning to broader scale model projections from the Office of Environment and Heritage (OEH) based on recent ensemble Global Climate Model output produced through the NARCliM project.

However, maximum temperature projections for the western zone, and spring maximum temperature projections in all zones were found to be a poor fit with the historic trend, and do not reflect broader scale model projections. As a result, OEH (NARCLiM) climate data for maximum temperature projections in these zones for these seasons were applied and underpin the projections presented in this section of the report.

Where OEH (NARCLiM) near and far projections to 2040 and 2080 were used, the respective baseline period from January 1990 to December 2009 (as per OEH projection calculations), was used as the basis for calculating the annual projected value for the years from 2020 to 2080. These interpolated annual projected values allowed for projected climate grids for the 2040, 2060 and 2080 time periods to be calculated. These periods align to the HCCREMS regionally downscaled projections and provide a consistent modeling approach for the region.

Tables 6 and 7 identify the source of climate data that underpins the seasonal climate projections and spatial grid surfaces that have been developed and are presented in this report. These projections are provided for:

1. average seasonal maximum temperature
2. average seasonal minimum temperature
3. average seasonal precipitation
4. average seasonal pan evaporation

The projections provided for these follow a similar trend to those evident in the historic record. The red vertical line on the graphs is used to indicate where the time series has been extended through the current review process. A linear trend line is fitted to the data to provide an indication of a general trend, if present, in the data.

Table 6. Data underpinning climate projections – Coastal and Central Climate Zones

		UNDERPINNING CLIMATE DATA	
CLIMATE VARIABLE	SEASON	HCCREMS	OEH
Maximum temperature	Summer		
	Autumn		
	Winter		
	Spring		
Minimum temperature	All		
Precipitation	All		

Table 7. Data underpinning climate projections – Western Climate Zone

		UNDERPINNING CLIMATE DATA	
CLIMATE VARIABLE	SEASON	HCCREMS	OEH
Maximum temperature	Summer		
	Autumn		
	Winter		
	Spring		
Minimum temperature	All		
Precipitation	All		

8.1. Seasonal maximum temperature: Coastal Zone

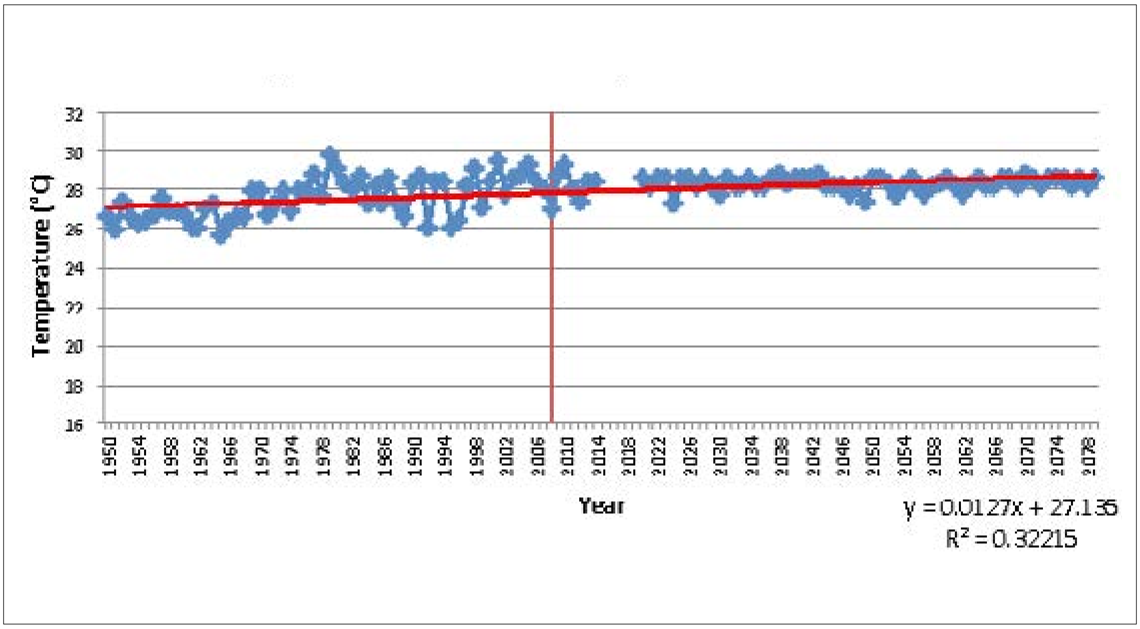

Figure 44. Average summer maximum temperature projections Williamtown

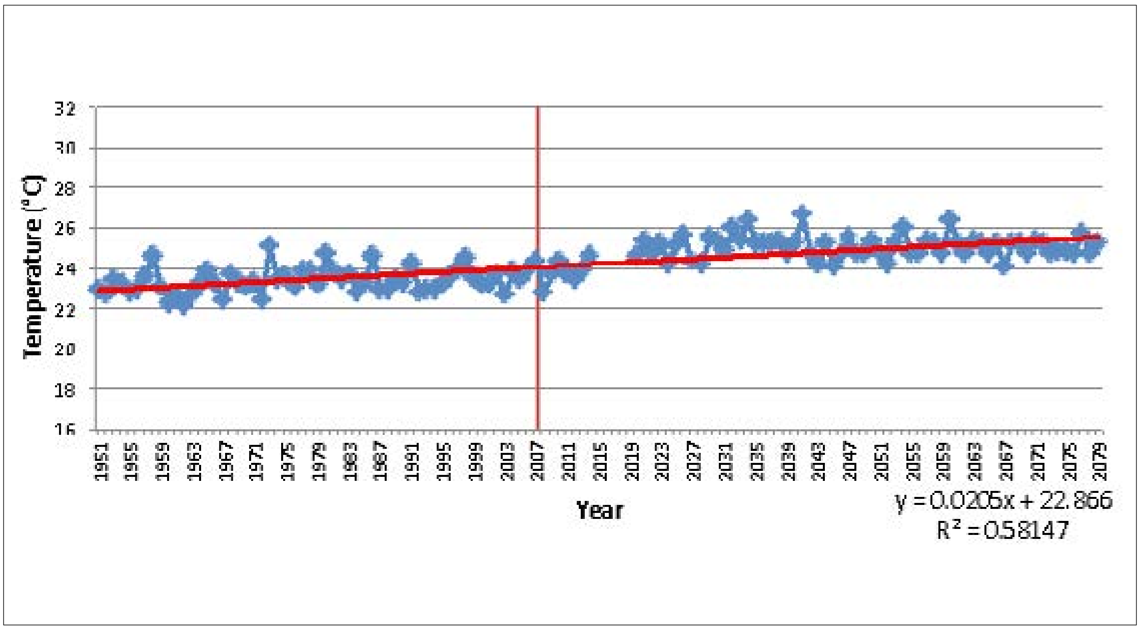

Figure 45. Average autumn maximum temperature projections Williamtown

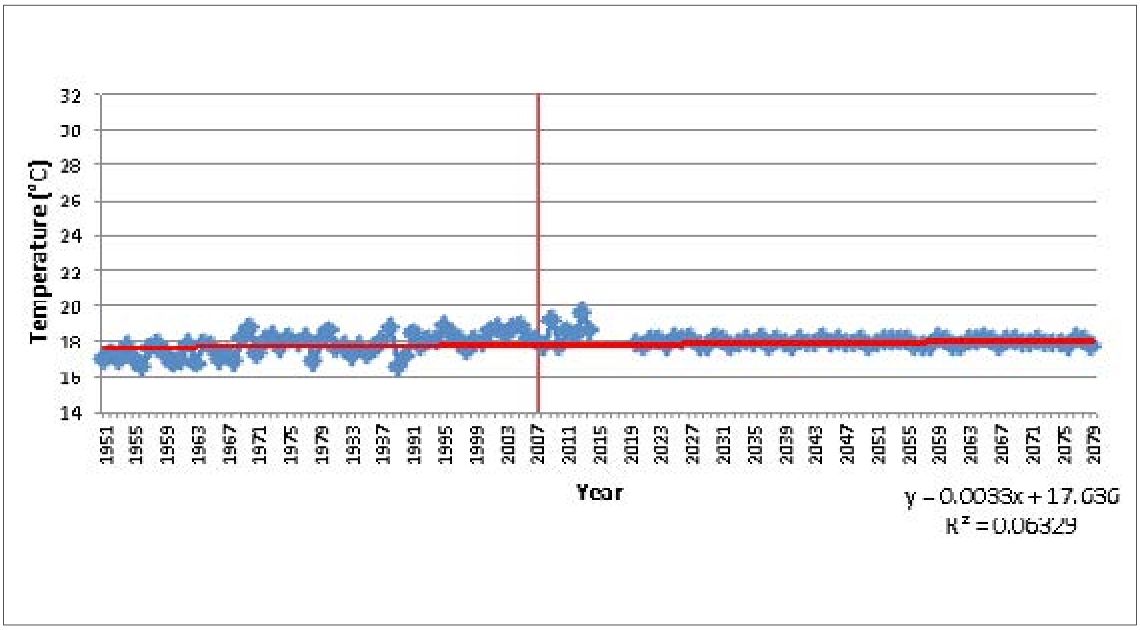

Figure 46. Average winter maximum temperature projections Williamtown

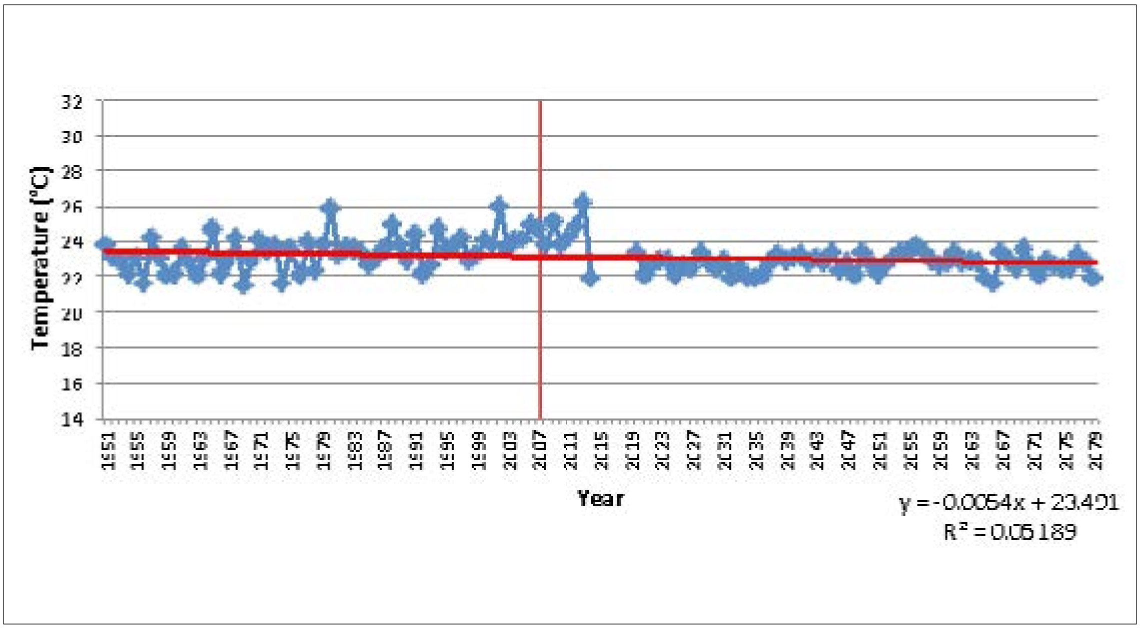

Figure 47. Average spring maximum temperature projections Williamtown

8.2. Seasonal maximum temperatures: Central Zone

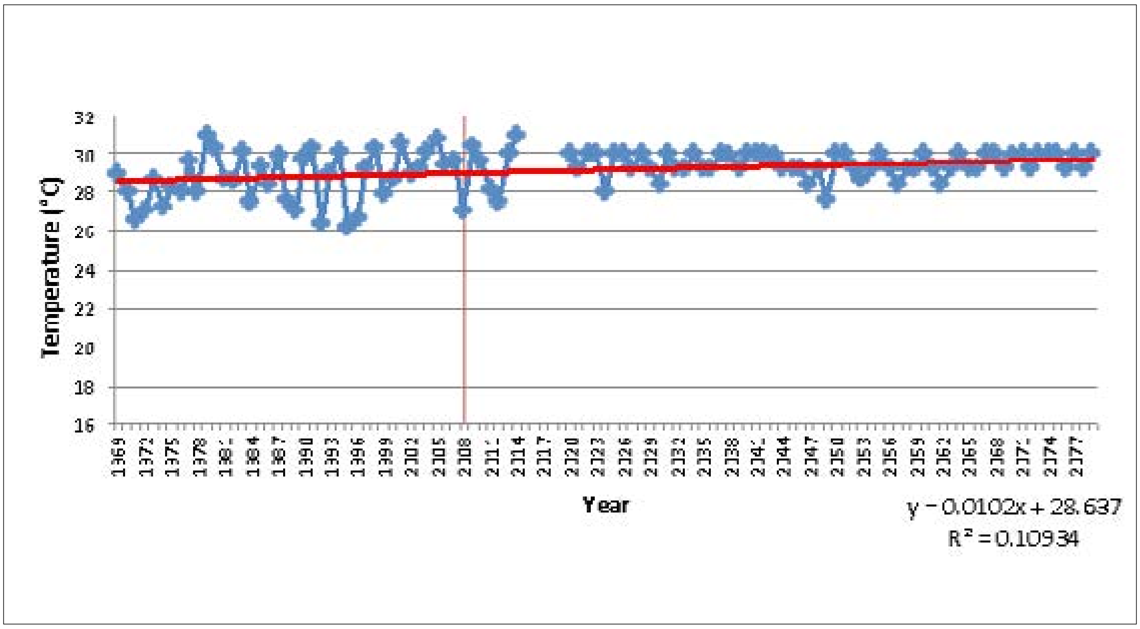

Figure 48. Average summer maximum temperature projections Lostock Dam

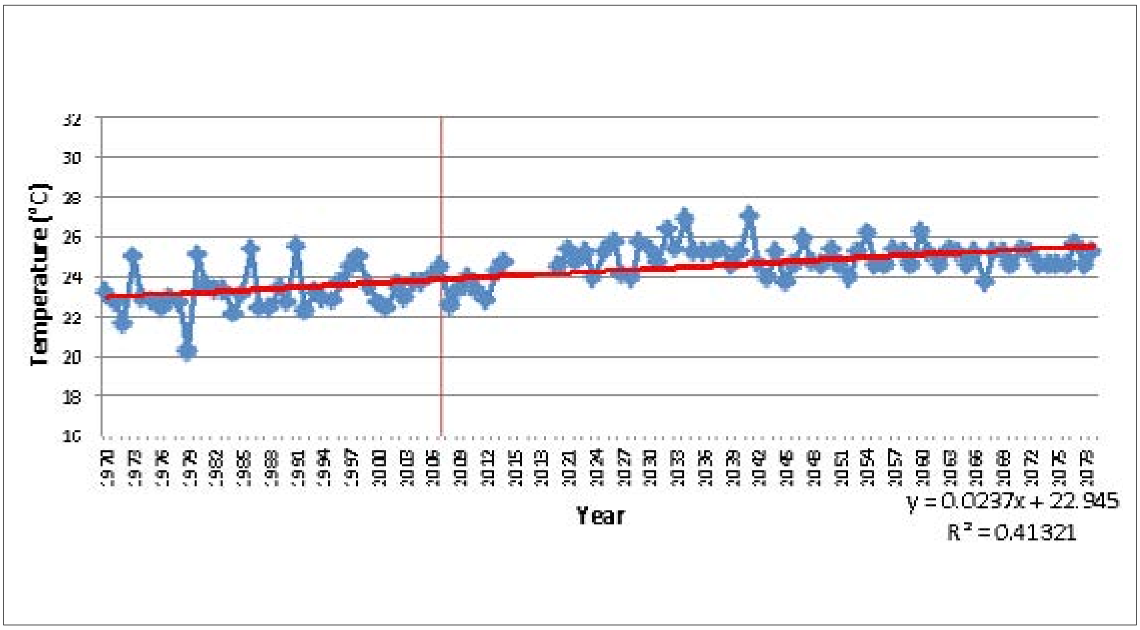

Figure 49. Average autumn maximum temperature projections Lostock Dam

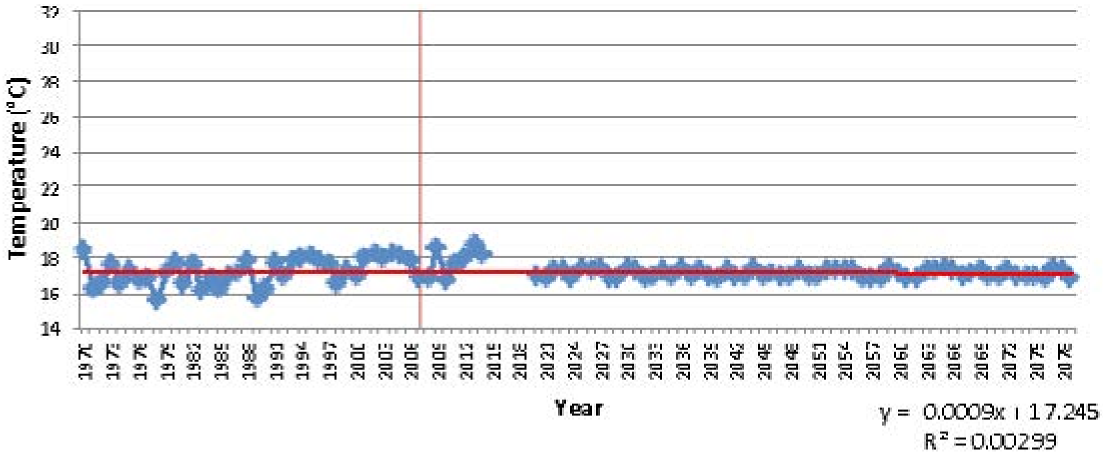

Figure 50. Average winter maximum temperature projections Lostock Dam

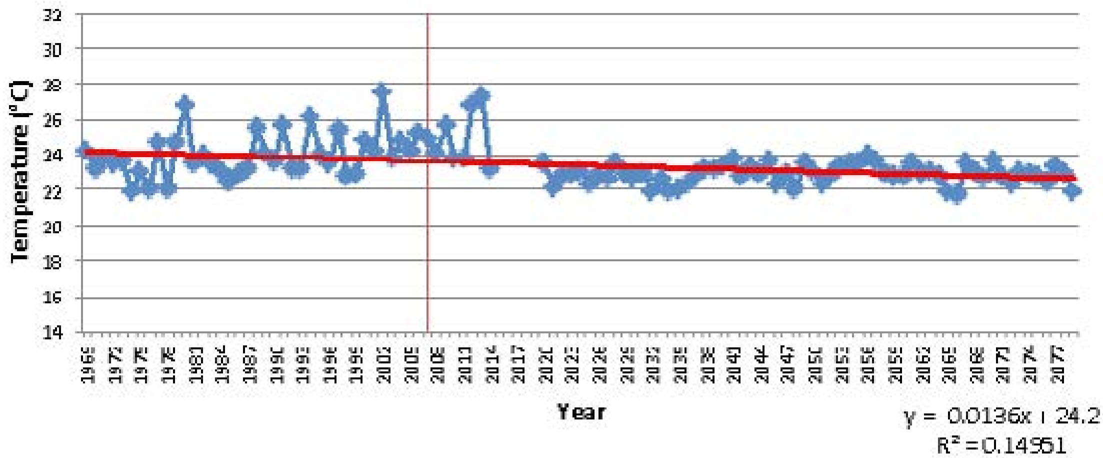

Figure 51. Average spring maximum temperature projections Lostock Dam

8.3. Seasonal maximum temperatures: Western Zone

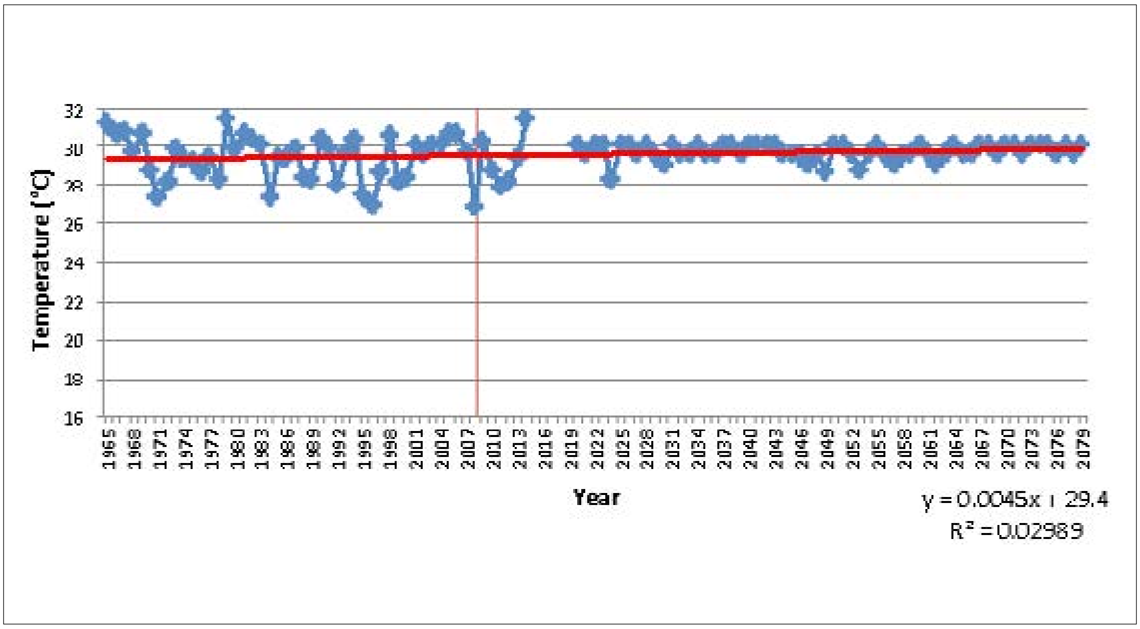

Figure 52. Average summer maximum temperature projections Murrurundi

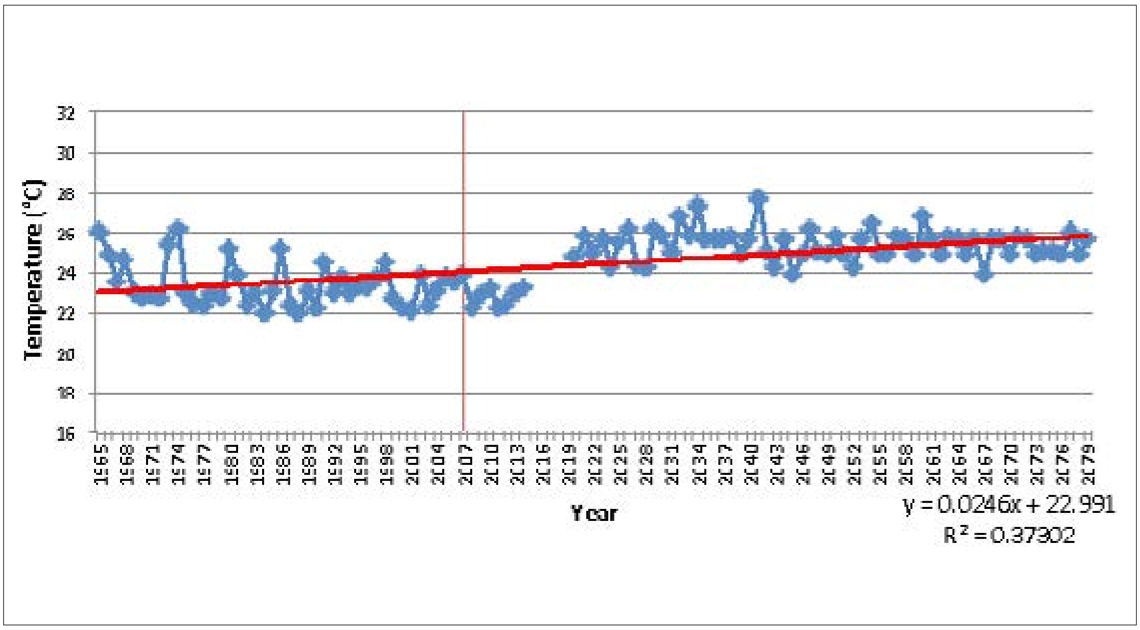

Figure 53. Average autumn maximum temperature projections Murrurundi

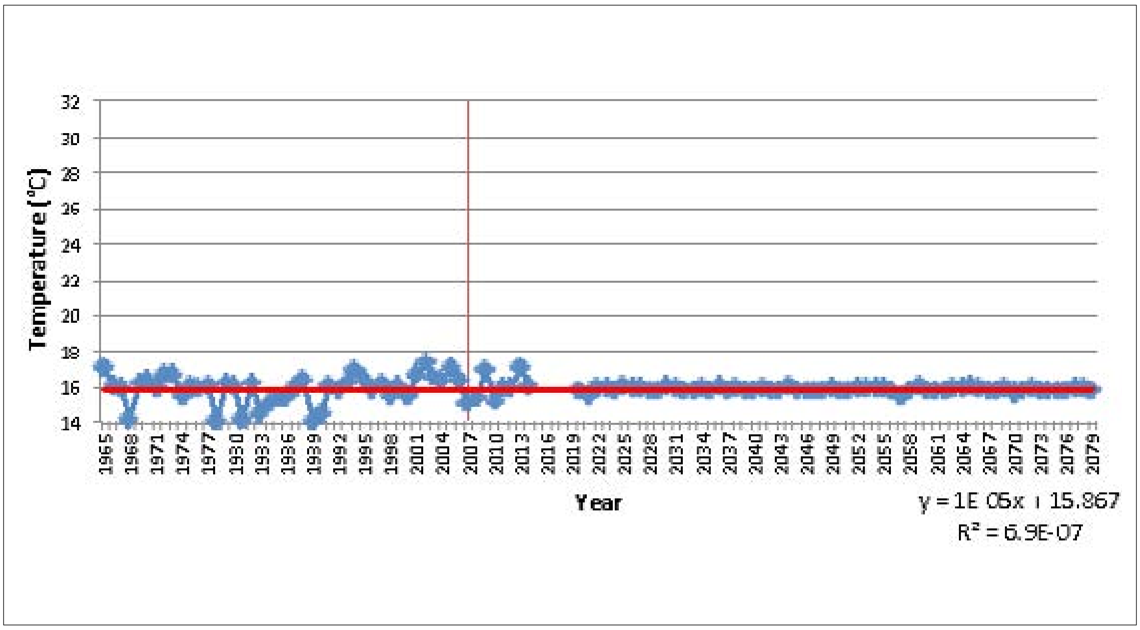

Figure 54. Average winter maximum temperature projections Murrurundi

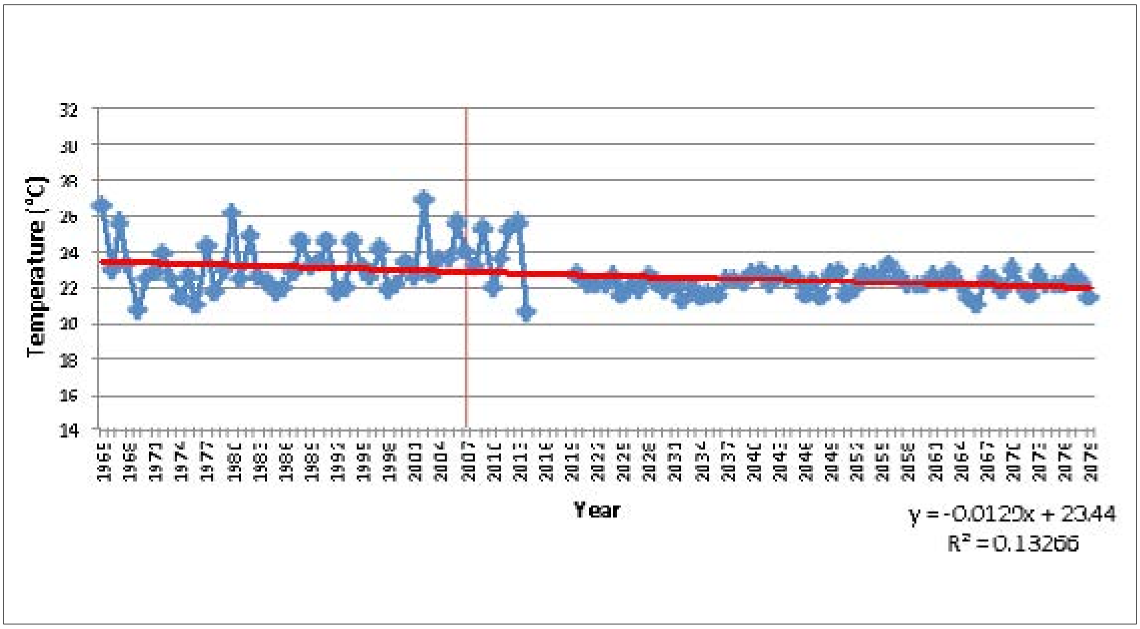

Figure 55. Average spring maximum temperature projections Murrurundi

8.4. Seasonal minimum temperature: Coastal Zone

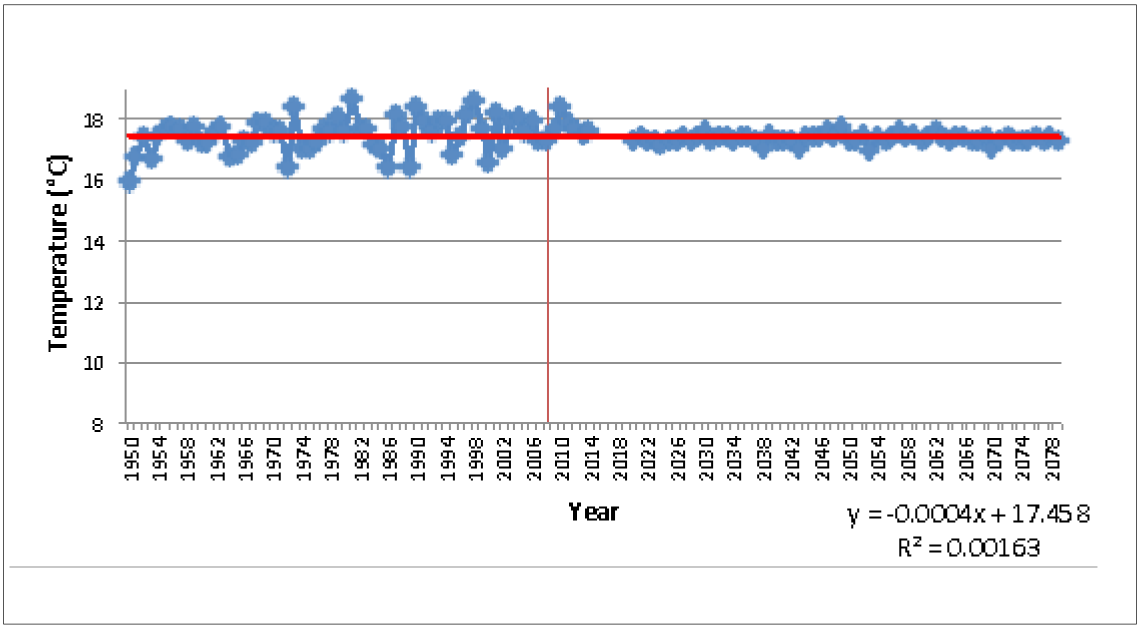

Figure 56. Average summer minimum temperature projections Williamtown

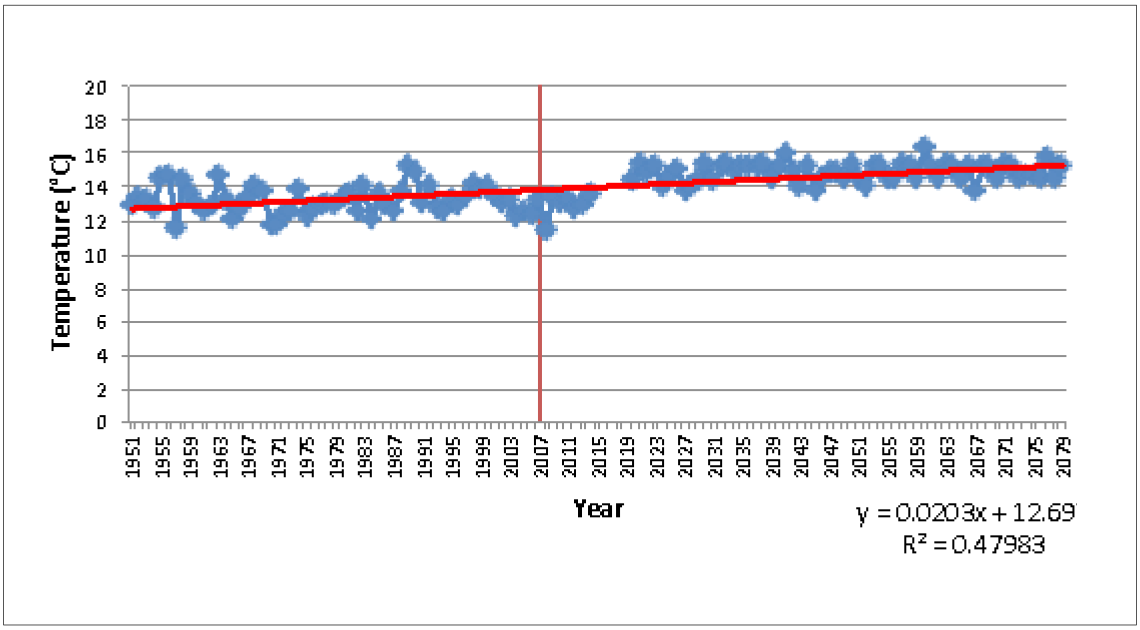

Figure 57. Average autumn minimum temperature projections Williamtown

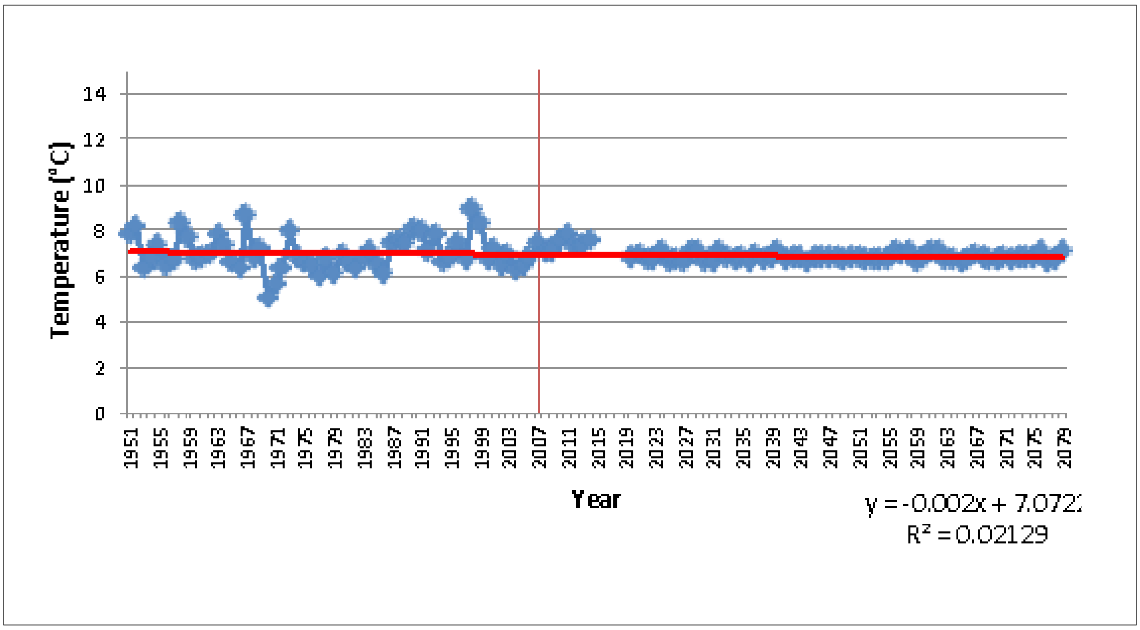

Figure 58. Average winter minimum temperature projections Williamtown

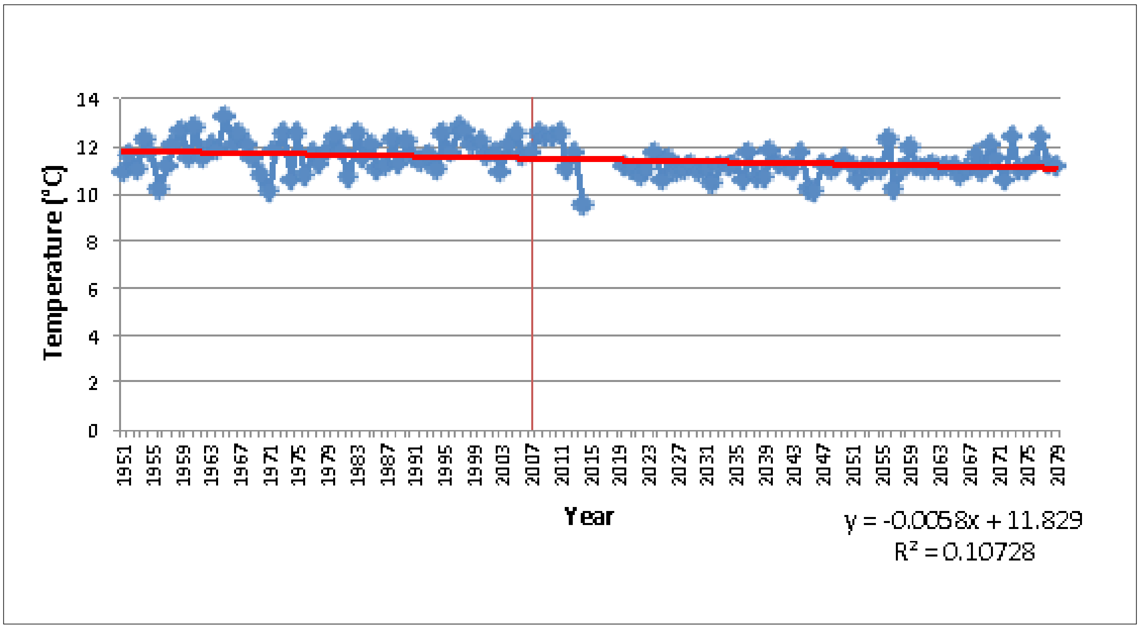

Figure 59. Average spring minimum temperature projections Williamtown

8.5. Seasonal minimum temperature: Central Zone

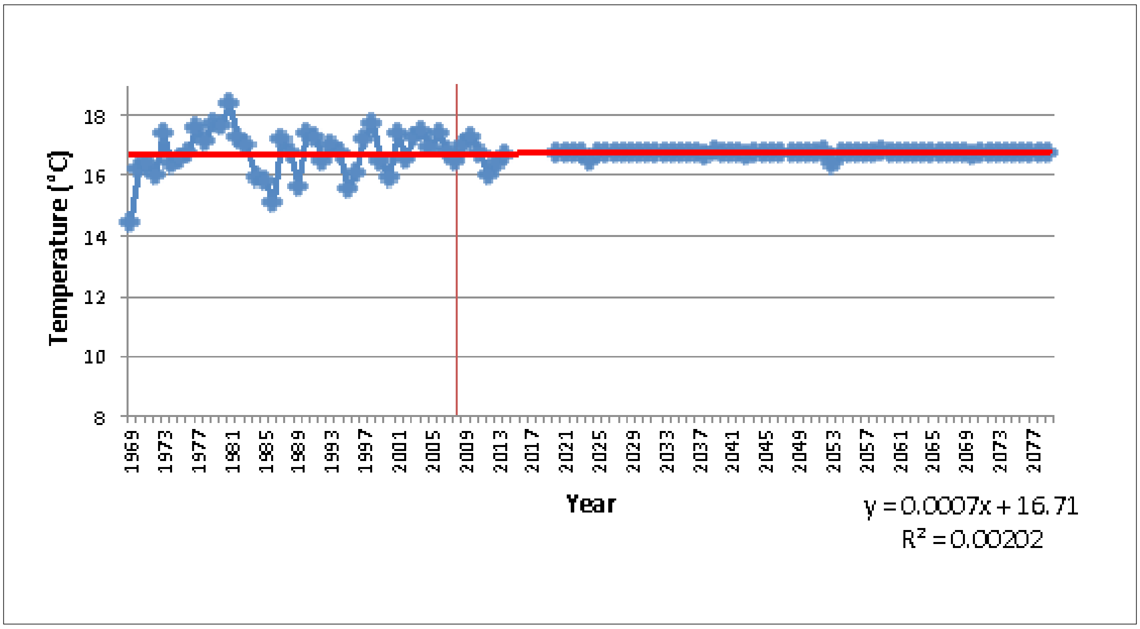

Figure 60. Average summer minimum temperature projections Lostock Dam

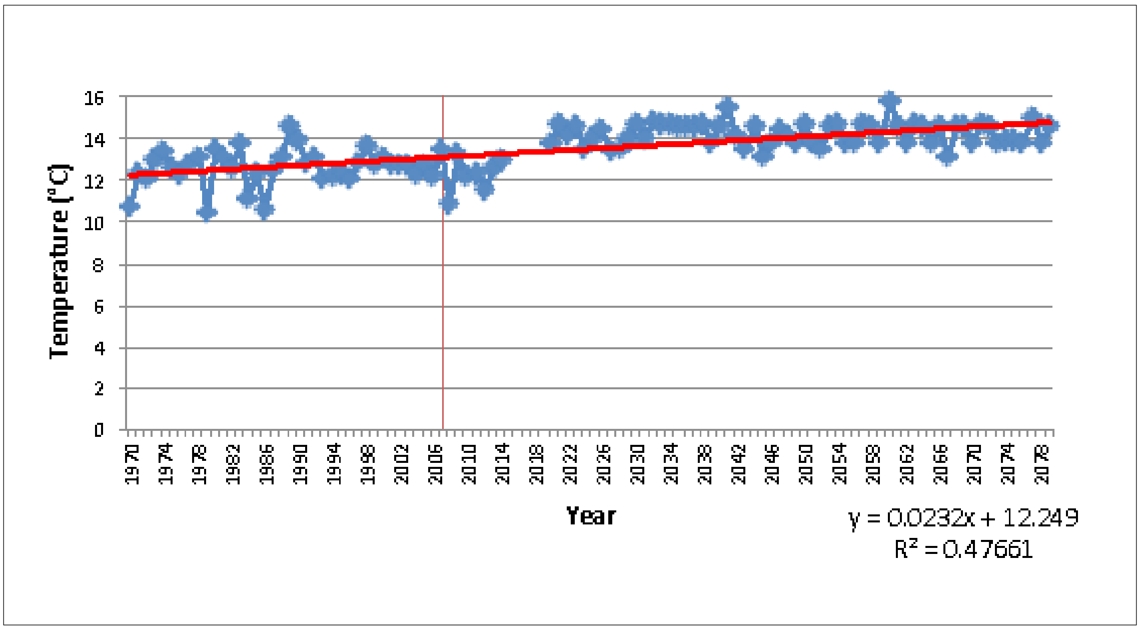

Figure 61. Average autumn minimum temperature projections Lostock Dam

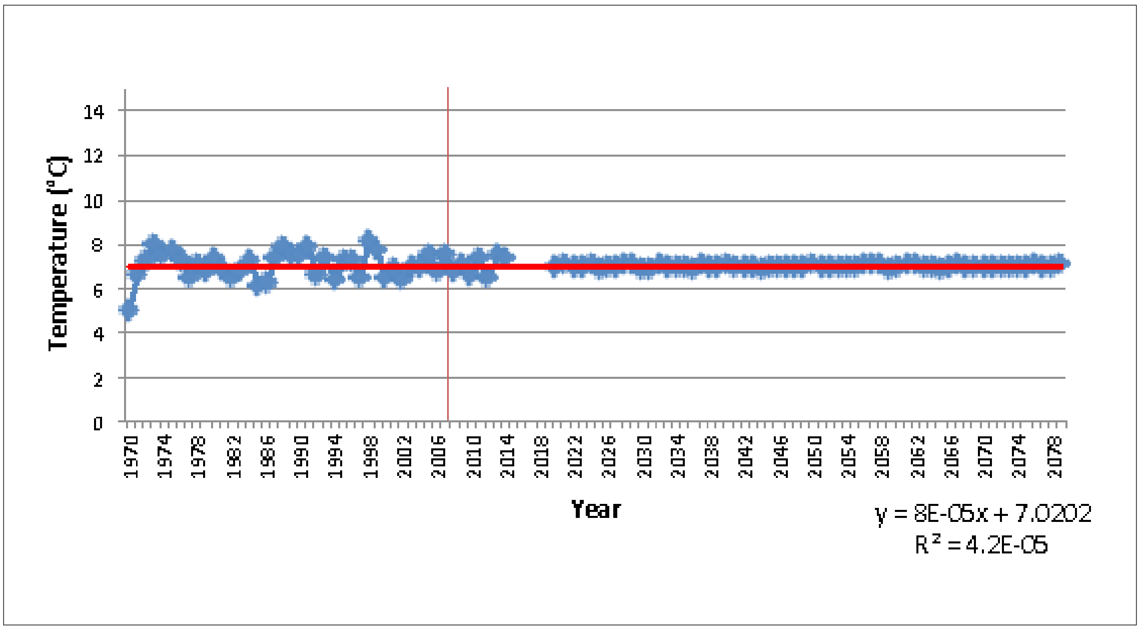

Figure 62. Average winter minimum temperature projections Lostock Dam

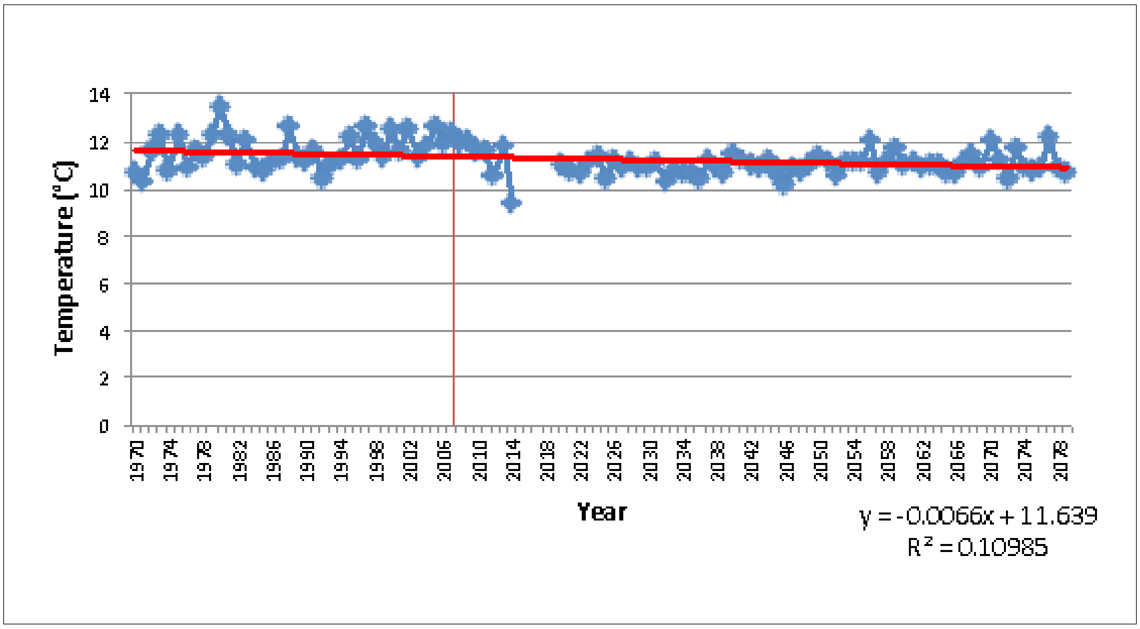

Figure 63. Average spring minimum temperature projections Lostock Dam

8.6. Seasonal minimum temperature: Western Zone

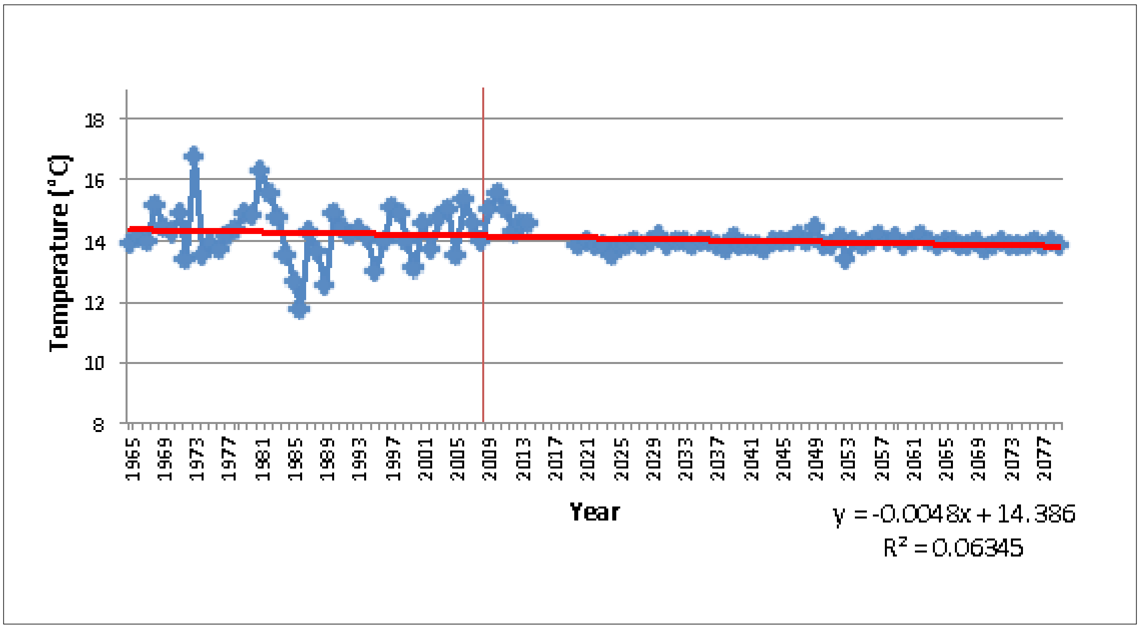

Figure 64. Average summer minimum temperature projections Murrurundi

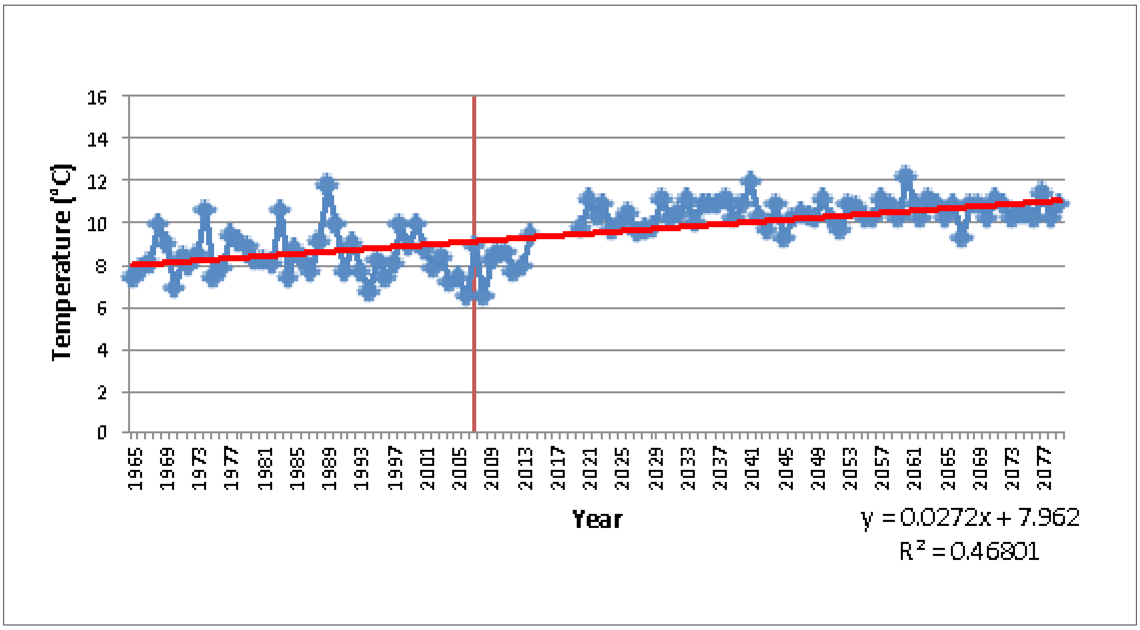

Figure 65. Average autumn minimum temperature projections Murrurundi

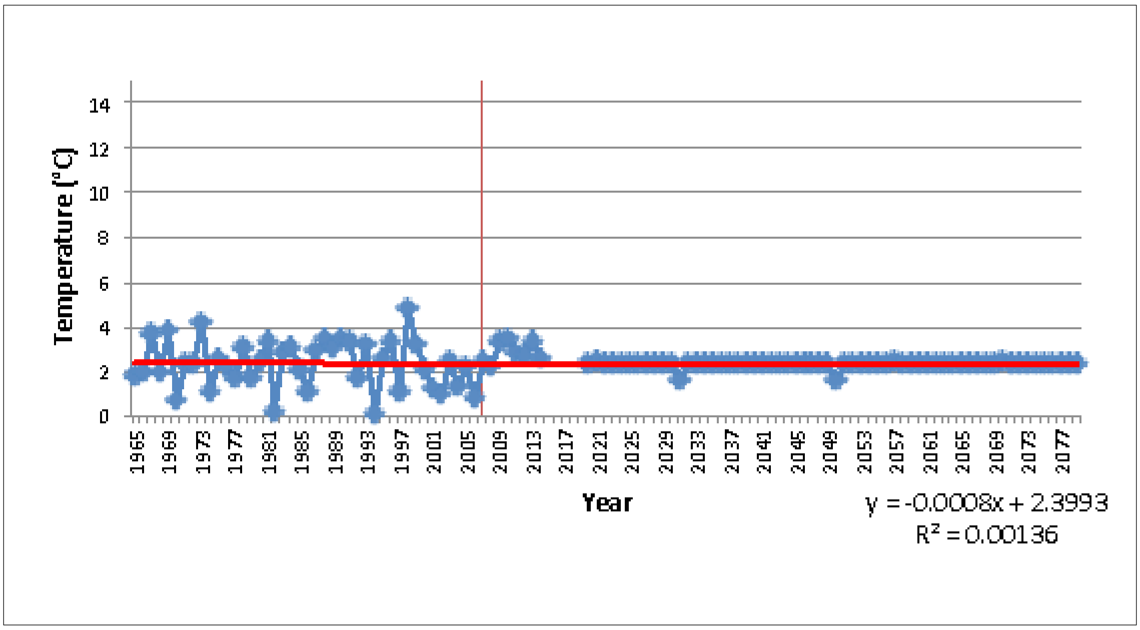

Figure 66. Average winter minimum temperature projections Murrurundi

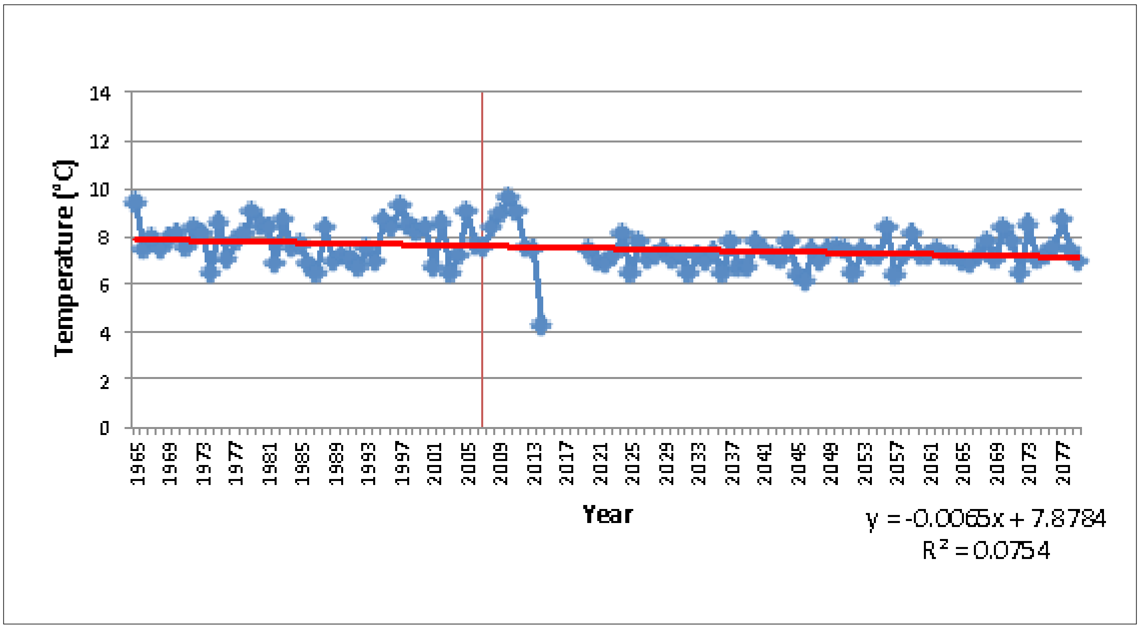

Figure 67. Average spring minimum temperature projections Murrurundi

8.7. Seasonal precipitation: Coastal Zone

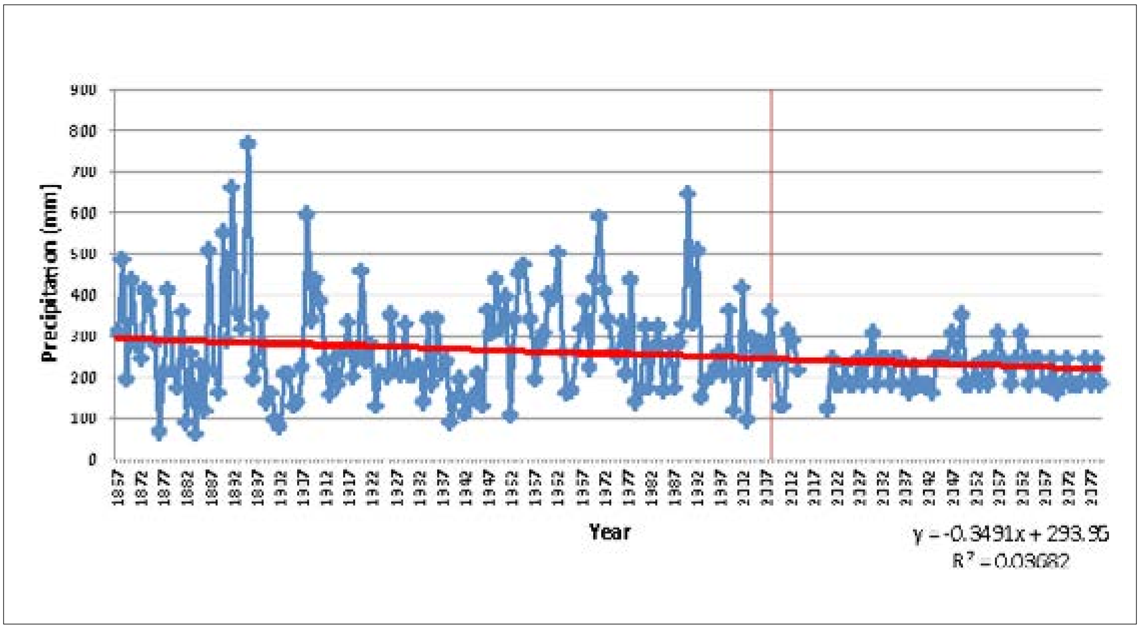

Figure 68. Average summer precipitation projections Newcastle

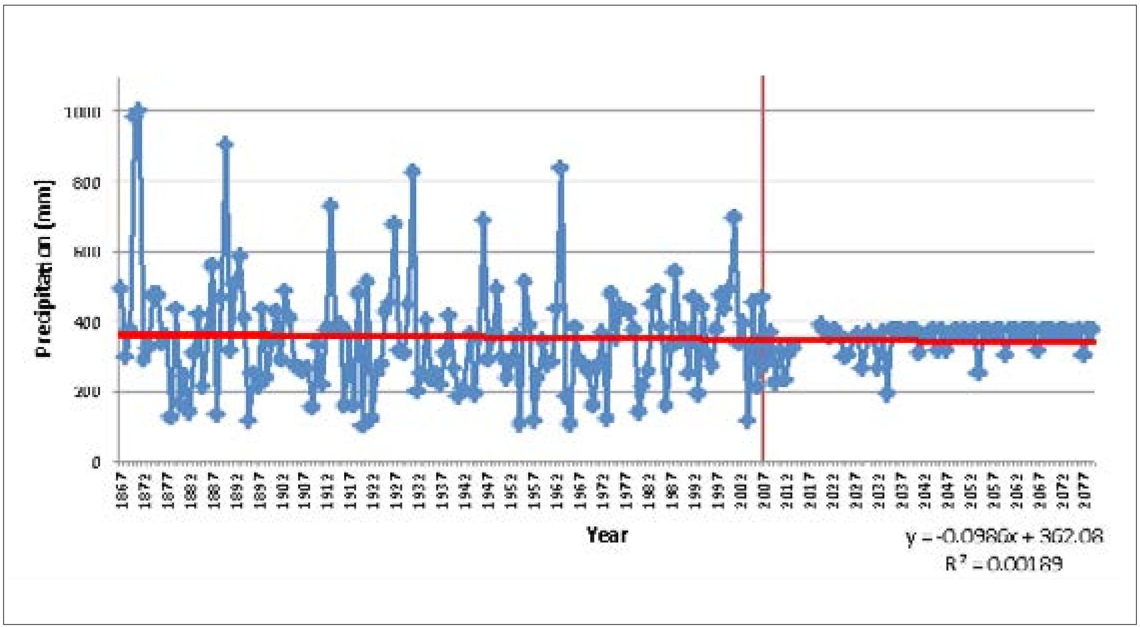

Figure 69. Average autumn precipitation projections Newcastle

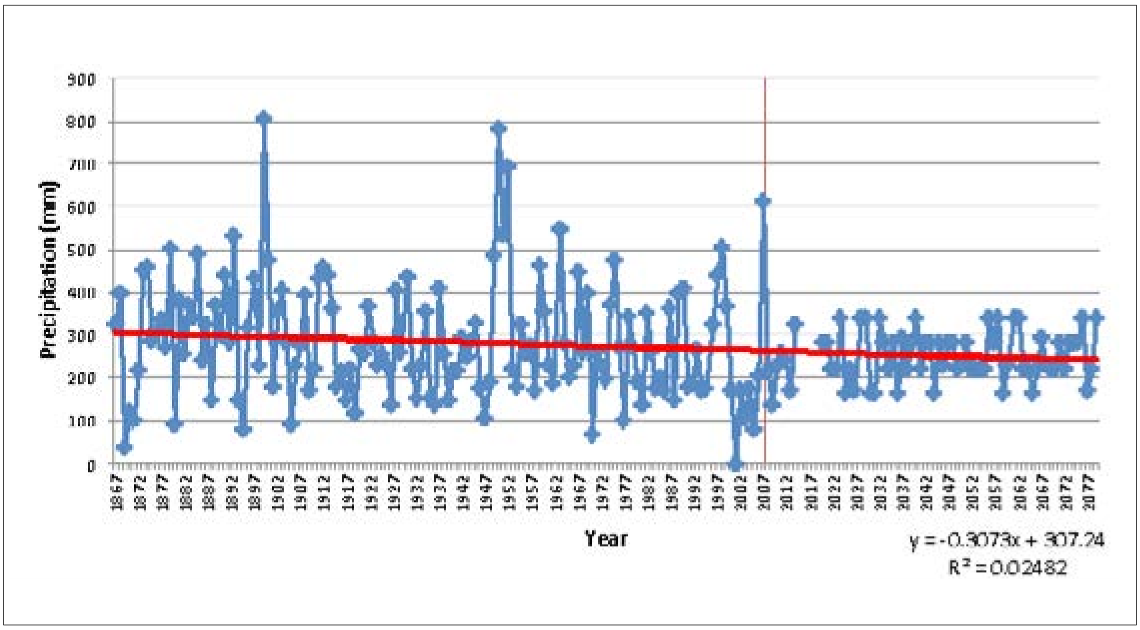

Figure 70. Average winter precipitation projections Newcastle

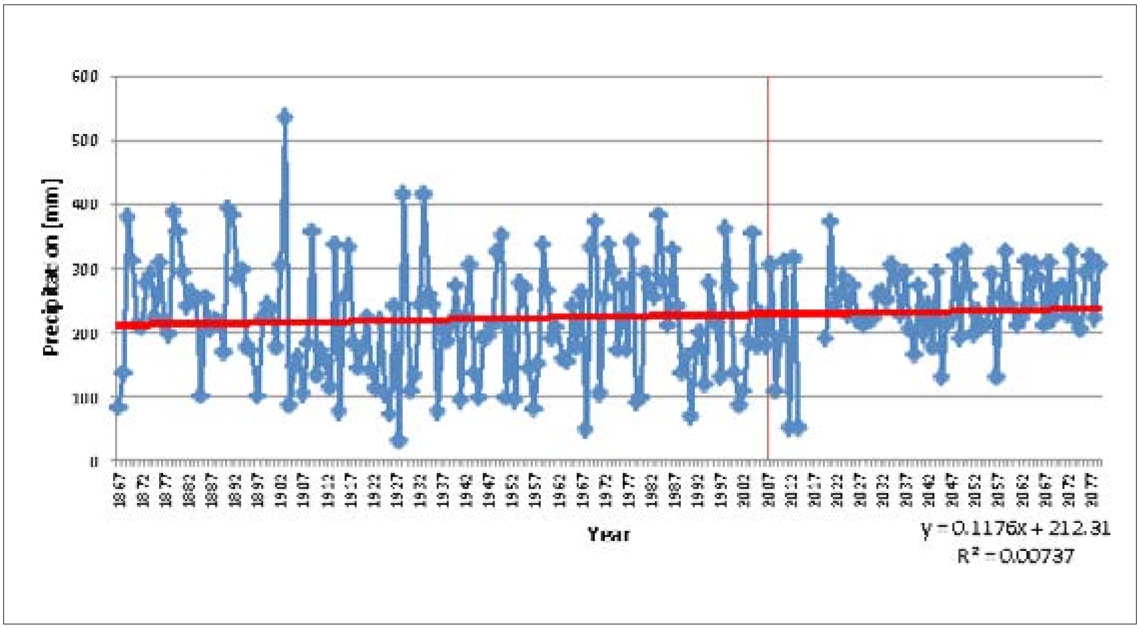

Figure 71. Average spring precipitation projections Newcastle

8.8. Seasonal precipitation: Central Zone

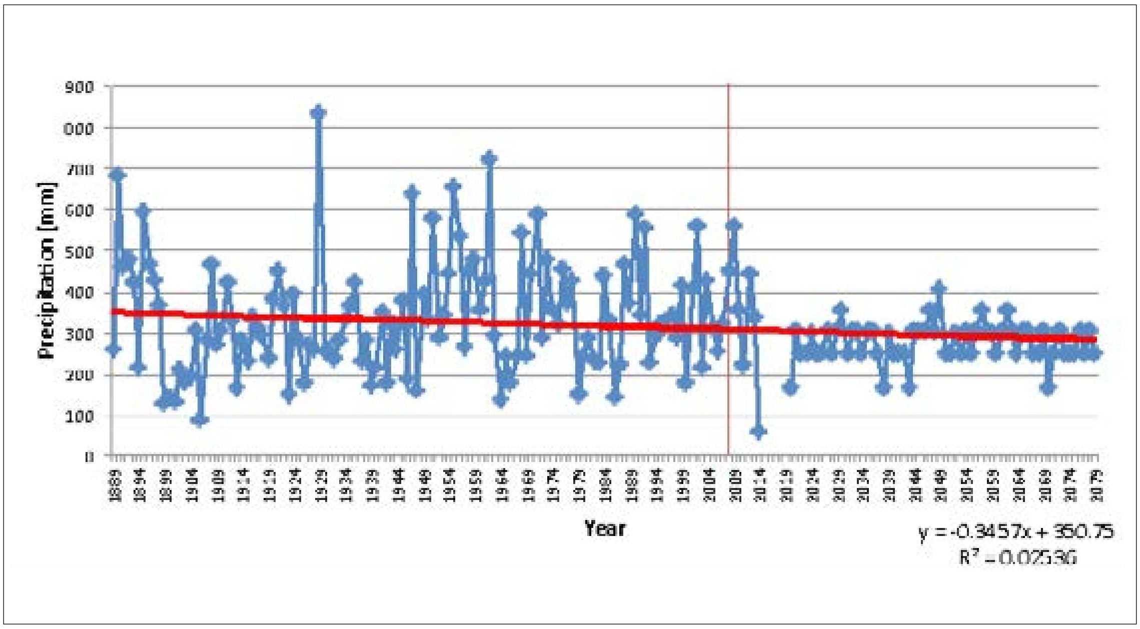

Figure 72. Average summer precipitation projections Gloucester

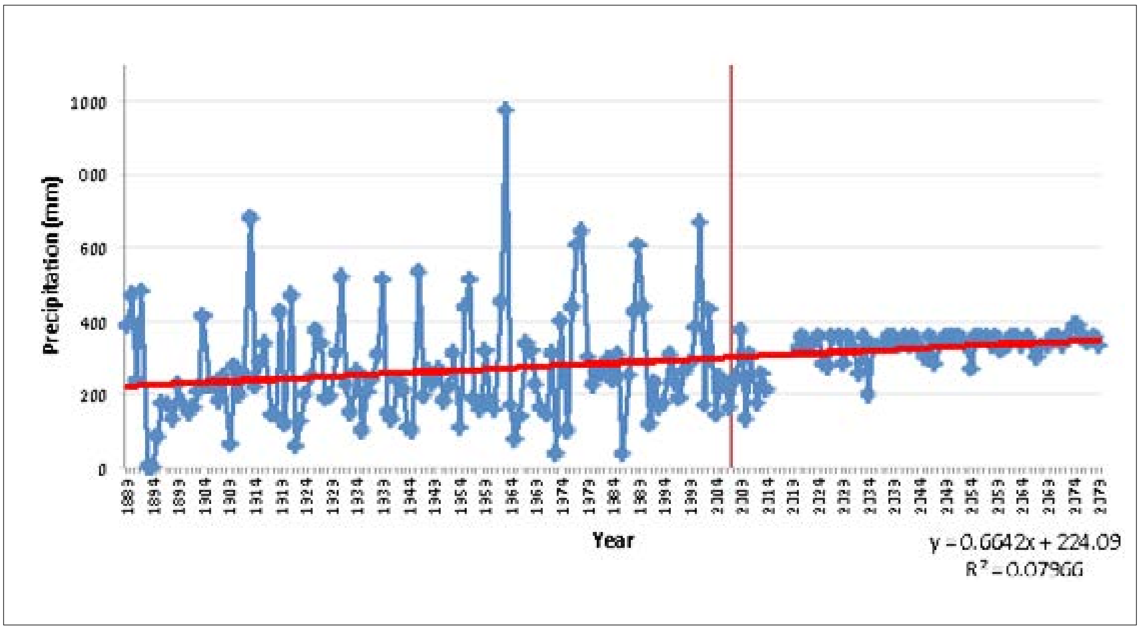

Figure 73. Average autumn precipitation projections Gloucester

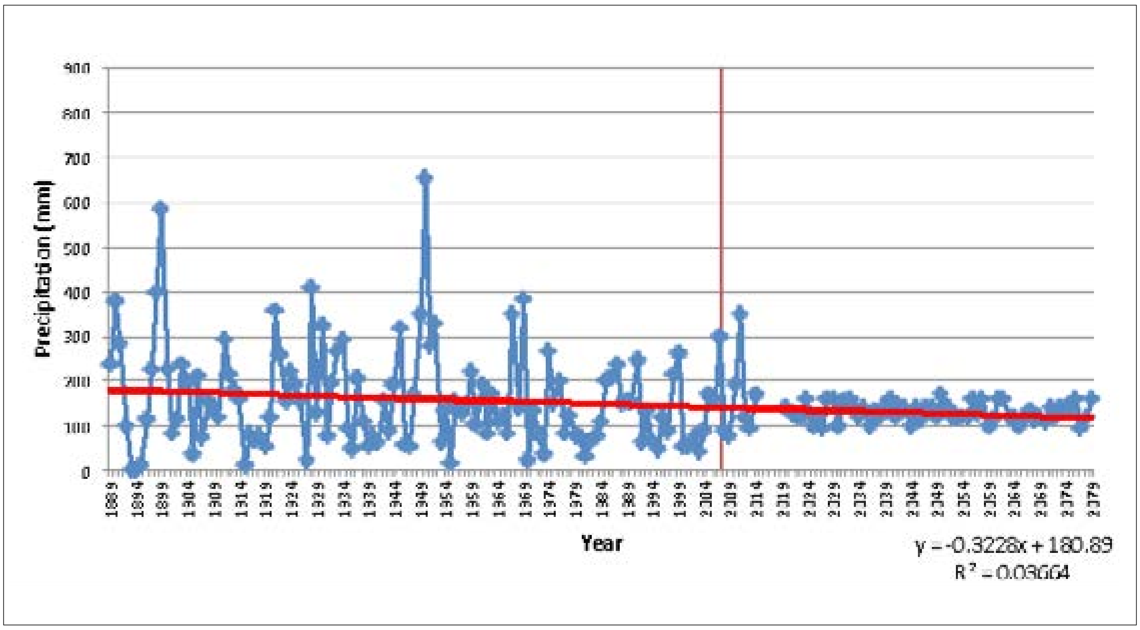

Figure 74. Average winter precipitation projections Gloucester

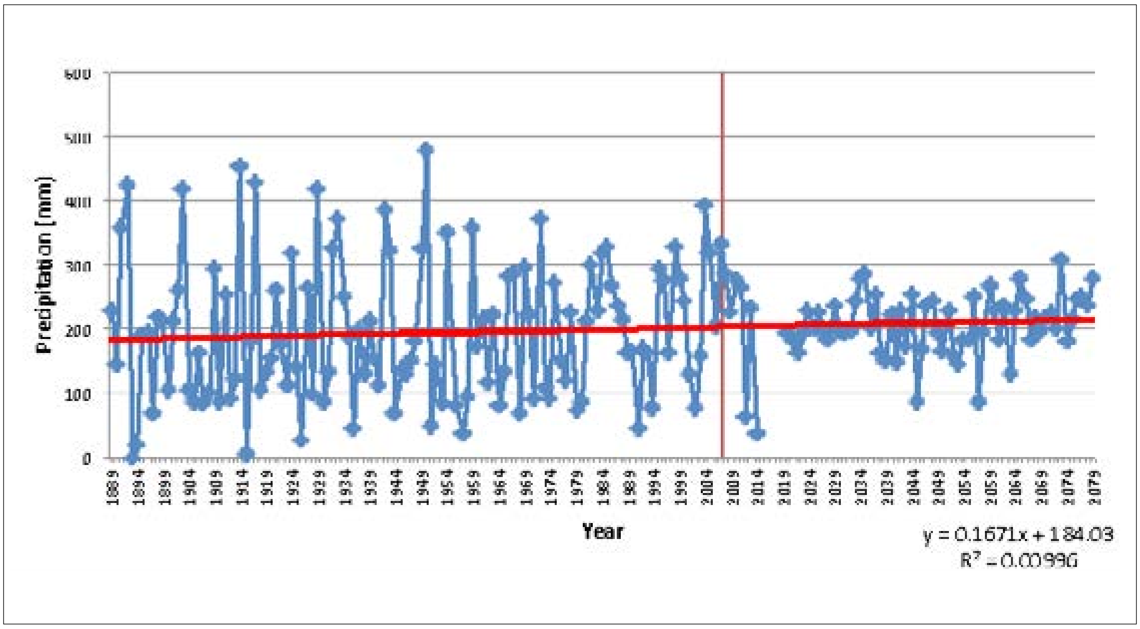

Figure 75. Average spring precipitation projections Gloucester

8.9. Seasonal precipitation: Western Zone

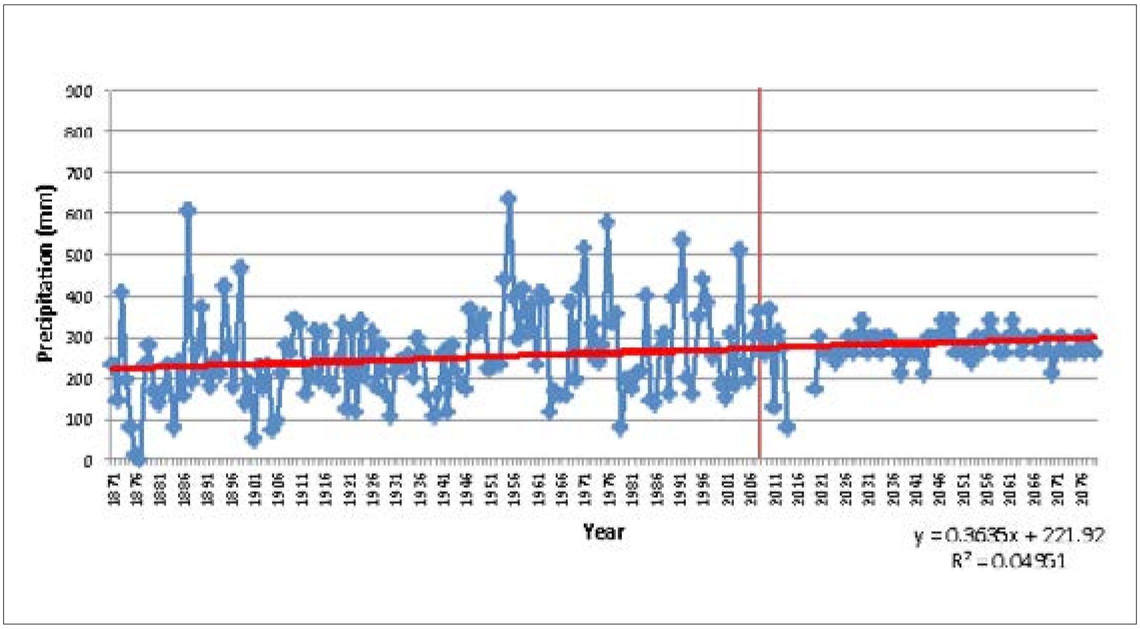

Figure 76. Average summer precipitation projections Murrurundi

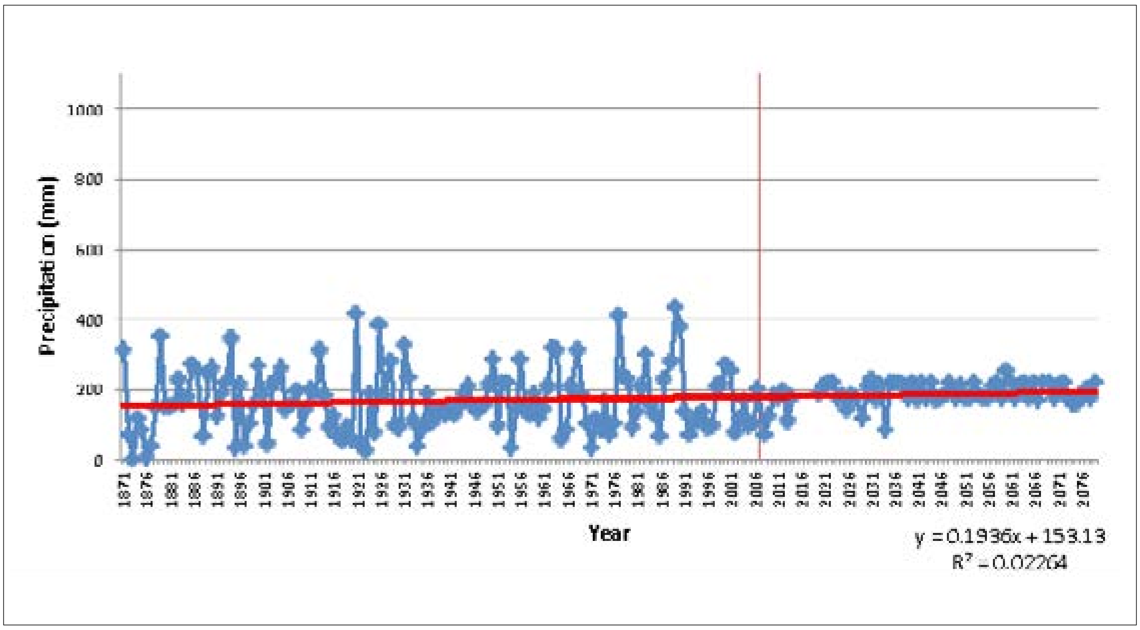

Figure 77. Average autumn precipitation projections Murrurundi

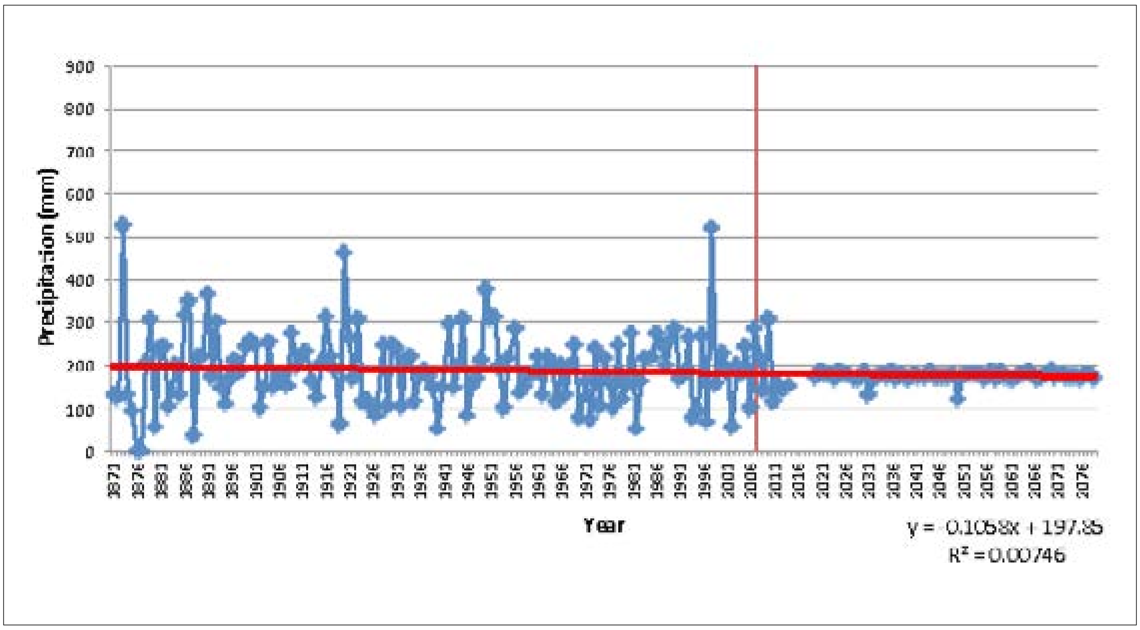

Figure 78. Average winter precipitation projections Murrurundi

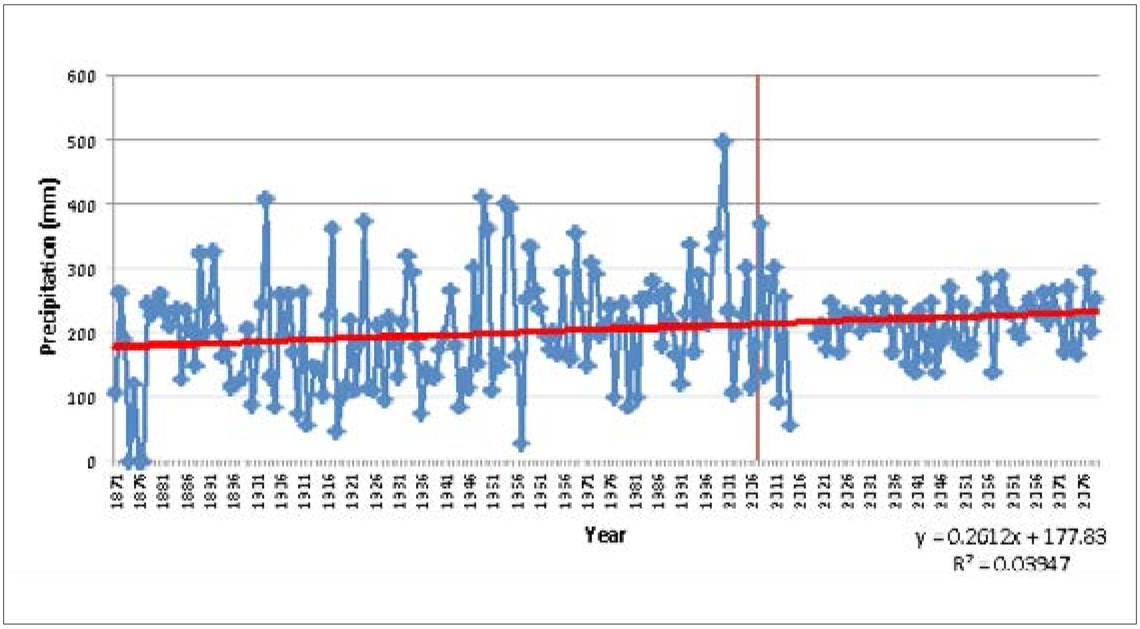

Figure 79. Average spring precipitation projections Murrurundi

8.10. Pan evaporation: Coastal Zone

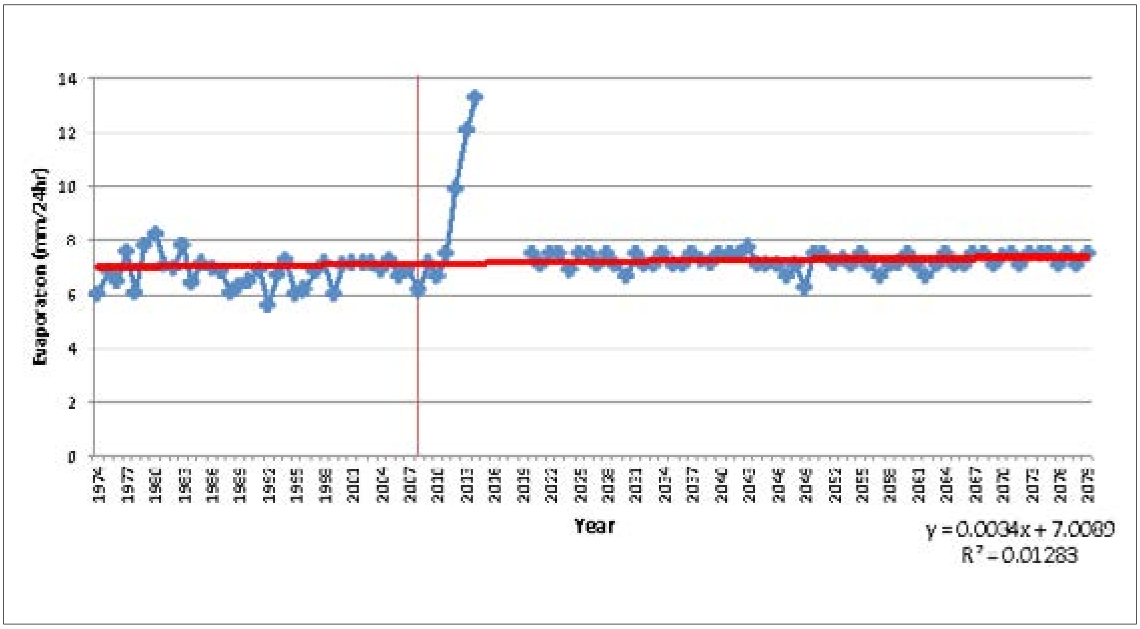

Figure 80. Average summer pan evaporation projections Williamtown

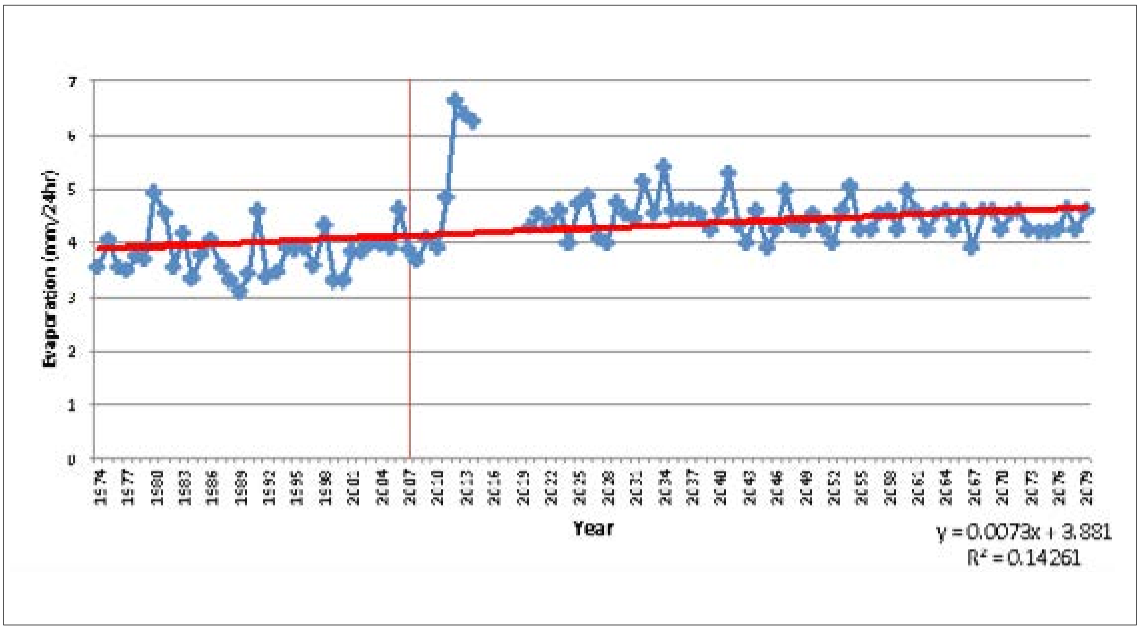

Figure 81. Average autumn pan evaporation projections Williamtown

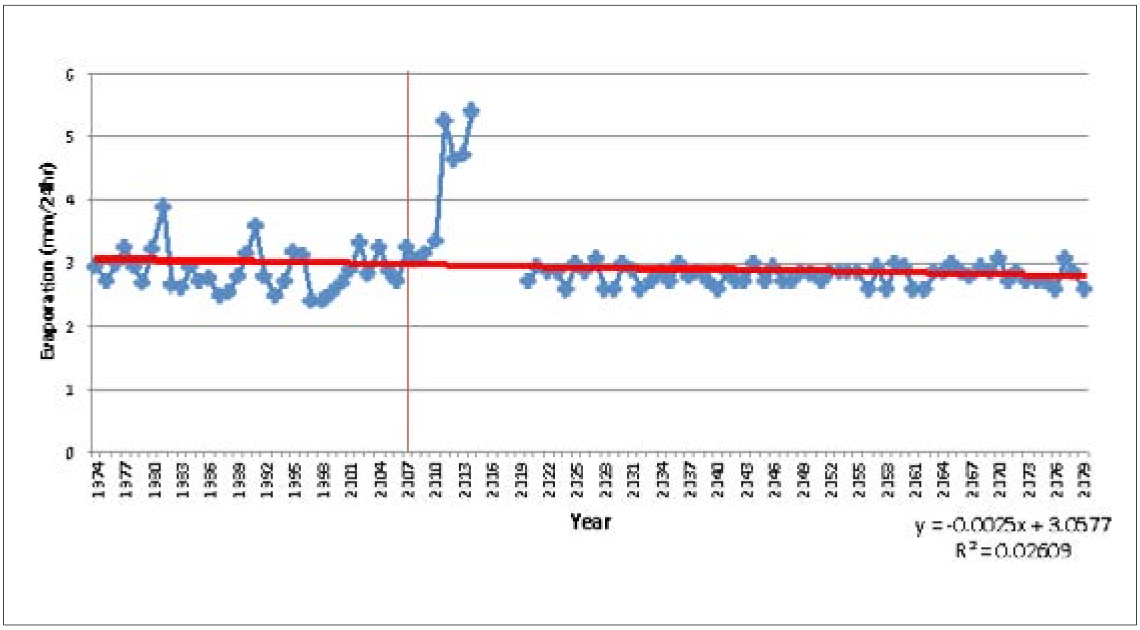

Figure 82. Average winter pan evaporation projections Williamtown

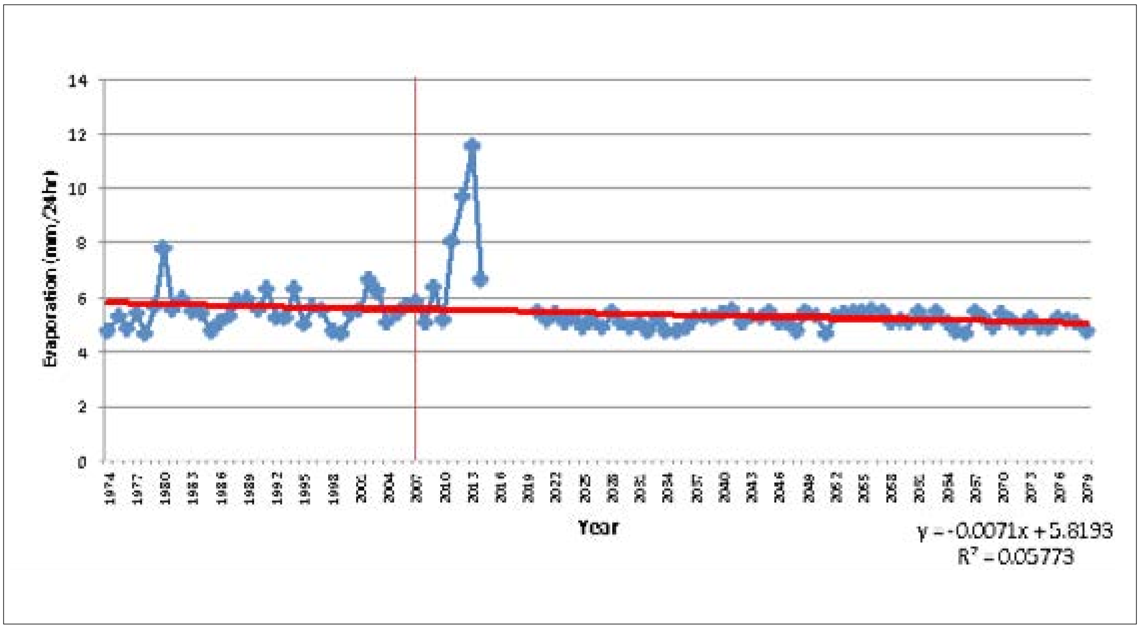

Figure 83. Average spring pan evaporation projections Williamtown

8.11. Pan evaporation: Central Zone

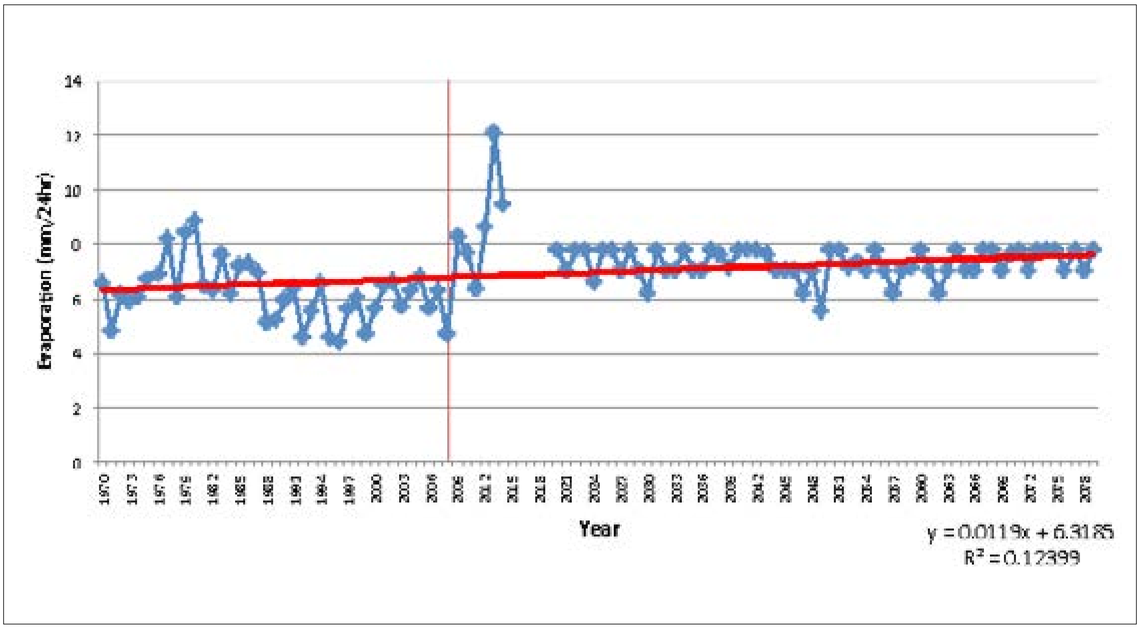

Figure 84. Average summer pan evaporation projections Lostock Dam

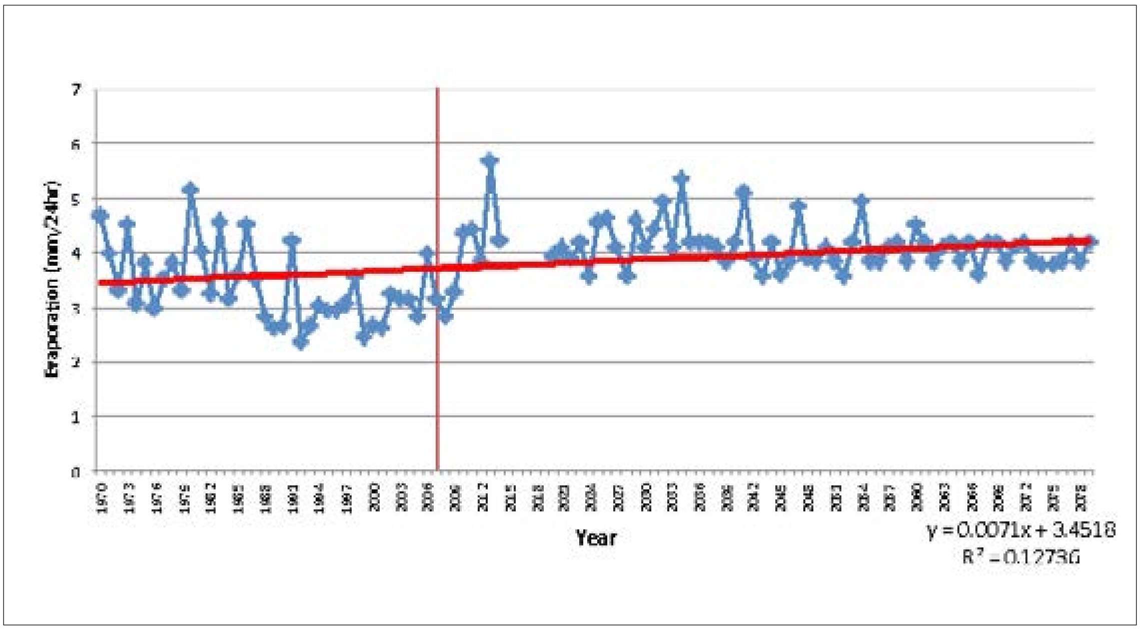

Figure 85. Average autumn pan evaporation projections Lostock Dam

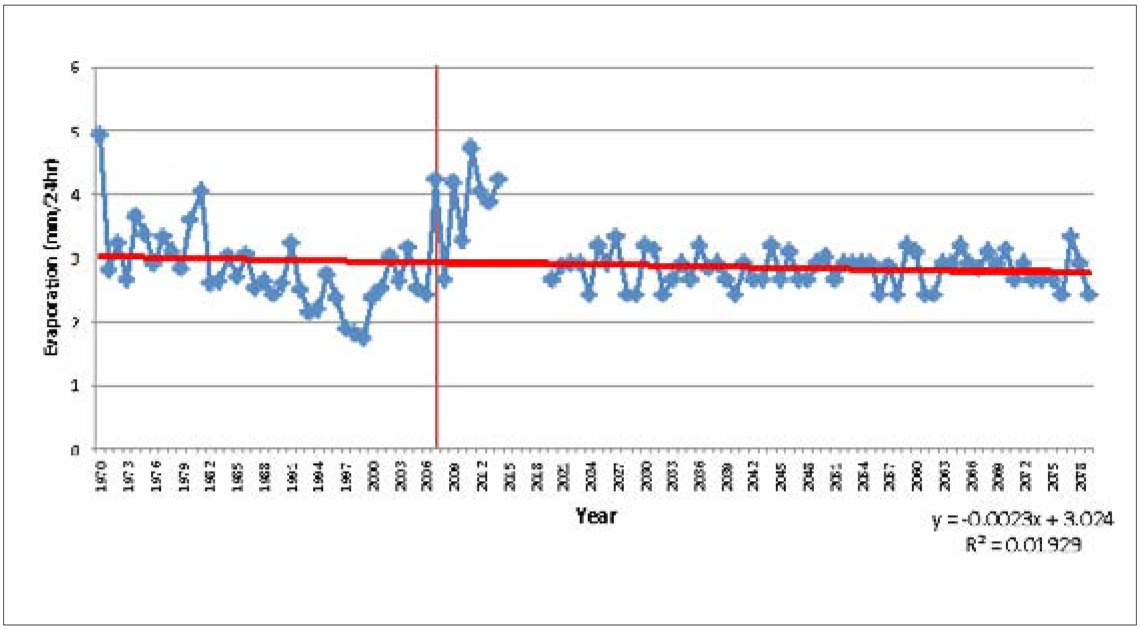

Figure 86. Average winter pan evaporation projections Lostock Dam

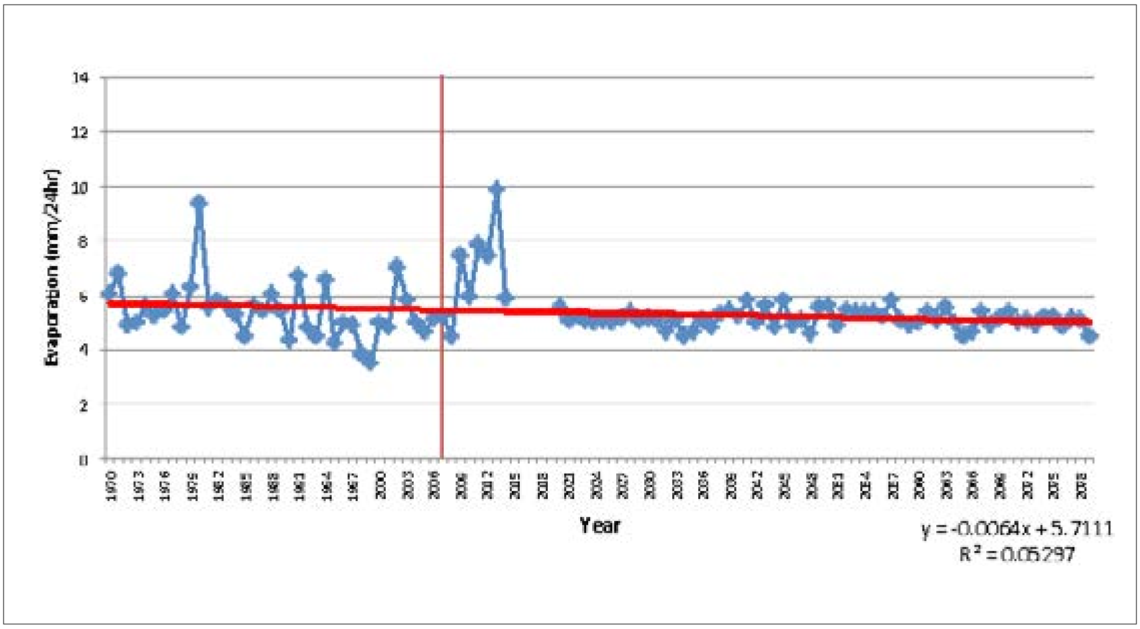

Figure 87. Average spring pan evaporation projections Lostock Dam

8.12. Pan evaporation: Western Zone

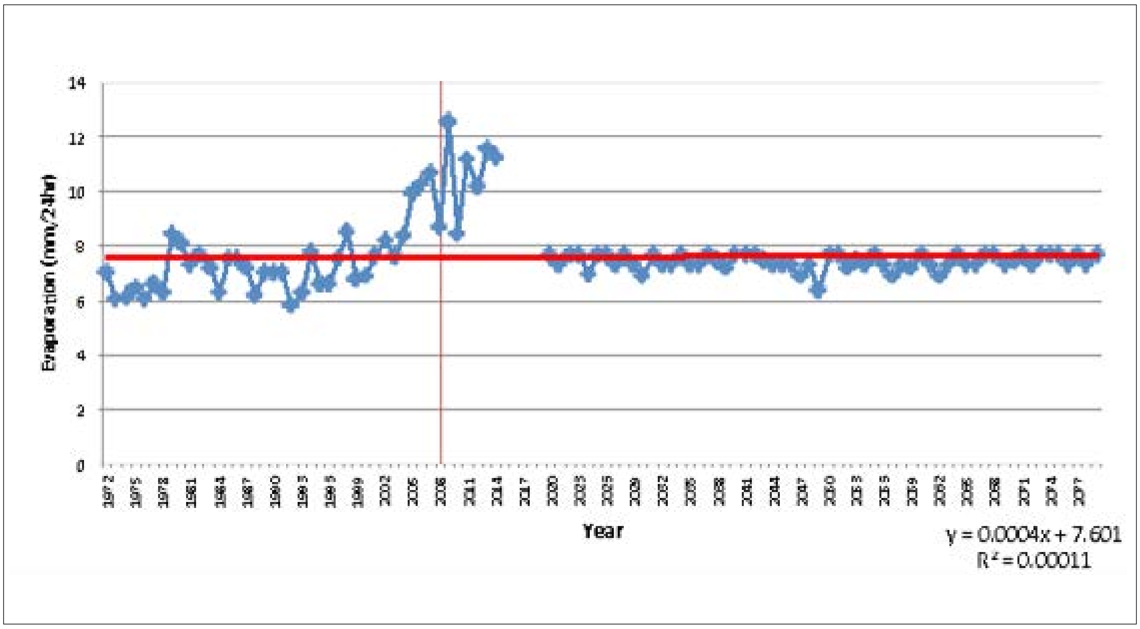

Figure 88. Average summer pan evaporation projections Scone

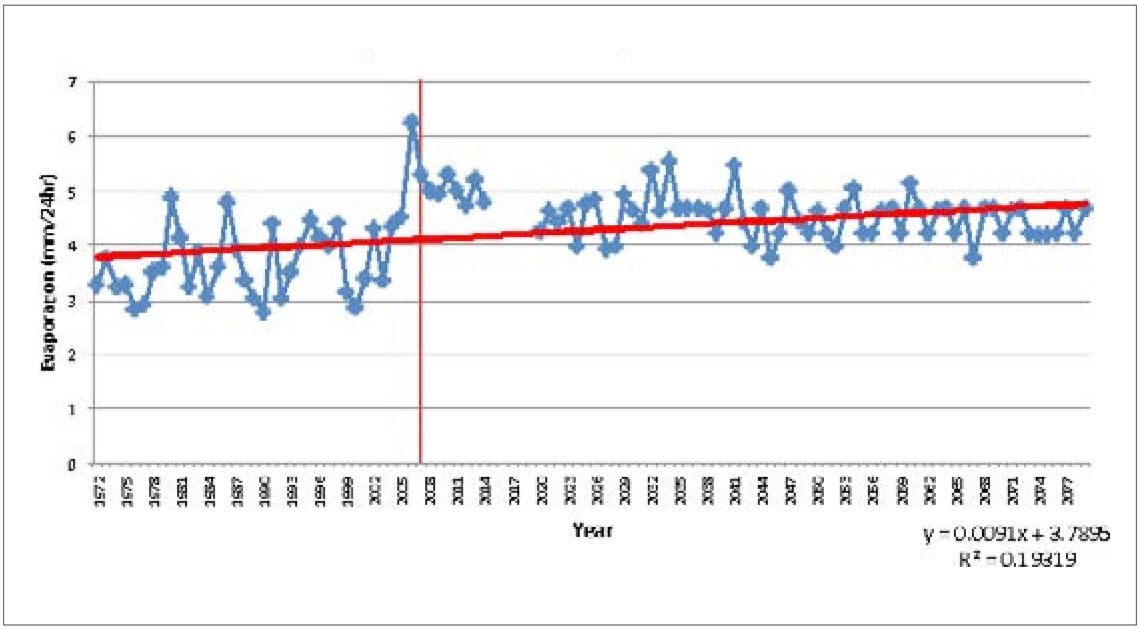

Figure 89. Average autumn pan evaporation projections Scone

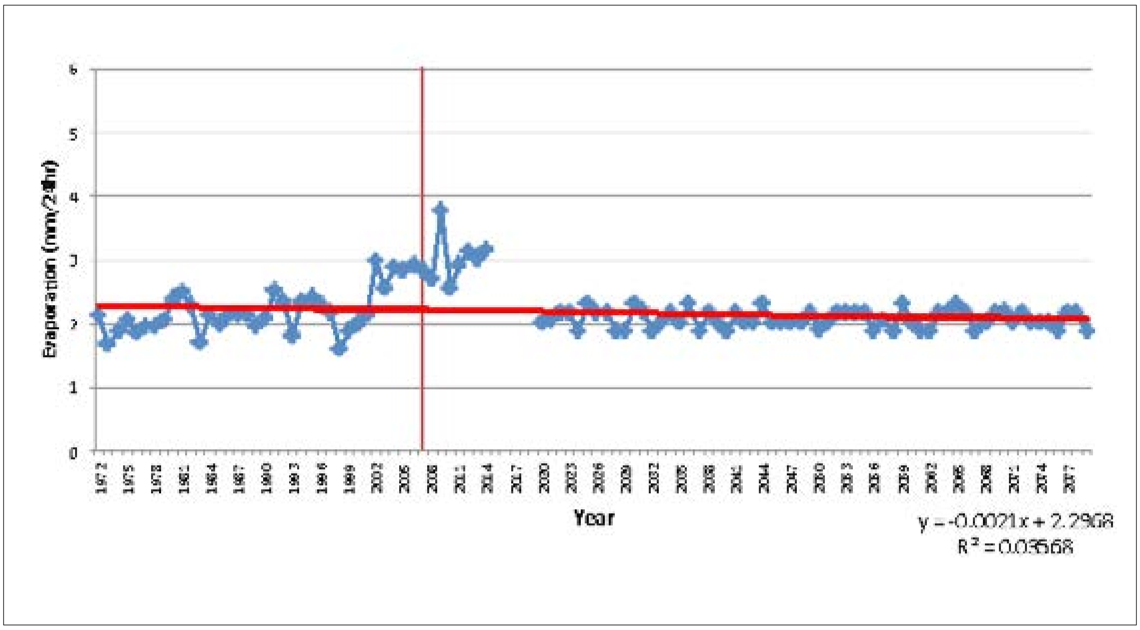

Figure 90. Average winter pan evaporation projections Scone

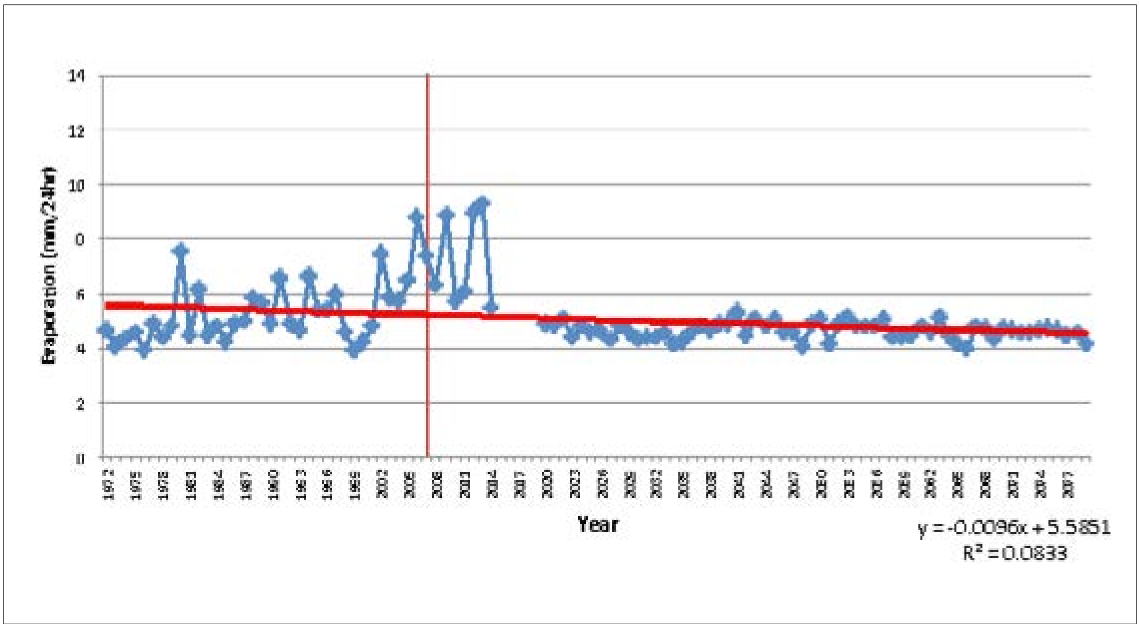

Figure 91. Average spring pan evaporation projections Scone

9. Climate grid layers

Twenty four gridded spatial datasets reflecting historic (1990) and current (2015) climate for the region, and thirty six layers depicting seasonal future climate conditions (2040, 2060 and 2080) have been created. The climate variables for which gridded datasets are provided include:

- Maximum temperature
- Minimum temperature
- Precipitation

These gridded spatial datasets integrate information provided by individual BOM stations to provide a spatial representation of the variation that is evident across the region for each climate variable. Providing spatial datasets for historic, current and projected climate conditions in this way visually illustrates existing and projected climate variation over time.

While the historic and current climate layers don't explicitly cover the two valid phases of the Interdecal Pacific Oscillation (IPO) – IPO –ve phase (La Nina-like) from 1948 to 1976; and, IPO +ve phase (El Nino-like) from 1977 to 2007, the regression function used to derive the values does. A summary of these 60 datasets is provided in Table 8.

An example grid layer for average 2040 autumn precipitation is provided in Figure 92. Seasonal grid layers for historic, current and projected climate are also provided in Appendix 1 (Maximum temperature), Appendix 2 (Minimum temperature) and Appendix 3 (Precipitation).

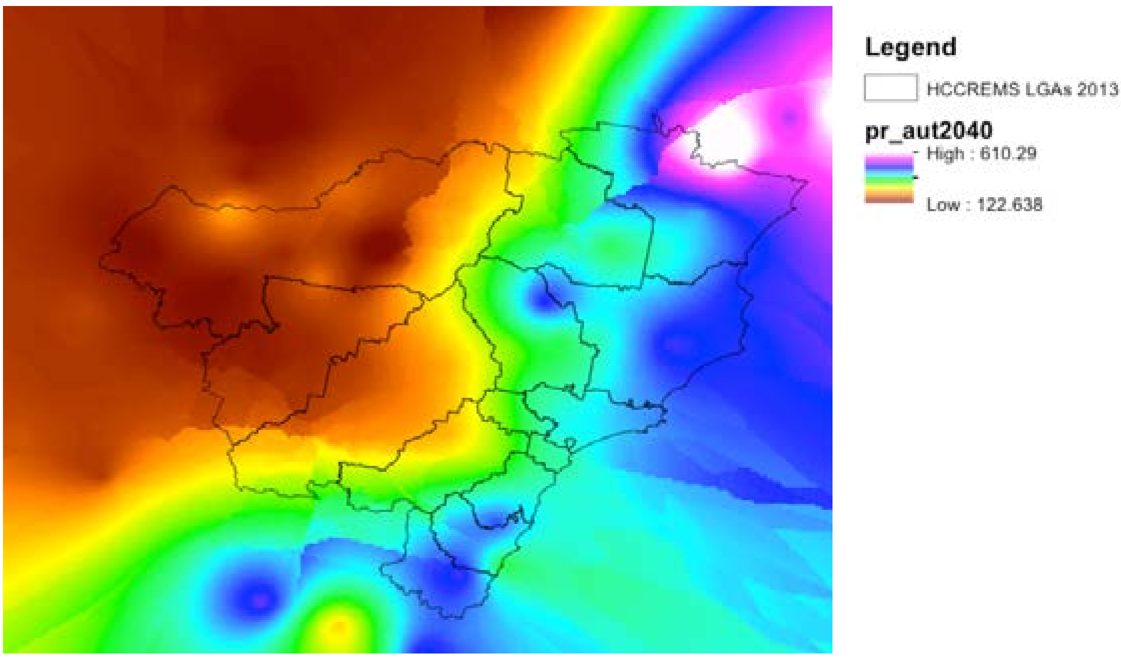

Figure 92. Precipitation grid layer for autumn 2040 climate projections

Table 8. Summary of grid data created

Layer Name	Description	Minimum Value	Maximum Value
mn_aut2040	Average minimum projected autumn temperatures for 2040	7.47	16.88
mn_aut2060	Average minimum projected autumn temperatures for 2060	8.09	17.25
mn_aut2080	Average minimum projected autumn temperatures for 2080	8.72	17.67
mn_spr2040	Average minimum projected spring temperatures for 2040	4.54	13.97
mn_spr2060	Average minimum projected spring temperatures for 2060	4.41	13.98
mn_spr2080	Average minimum projected spring temperatures for 2080	4.29	13.99
mn_sum2040	Average minimum projected summer temperatures for 2040	11.94	18.81
mn_sum2060	Average minimum projected summer temperatures for 2060	11.82	18.87
mn_sum2080	Average minimum projected summer temperatures for 2080	11.71	18.92
mn_win2040	Average minimum projected winter temperatures for 2040	-0.81	9.68
mn_win2060	Average minimum projected winter temperatures for 2060	-0.88	9.84
mn_win2080	Average minimum projected winter temperatures for 2080	-0.88	9.84
mt_aut2040	Average maximum projected autumn temperatures for 2040	22.72	26.58
mt_aut2060	Average maximum projected autumn temperatures for 2060	23.13	27.28
mt_aut2080	Average maximum projected autumn temperatures for 2080	23.67	27.85
mt_spr2040	Average maximum projected spring temperatures for 2040	22.87	26.69
mt_spr2060	Average maximum projected spring temperatures for 2060	23.67	27.49
mt_spr2080	Average maximum projected spring temperatures for 2080	24.47	28.29
mt_sum2040	Average maximum projected summer temperatures for 2040	27.28	30.37
mt_sum2060	Average maximum projected summer temperatures for 2060	26.77	31.03
mt_sum2080	Average maximum projected summer temperatures for 2080	27.05	30.96
mt_win2040	Average maximum projected winter temperatures for 2040	13.49	19.56
mt_win2060	Average maximum projected winter temperatures for 2060	13.50	19.57
mt_win2080	Average maximum projected winter temperatures for 2080	13.51	19.59
pr_aut2040	Average total projected autumn precipitation for 2040	122.64	610.29
pr_aut2060	Average total projected autumn precipitation for 2060	121.71	628.11
pr_aut2080	Average total projected autumn precipitation for 2080	120.79	645.93
pr_spr2040	Average total projected spring precipitation for 2040	140.40	360.36
pr_spr2060	Average total projected spring precipitation for 2060	141.37	366.25
pr_spr2080	Average total projected spring precipitation for 2080	143.84	367.25
pr_sum2040	Average total projected summer precipitation for 2040	174.65	488.34
pr_sum2060	Average total projected summer precipitation for 2060	193.12	392.10
pr_sum2080	Average total projected summer precipitation for 2080	194.81	374.47
pr_win2040	Average total projected winter precipitation for 2040	98.87	318.57
pr_win2060	Average total projected winter precipitation for 2060	97.47	298.39
pr_win2080	Average total projected winter precipitation for 2080	95.66	278.81
mn_aut1990	Average minimum projected autumn temperatures for 1990	5.92	16.00
mn_aut2015	Average minimum projected autumn temperatures for 2015	6.69	16.44
mn_spr1990	Average minimum projected spring temperatures for 1990	4.86	13.97
mn_spr2015	Average minimum projected spring temperatures for 2015	4.70	13.96
mn_sum1990	Average minimum projected summer temperatures for 1990	11.78	19.06
mn_sum2015	Average minimum projected summer temperatures for 2015	11.61	19.16
mn_win1990	Average minimum projected spring temperatures for 1990	-0.72	9.48
mn_win2015	Average minimum projected spring temperatures for 2015	-0.76	9.58
mt_aut1990	Average maximum projected autumn temperatures for 1990	21.62	24.93
mt_aut2015	Average maximum projected autumn temperatures for 2015	22.44	25.51
mt_spr1990	Average maximum projected spring temperatures for 1990	21.16	25.38
mt_spr2015	Average maximum projected spring temperatures for 2015	23.46	24.94
mt_sum1990	Average maximum projected summer temperatures for 1990	28.10	29.38
mt_sum2015	Average maximum projected summer temperatures for 2015	27.29	30.05
mt_win1990	Average maximum projected spring temperatures for 1990	13.91	19.39
mt_win2015	Average maximum projected spring temperatures for 2015	13.48	19.54
pr_aut1990	Average total projected autumn precipitation for 1990	188.03	565.74
pr_aut2015	Average total projected autumn precipitation for 2015	123.79	588.01
pr_spr1990	Average total projected spring precipitation for 1990	137.97	346.51
pr_spr2015	Average total projected spring precipitation for 2015	139.18	353.56
pr_sum1990	Average total projected summer precipitation for 1990	177.00	549.25
pr_sum2015	Average total projected summer precipitation for 2015	177.11	518.79
pr_win1990	Average total projected spring precipitation for 1990	105.63	352.51
pr_win2015	Average total projected spring precipitation for 2015	99.88	340.96

* All data obtained from regression analysis of available BOM station data and climate projections from 2020-2080

10. Conclusion

The review process has determined that the seasonal minimum temperature and precipitation projections from the Hunter & Central Coast Regional Environmental Management Strategy (HCCREMS) regional scale climate projections (Blackmore & Goodwin, 2008 & 2009) remain valid across all climate zones, with the projections following a similar trend to those evident in the historic record and aligning to broader scale model projections from the Office of Environment and Heritage (OEH) based on recent ensemble Global Climate Model output.

However maximum temperature projections for the western zone, and spring maximum temperature projections in all zones were found to be a poor fit with the historic trend, and do not reflect broader scale model projections. As a result, OEH (NARCliM) climate data for maximum temperature projections in these zones for these seasons were applied and underpin the projections presented in this report.

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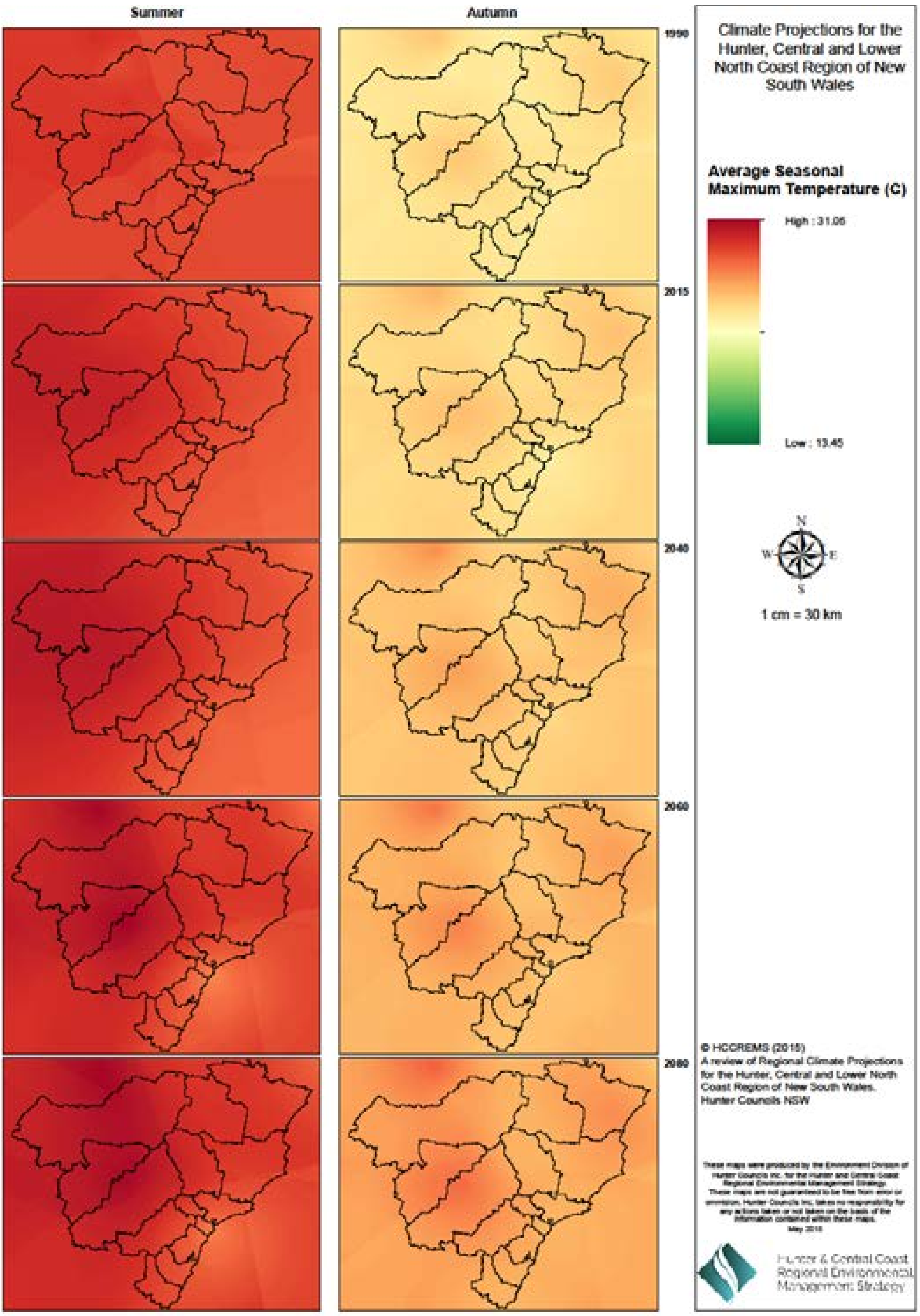
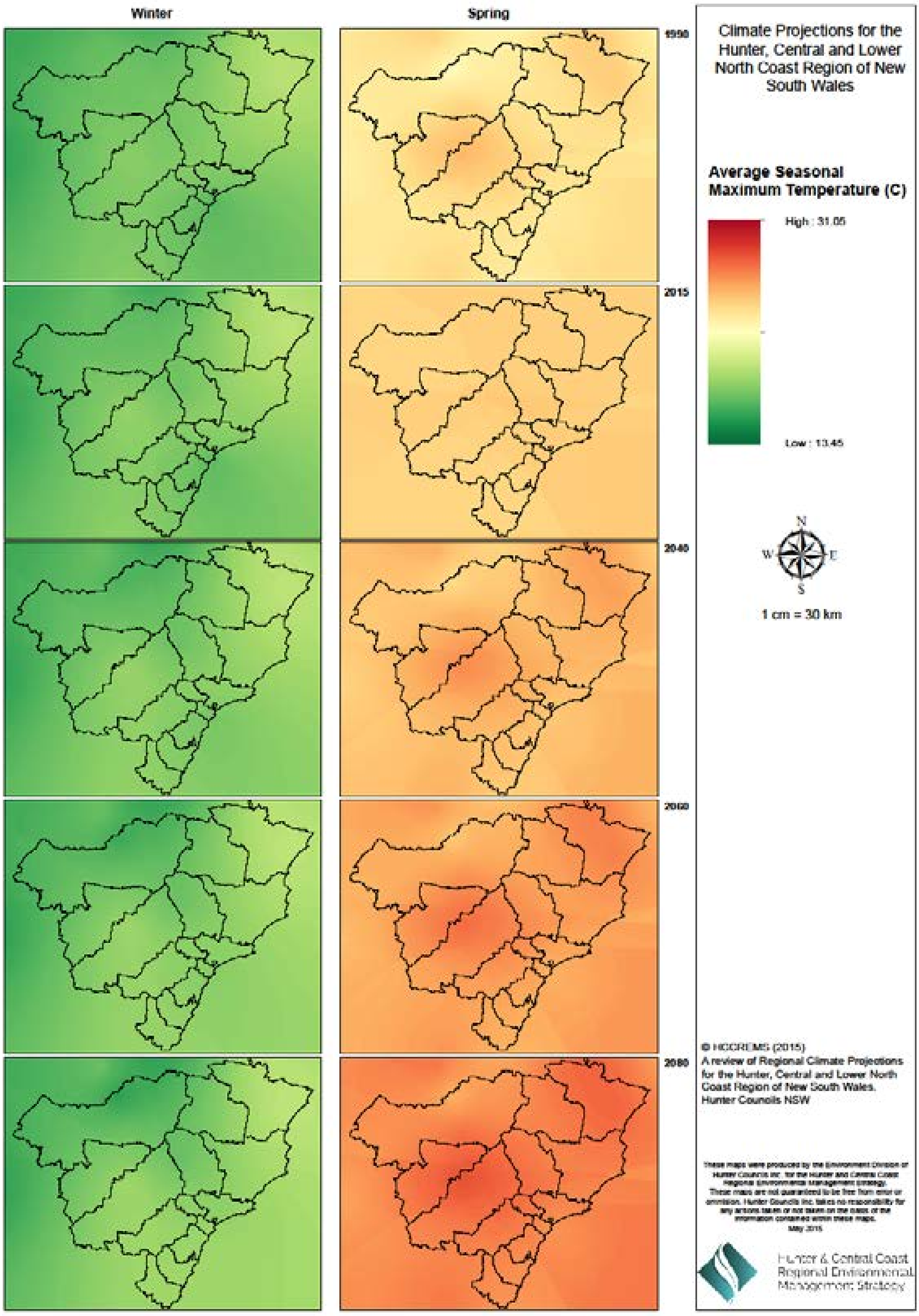
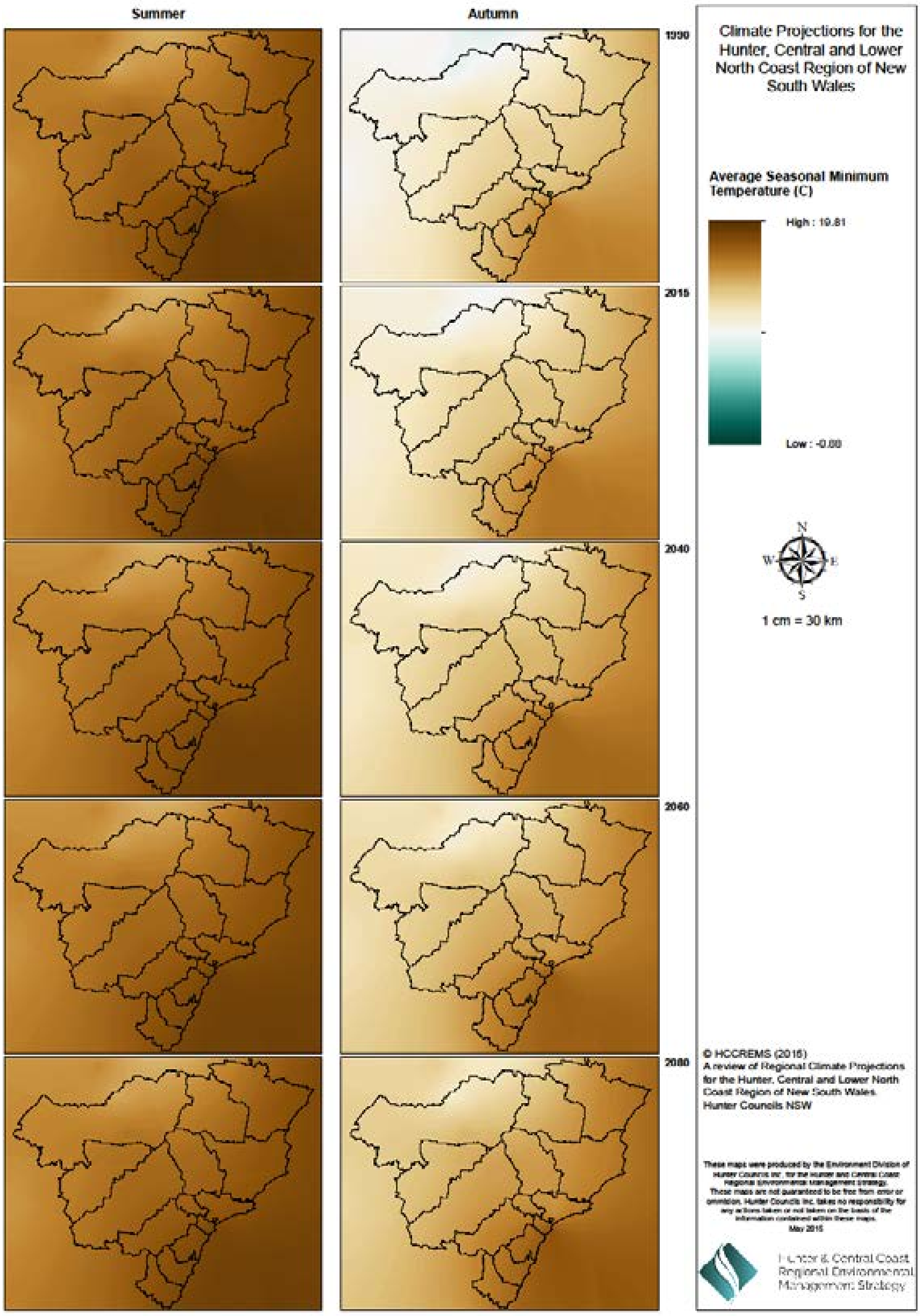
Appendixes

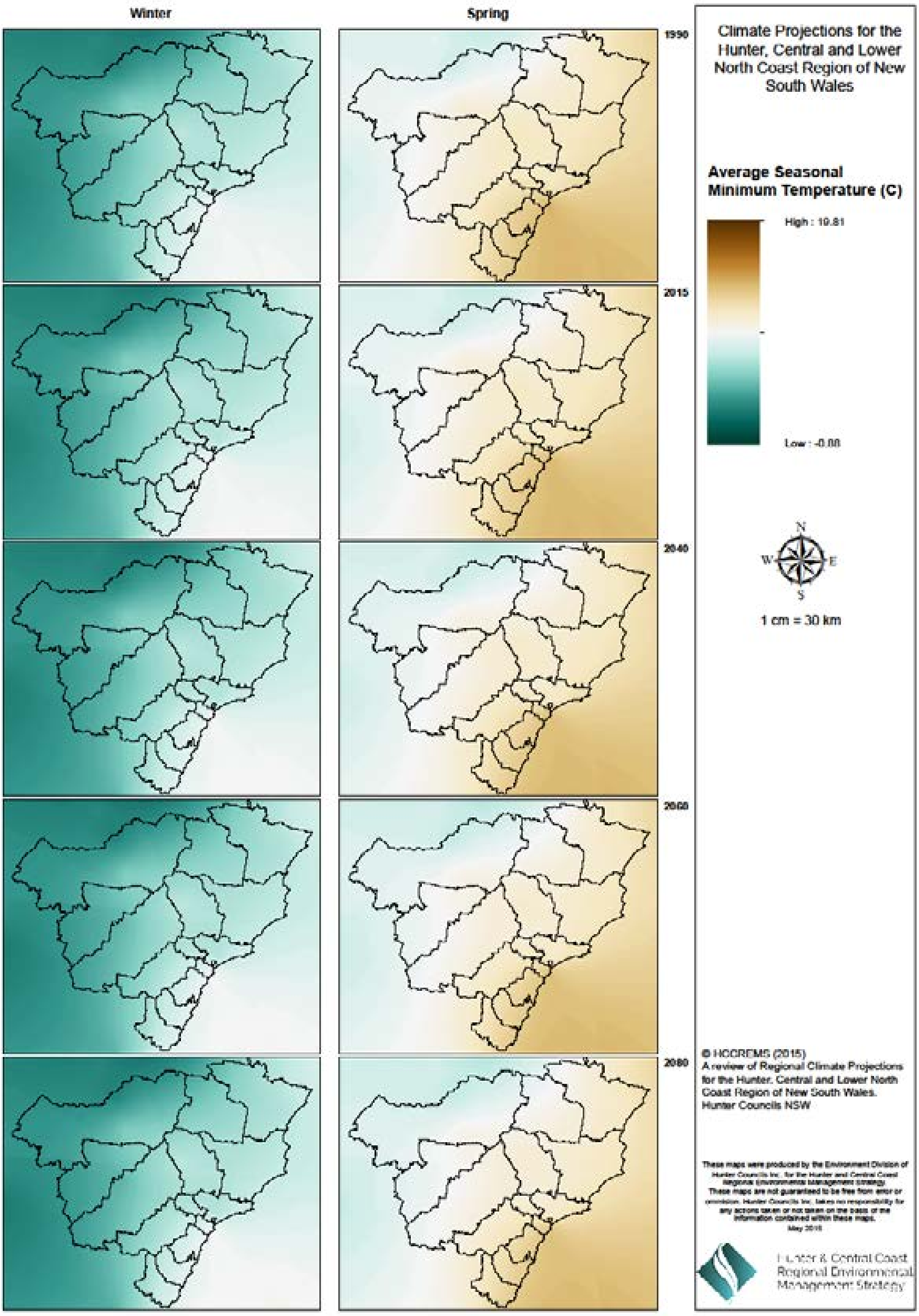
Appendix 1. Spatial grid layers – Average maximum temperature (seasonal)




Winter
Spring
1990
2015
2040
2060
2080
Climate Projections for the Hunter, Central and Lower North Coast Region of New South Wales
Average Seasonal Maximum Temperature (C)
High : 31.05
Low : 13.45
N
W
E
S
1 cm = 30 km
© HCCREMS (2015)
A review of Regional Climate Projections for the Hunter, Central and Lower North Coast Region of New South Wales.
Hunter Councils NSW
Hunter & Central Coast Regional Environmental Management Strategy

Appendix 2. Spatial grid layers – Average minimum temperature (seasonal)




Winter
Spring
1990
2015
2040
2060
2080
Climate Projections for the Hunter, Central and Lower North Coast Region of New South Wales
Average Seasonal Minimum Temperature (C)
High : 19.81
Low : -0.88
N
W
E
S
1 cm = 30 km
© HCCREMS (2015)
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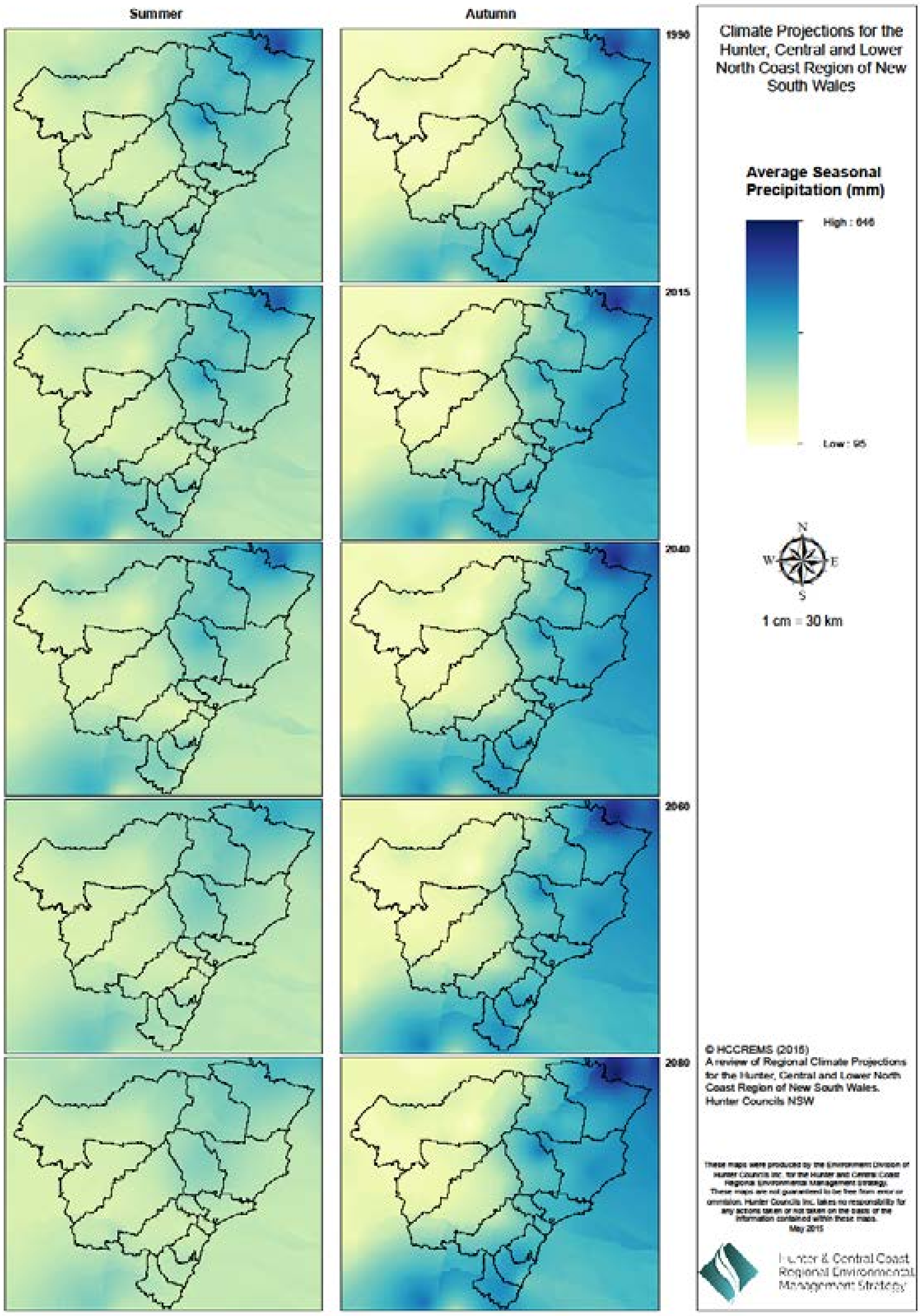
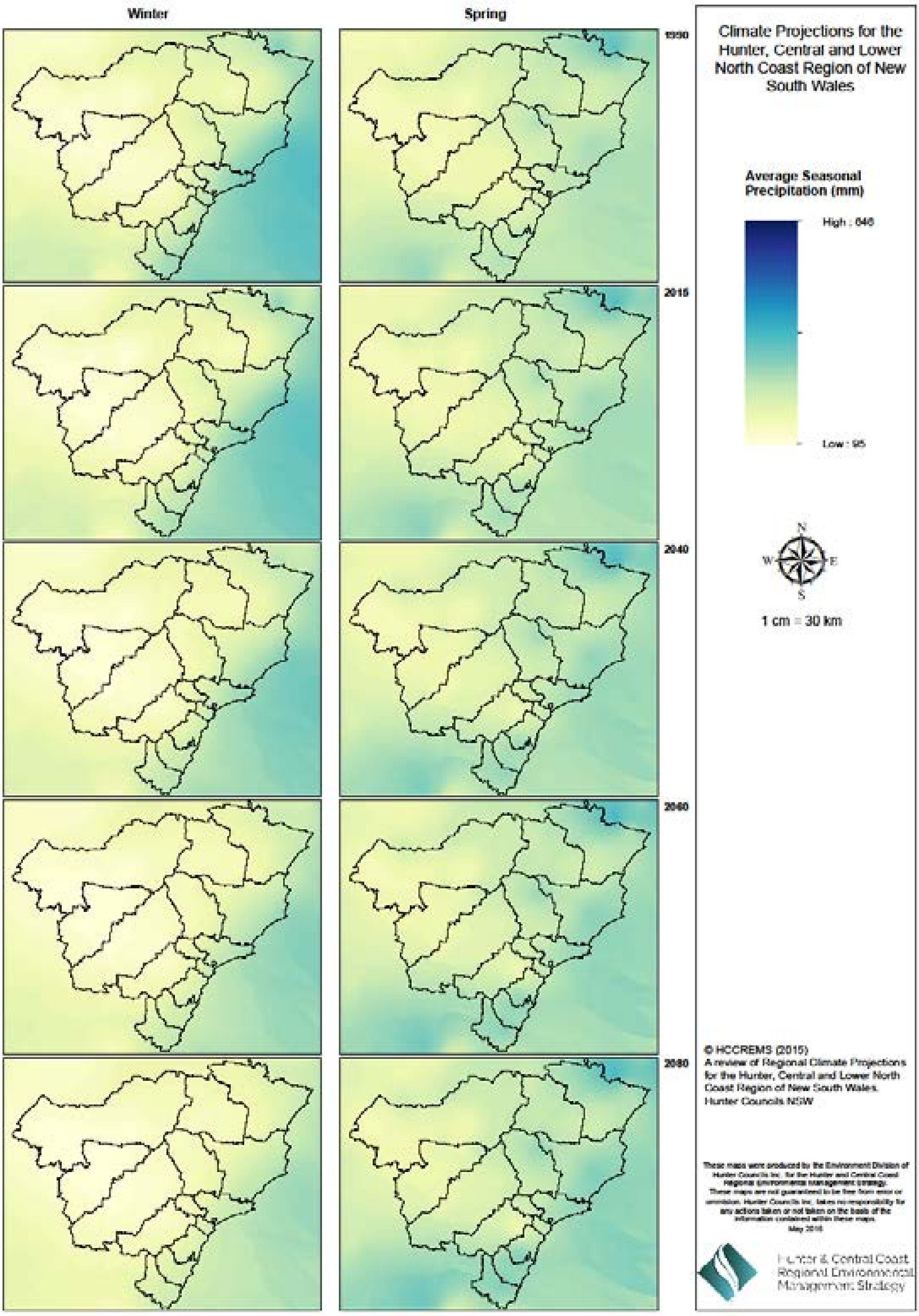
Hunter Councils NSW
Hunter & Central Coast
Regional Environmental
Management Strategy

Appendix 3. Spatial grid layers – Average precipitation (seasonal)




Winter
Spring
1990
2015
2040
2060
2080
Climate Projections for the Hunter, Central and Lower North Coast Region of New South Wales
Average Seasonal Precipitation (mm)
High : 646
Low : 95
N
W
E
S
1 cm = 30 km
© HCCREMS (2015)
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Hunter Councils NSW
Hunter & Central Coast Regional Environmental Management Strategy

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