Climate change and extreme events in Tweed Shire

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The Amendment Record below records the history and issue status of this document.

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1	06 September 2022	Tweed Shire Council	Draft
2	13 October 2022	Tweed Shire Council	Final
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Executive Summary

Tweed Shire's climate is changing and is likely to continue to change in coming years. This report summarises key climate trends and future projections for the Tweed Shire based on the best available scientific information. It also summarises the impacts of recent extreme events on Tweed Shire's communities, environment and infrastructure.

These data and associated trends will help to underpin Tweed Shire Councils' planning and actions to address climate related risks. They will also support engagement and capacity building in the community.

A summary of present-day climate and future projections for the region is summarised in the table below. NSW Government data sources and CSIRO reports were used to compile this information.

Hazard	Present day climate	Future climate (High emission scenario)
High Temperature (days over 30ºC)	• 30 days on average annually • In the last 34 years, the coastal areas of Tweed Shire have had an average of 16.6 days per year of temperatures above 30ºC while inland areas (Murwillumbah), in the past 46 years, had an average of 56.6 days per year over 30ºC. • January has the highest average number of days over 30ºC for both areas.	• 2030: 52 days • 2050: 74 days • 2100: 134 days
Heatwave (continuous run of days over 30°C)	• 6 days average annually • 11 of the last 13 years have had >8 days of heatwave conditions	• 2030: 9 days • 2050: 13 days • 2100: 28 days
Rainfall (annual average)	• 1510 mm with February and March having the highest monthly rainfall averages for inland (Murwillumbah) and coastal areas. • Highest monthly rainfall recorded was 702 mm in February 2020.	• Highly variable with periods of low rainfall and periods of high rainfall • 1.6% increase by 2040 • 8.2% increase by 2080 • Less rain in Summer & Winter and more in Autumn and spring. • Very wet days will increase.
Bushfire	• The frequency of the most dangerous 10 per cent of fire weather days has increased significantly in the Tweed region. There are about 20 to 25 more days	Severe fire weather (annual average days where FFDI>50) is currently 0.3 days in the region which is projected to increase during summer and spring by 0.1

Hazard	Present day climate	Future climate (High emission scenario)
	of dangerous fire weather than in 1985.	days by 2040 and 0.3 days by 2070.
Sea level rise	• Tweed region: increased 0.1 m since 1993 • Global mean sea levels increased by 0.2 m between 1901 and 2018	Mid-range of SLR projections are:. 2030: 0.14 m 2050: 0.27 m 2100: 0.66 m High range of SLR projection at 2100 is 0.88m

Contents

Tables

Figures

1 Introduction

1.1 Background and purpose of this report

Tweed Shire Council (Council) has commenced an update of its climate risk assessment with the assistance of State-wide Mutual. It is aligning its climate risk assessment with the Global Covenant of Mayors standard (climate risk assessment context requirements listed below in Resources). To support this work, Council is collating information on climate trends and projections, broad socio-economic-environmental trends and a summary of recent extreme event impacts.

The purpose of this report is to collate existing climate data and trends for Tweed Shire and develop an easy-to-understand summary highlighting major events and associated impacts to the Tweed community and its environment. It also summarises future climate change projections for the Tweed using existing scientific resources (CSIRO and NARCliM).

The report has the following sections

- Section 1: Introduction and summary profile of Tweed
- Section-2: Climate of Tweed Shire
- Section-3: Observed climate change in the region
- Section-4: Future climate projections for Tweed Shire
- Section-5: A summary of impacts of extreme events and climate change in the Tweed

1.2 Tweed Shire

Tweed Shire is a local government area located in the Northern Rivers region of New South Wales, Australia. It is adjacent to the border with Queensland, where that meets the Tasman Sea. Administered from the town of Murwillumbah. Tweed Shire covers 1303 square kilometres and adjoins the NSW shires of Byron, Lismore and Kyogle. The NSW/Queensland border to the north divides the twin towns of Tweed Heads and Coolangatta.

Tweed Shire’s population is approaching 100,000 and is estimated to reach 112,000 by 2041. Its diverse population is geographically spread amongst urban communities, coastal and rural towns and more than 15 villages. Much like other Australian coastal local governments, Tweed Shire has a higher population density in coastal areas compared to its inland areas.

Tweed Shire includes 37 km of coastline, wetlands and forests, pastoral and farmland, the entire basin of the Tweed River, and mountainous regions containing three World Heritage listed national parks. The Tweed is located in one of the largest natural erosion calderas in the world and has the highest biodiversity in NSW. Figure 1.1 shows the diversity of topography of Tweed Shire, including flatter terrain near the coast and steep hilly terrain in the inland.

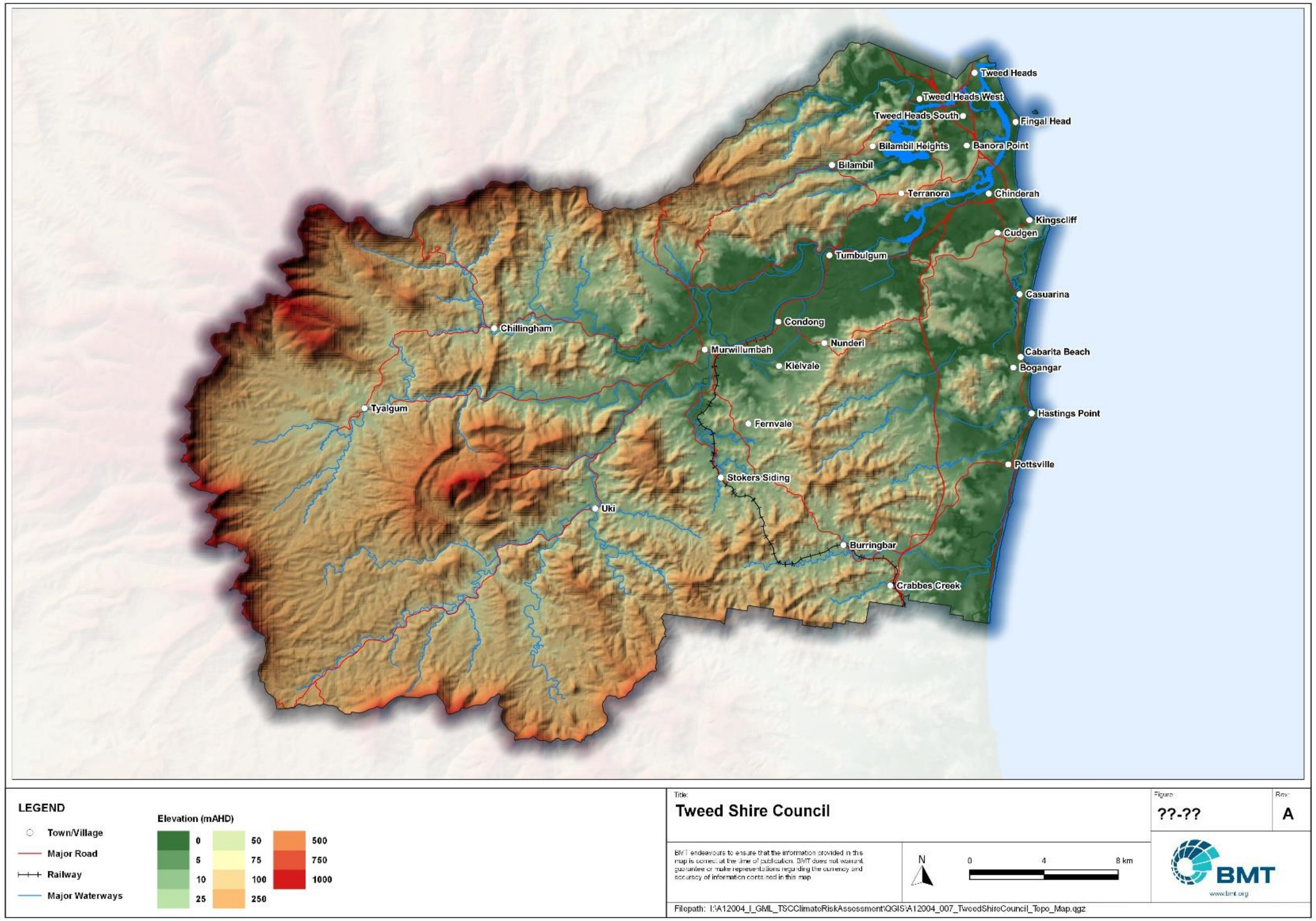


Figure 1.1 Topographic representation of Tweed Shire Council showing the varying topography in the shire.

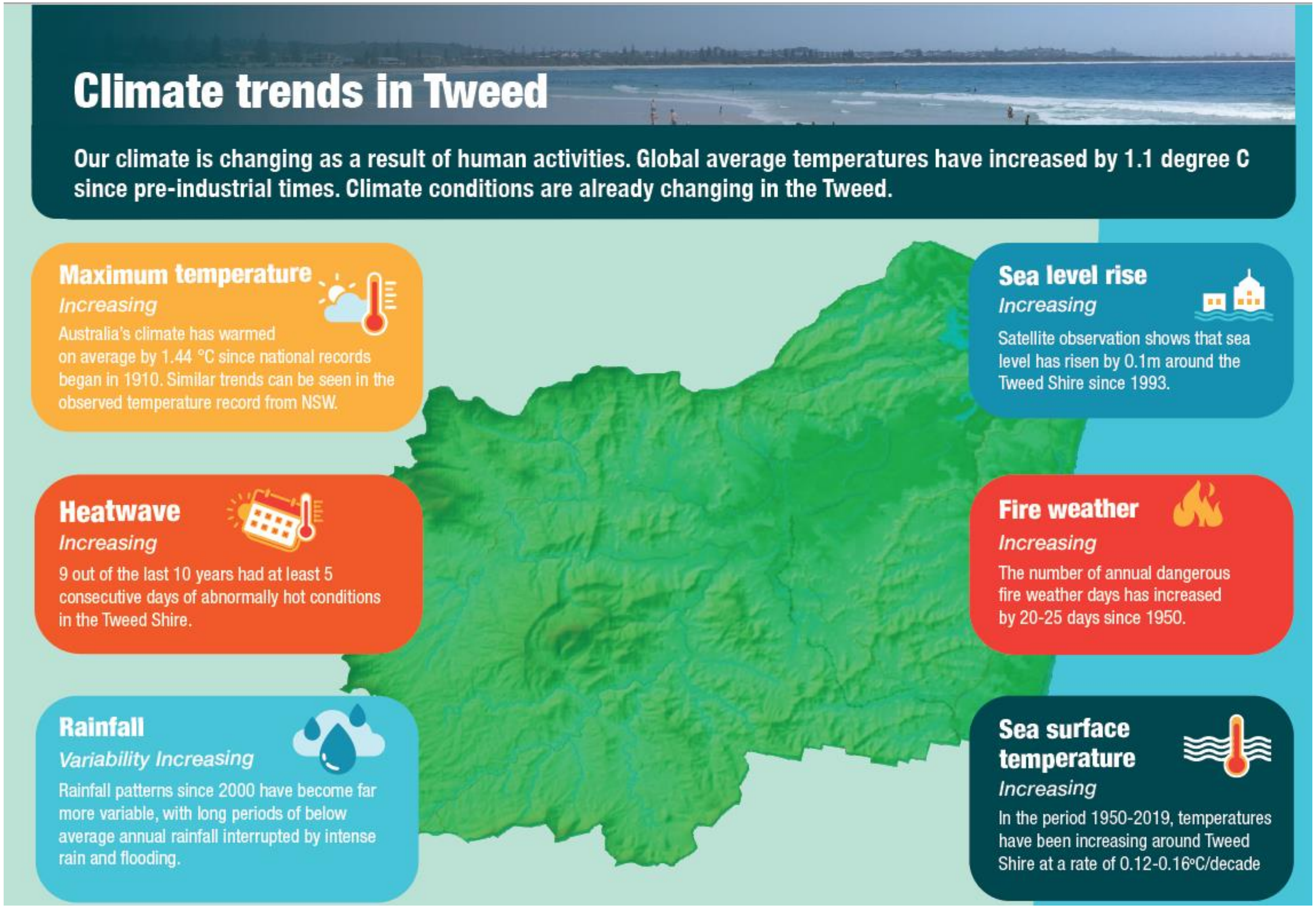
2 Current climate and climate change trends for the Tweed Shire

2.1 Australian weather and climate change

Australian weather is driven by a number of climatic factors, with one of the main influences being the El Niño and La Niña cycles. These cycles are part of the El Niño–Southern Oscillation (ENSO) where the El Niño is associated with sustained periods of warming and La Niña is associated with periods of cooling. El Niño is also associated with reduced rainfall, later monsoon onset, a change in temperature extremes, reduced number of cyclones and increased fire danger in southeast Australia. La Niña is associated with periods of warmer ocean temperatures, more atmospheric moisture and higher rainfall.

Human activities are causing our climate to change, for example through activities such as burning fossil fuels and clearing trees. These activities add carbon dioxide and other 'greenhouse gases' such as methane to the atmosphere. Greenhouse gases do not influence solar energy as it passes through the atmosphere to the Earth, but they do absorb or trap some of the back radiation from the Earth. The net effect of increased amounts in the atmosphere is to cause warming of the whole earth-ocean-atmosphere system. Not only is the system warming, but there is more energy available, so that every aspect of our climate is changing – the amount of rainfall and evaporation, the occurrence of storms, the frequency and severity of heat waves etc.

In the sections below we present some general global information on each climatic variable, followed by trends and projections for the Tweed Shire.


Climate trends in Tweed
Our climate is changing as a result of human activities. Global average temperatures have increased by 1.1 degree C since pre-industrial times. Climate conditions are already changing in the Tweed.
Maximum temperature
Increasing
Australia's climate has warmed on average by 1.44 °C since national records began in 1910. Similar trends can be seen in the observed temperature record from NSW.
Heatwave
Increasing
9 out of the last 10 years had at least 5 consecutive days of abnormally hot conditions in the Tweed Shire.
Rainfall
Variability Increasing
Rainfall patterns since 2000 have become far more variable, with long periods of below average annual rainfall interrupted by intense rain and flooding.
Sea level rise
Increasing
Satellite observation shows that sea level has risen by 0.1m around the Tweed Shire since 1993.
Fire weather
Increasing
The number of annual dangerous fire weather days has increased by 20-25 days since 1950.
Sea surface temperature
Increasing
In the period 1950-2019, temperatures have been increasing around Tweed Shire at a rate of 0.12-0.16°C/decade

2.2 Temperature

Our climate is already changing, which is clearly represented in records of observed temperatures. Figure 2.1 shows the long-term land-based temperature record for Australia, combining data from measuring stations across the nation. This demonstrates warming of around 1.5^{o}C since 1910. This long-term warming trend means that most years are now warmer than almost any observed during the 20th century (State of the Climate, 2020). A similar trend is also observed in NSW (Figure 2.2).

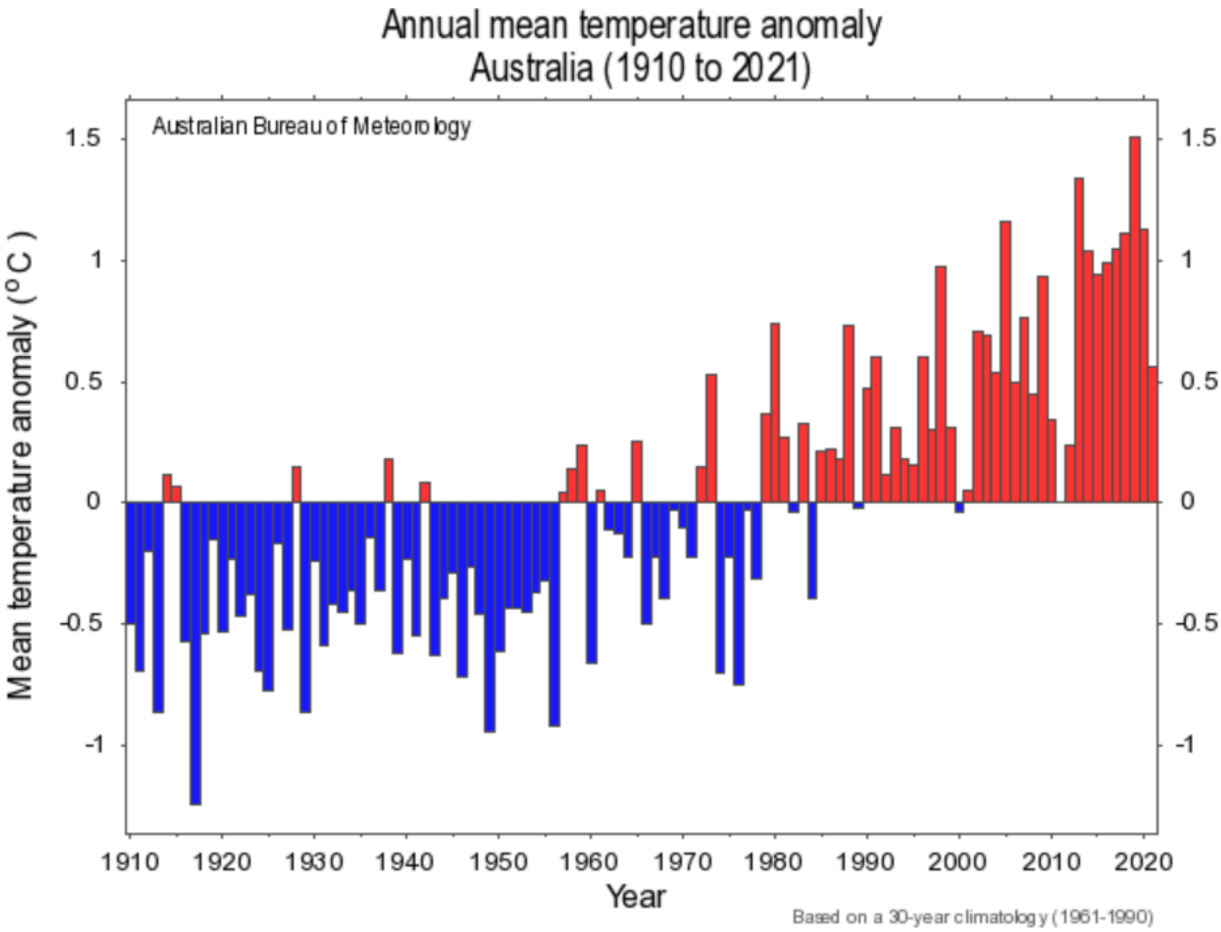


Figure 2.1 Annual mean temperature anomaly for Australia

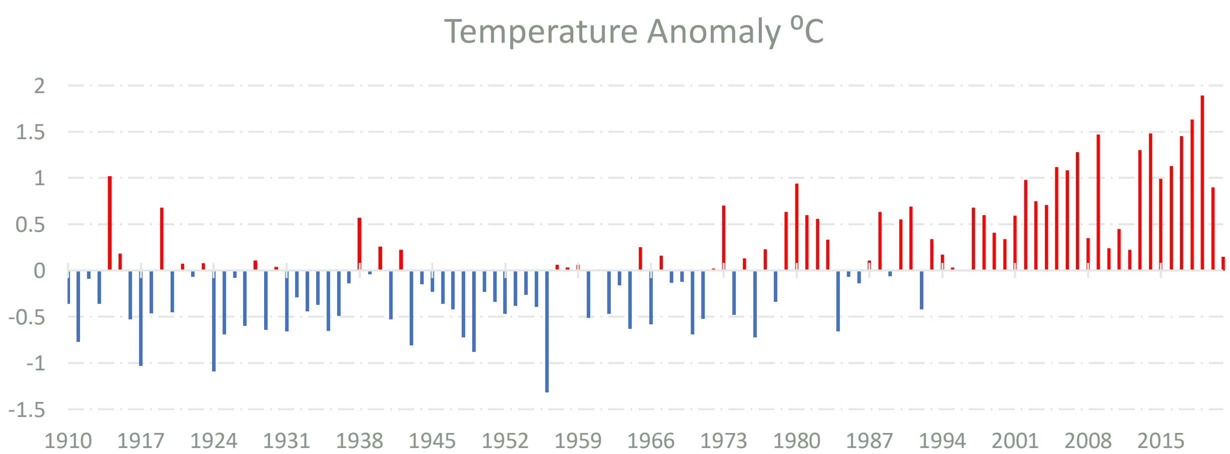


Figure 2.2 Annual mean temperature anomaly for NSW (Source BoM)

The Tweed region has a subtropical climate with hot, humid summers and cool to mild winters. Much like other Australian coastal settlements, Tweed has a higher population density in coastal areas compared to its inland areas. Coastal areas have relatively cooler and more humid conditions than those experienced in the inland, illustrated by the statistics from the Coolangatta airport (coastal) and Bray Park in Murwillumbah (inland) weather stations (Figure 2.3). Between January and March, the average monthly maximum (daytime high) temperature in Coolangatta is between 27°C and 28°C whereas in Murwillumbah is between 28°C and 29.5°C. However, at night in summer months, this reverses as monthly minimum temperature in Murwillumbah ranges between 19°C and 20°C whereas Coolangatta ranges between 20°C and 21°C. Despite this variation, the hottest month in the Tweed is January and the coolest is July. The winters in Murwillumbah are cool with monthly average overnight temperatures around 8.6°C in July.

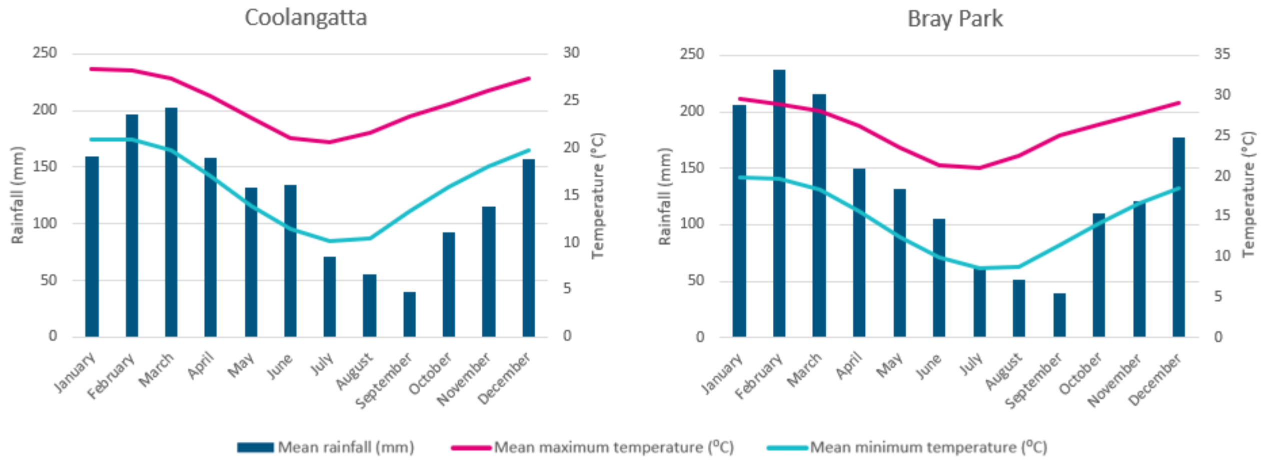


Figure 2.3 Climate statistics from Coolangatta Airport (left) and Bray Park in Murwillumbah (right). Data are averaged across 1972-2022. Data source: Bureau of Meteorology, Accessed at (http://www.bom.gov.au/climate/averages/tables/cw_040717.shtml and http://www.bom.gov.au/climate/averages/tables/cw_058158.shtml)

In the last 50 years (1972-2022), annually on an average there were 56 days where temperatures reached over 30°C and 4.6 days where temperatures reached over 35°C (Figure 2.4). Within the last 10 years the annual average of days over 35°C has increased to 5 days. The highest recorded temperature in the region is 42.9°C recorded on the 12th January 2002, followed by 40.9°C in 2004 and 40.6°C in 2014.

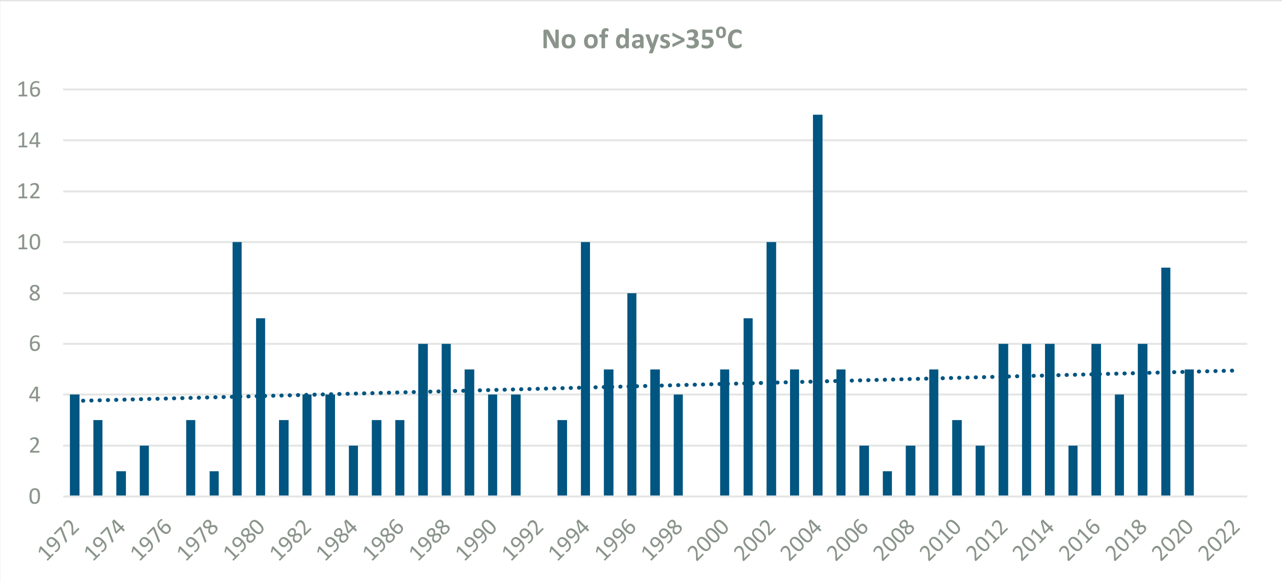


Figure 2.4 Annual number of days over 35 degrees (Data from Bray Park station in Murwillumbah)

The Bureau of Meteorology (BoM) defines heatwaves as three or more consecutive days of hot weather that are unusual for the location. Heatwaves are of key concern due to their potential impacts upon human health, wildlife, and infrastructure. Figure 2.5 shows the temperature statistics using BoM data for which the following definitions apply:

- Heatwaves (a period of hot days): this is a count of occurrence where both maximum and minimum temperatures are above normal (the 85th percentile of historical data) for that location for **three or more consecutive days** (Source: BoM). This includes all three types of heatwaves (low, severe and extreme intensity)

- Longest heatwave: the longest number of consecutive days where both the maximum and minimum temperatures are above normal (the 85th percentile of historical data) for that location in a particular year.

2010 had the highest number of days where heatwaves condition prevailed in Tweed Shire, 2006 had the highest total length of heatwaves and 2017 had the longest heatwave. For Murwillumbah, 1998 had the highest number of heatwaves and 2017 had the highest total length of heatwaves and longest heatwave. In 2017 extreme heatwave conditions in Tweed were reported by BoM (Figure 2.6).

Nine out of last 10 years had at least five days of consecutive heatwave conditions in Tweed (Figure 2.5) indicating that heatwave occurrences have increased.

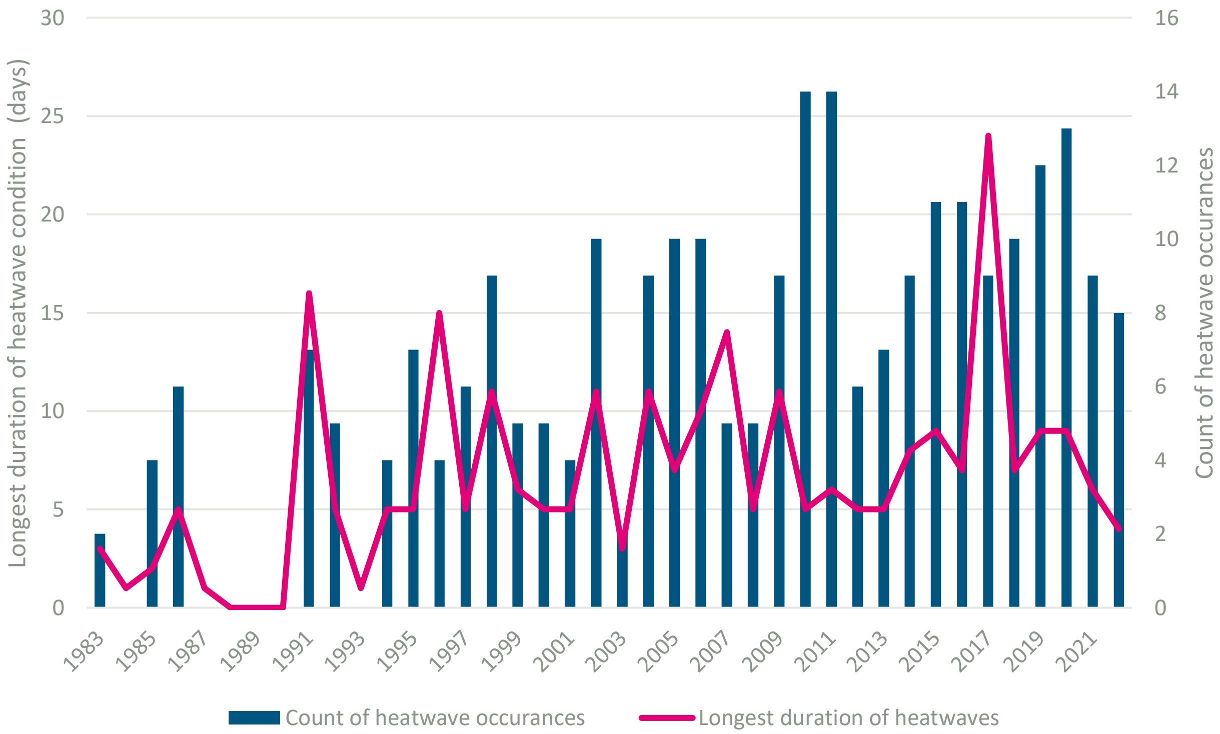


Figure 2.5 Heatwave statistics for the Tweed (BoM site at Coolangatta)

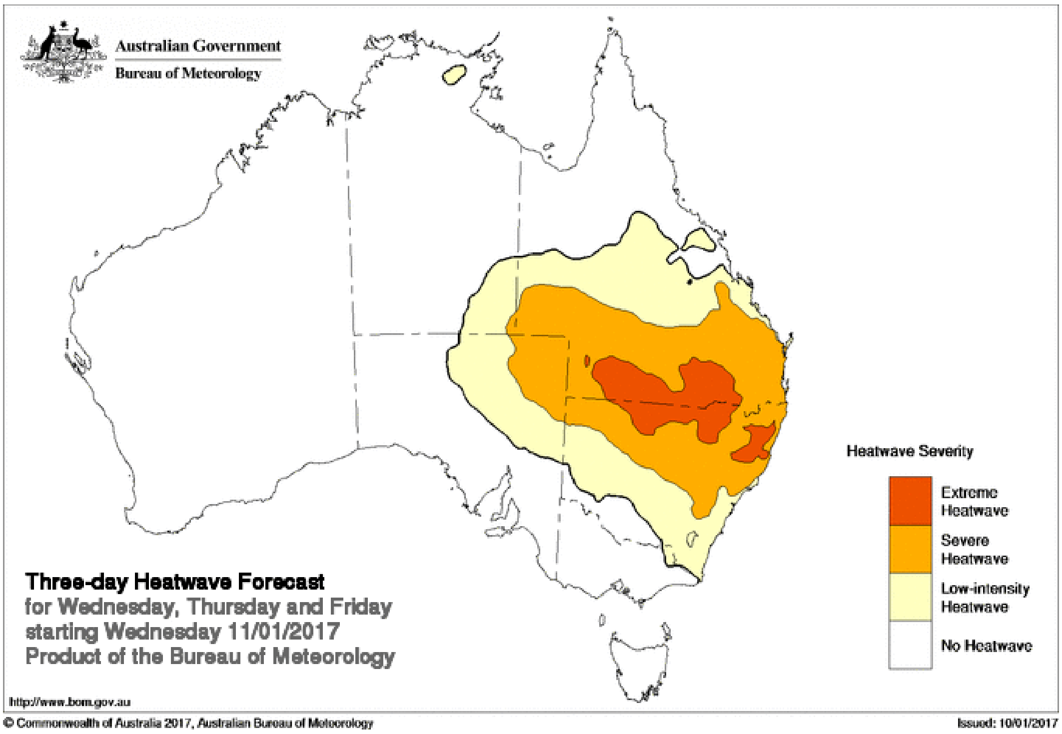


Figure 2.6 Extreme heatwave conditions in 2017 in the Tweed (source BoM)

2.3 Sea surface temperature

National and regional trends

Just as temperatures over the land are changing, so also are marine temperatures. Figure 2.7 shows a map of surface temperature change in the offshore waters of Australia. In the period 1950-2019, temperatures have been increasing in the ocean off Tweed at a rate of 0.12-0.16^{o}C/decade. Figure 2.8 shows a time series from 1900 to the present day for the seas off the Tasman Sea, including Tweed. Sea surface temperatures have increased over this period by around 1^{o}C. (State of the Climate, 2020).

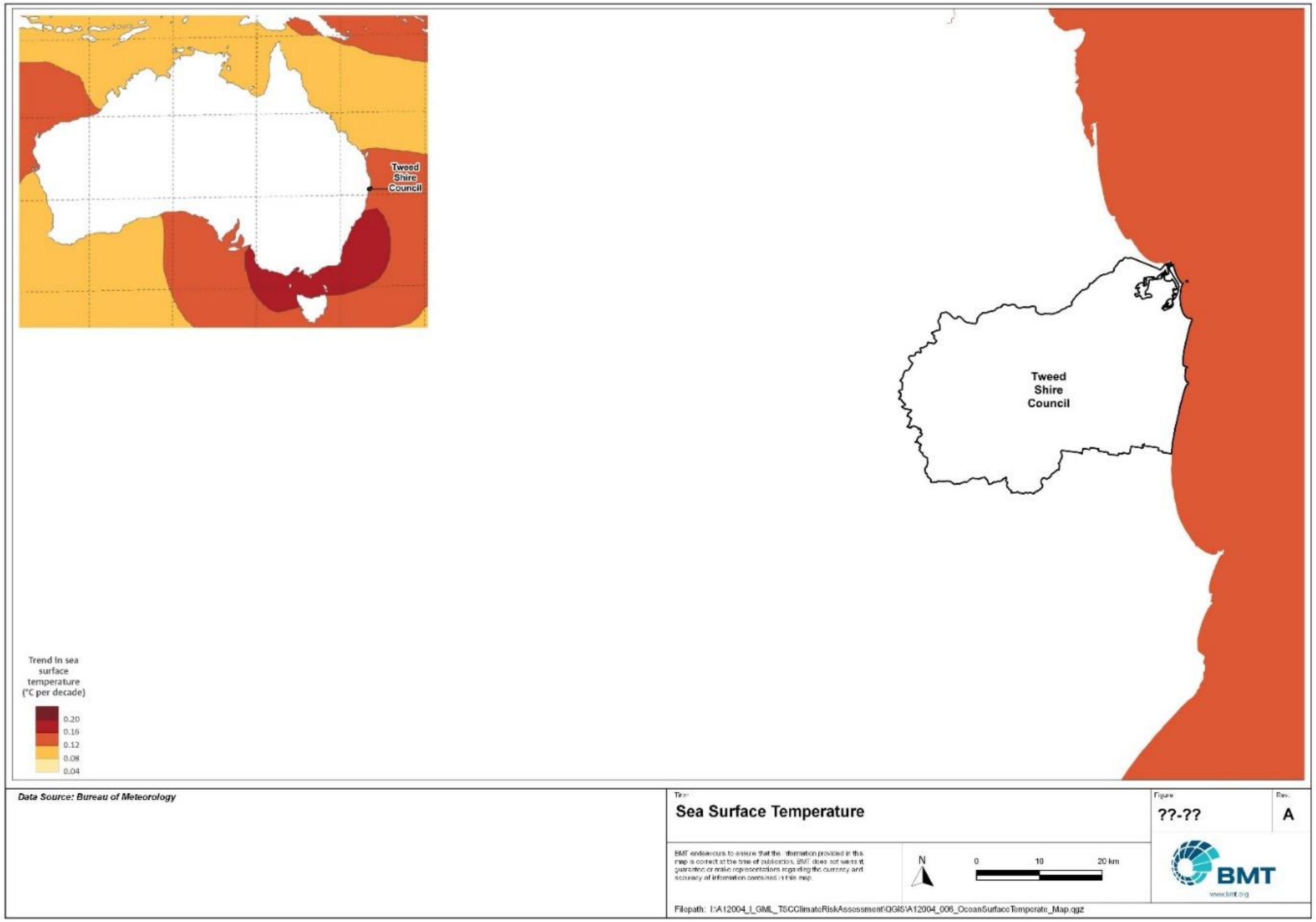


Figure 2.7 Map of sea surface temperature trends in the Australian region from 1950 to 2019. Source: https://www.csiro.au/en/research/environmental-impacts/climate-change/state-of-the-climate. Accessed 6 June 2022

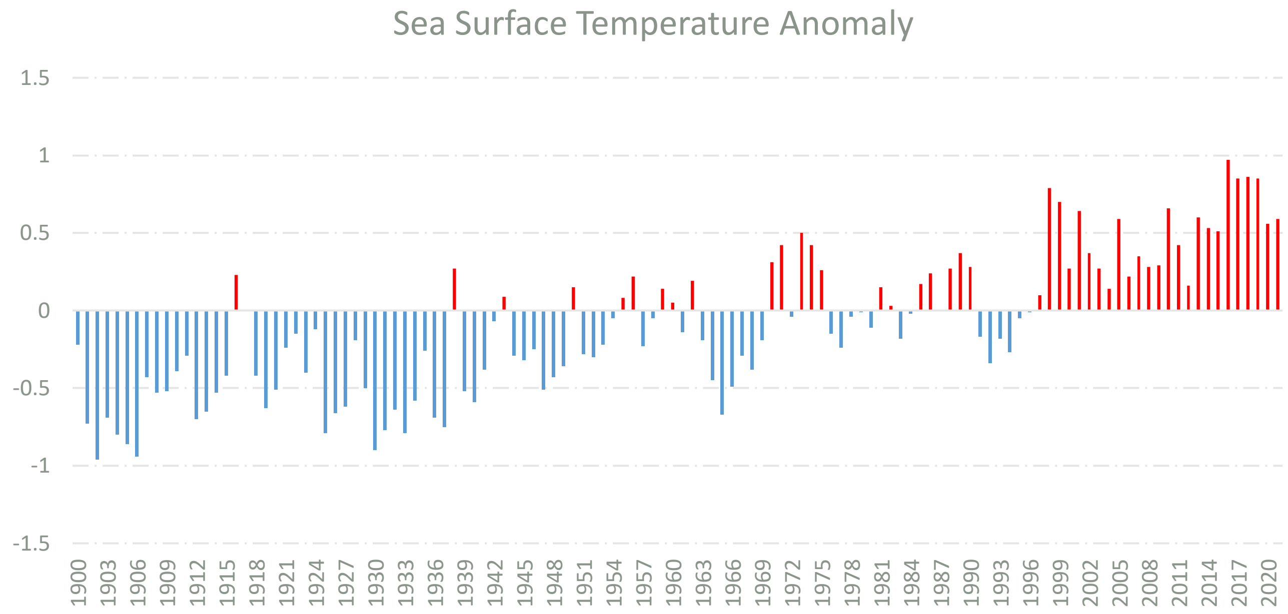


Figure 2.8 Time series of sea surface temperature anomalies for 1900 to 2020 for the waters off Tasman Sea around the east coast of Australia. Data source: http://www.bom.gov.au/climate/change/index.shtml#tabs=Tracker&tracker=timeseries&tQ=graph%3Dsst%26area%3Dnw%26season%3D0112%26ave_yr%3D0. Accessed 12 October 2021

2.4 Rainfall

Analysis of observed rainfall over the whole of Australia shows that conditions are becoming wetter over the north of the country and drier over southern regions (BoM and CSIRO 2020). Specifically, Autumn and Spring rainfall has decreased in the region around the Tweed and received 'very much below average' rainfall between 2000 and 2020 (State of Climate 2020). (Figure 2.9) Although average rainfall has decreased in the Tweed the intensity of rainfall has increased which was demonstrated by two significant rainfall events in 2020 and 2022 (Figure 2.10).

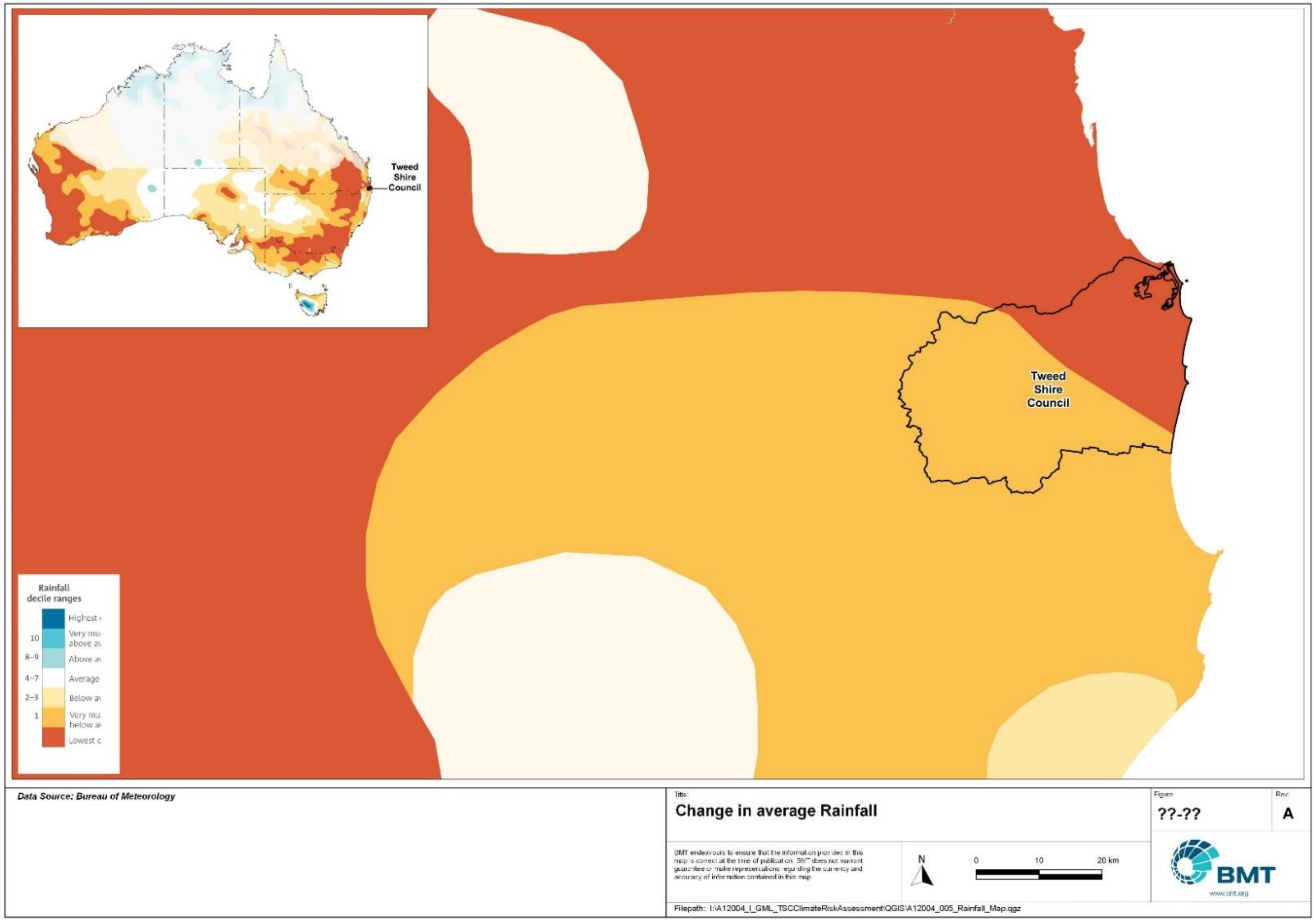


Figure 2.9 April to October rainfall deciles for the last 20 years (2000–19). A decile map shows where rainfall is above average, average or below average for the recent period, in comparison with the entire rainfall record from 1900. Areas around Tweed has received ‘very much below average’ rainfall.

The mean annual rainfall is 1510 mm with most of the rainfall occurring between December and March. The BoM rain gauge at Coolangatta has been collecting rainfall data since 1983 and the highest recorded monthly rainfall at this site was 702 mm in February 2020. In recent years there was a relatively dry period between 2018 and 2019 which followed by few very wet years from 2020 onwards which resulted in multiple devastating floods in the region (Figure 2.10).

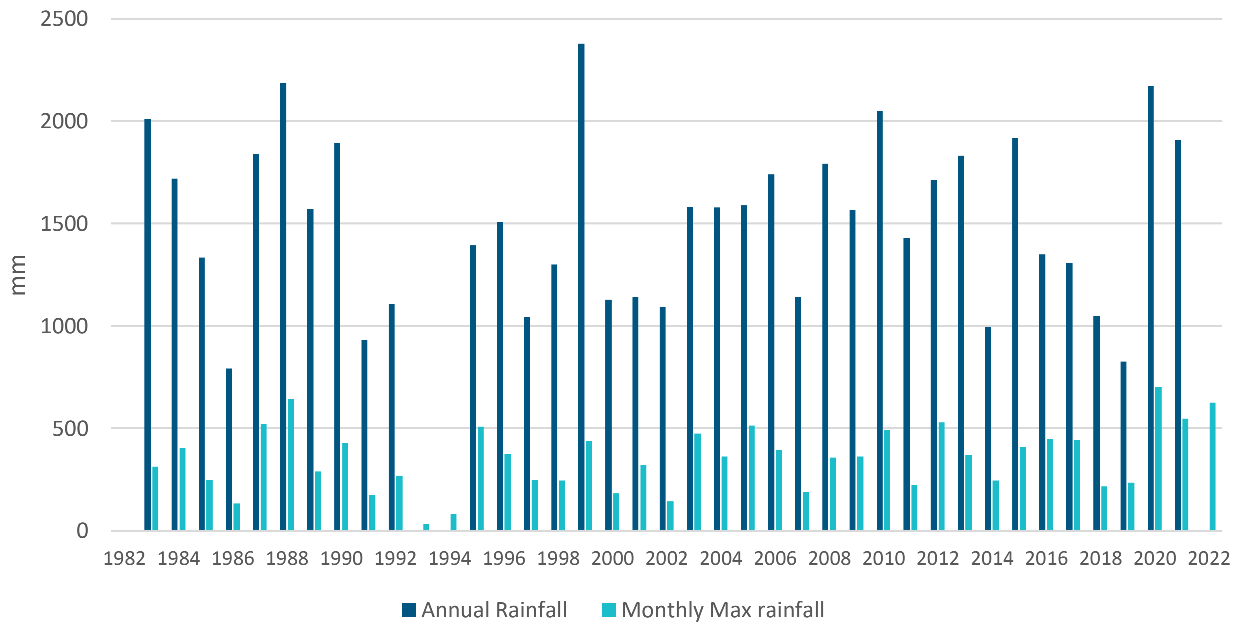


Figure 2.10 Annual total rainfall (dark blue bars) and monthly maximum rainfall in a given year (Teal bars) in Coolangatta. Teal bars in last three years (2020-2022) demonstrate a very wet period that resulted in multiple flood events in the region. Accessed from BoM rain gauge at Coolangatta. http://www.bom.gov.au/climate/data/index.shtml

2.5 Humidity

Humidity in the Tweed varies across seasons. The highest humidity is experienced in the summer months of January to March, peaking in February with a monthly average at 9am of 83% and at 3pm of 65% (Figure 2.11). The lowest monthly humidity occurs in October, with 65% at 9am and 56% at 3pm. Higher humidity along with high temperature increases outdoor thermal discomfort impacting outdoor activities such as road maintenance, landscaping, and movement of tourists and pedestrians in the Tweed area.

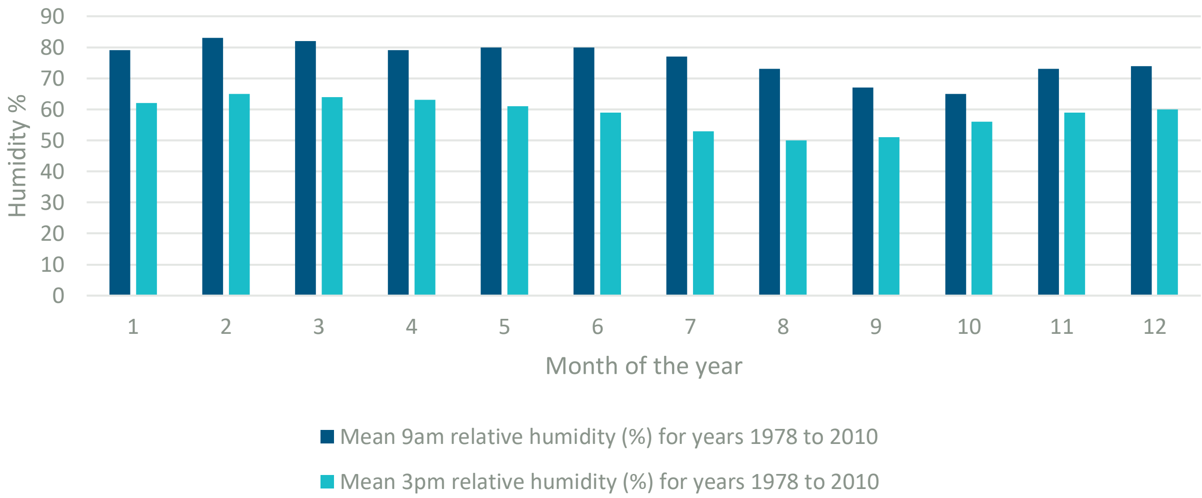


Figure 2.11 Monthly relative humidity in Murwillumbah (Bray Park) based on data for 1978-2010. Data source: Bureau of Meteorology (BOM, Climate statistics for Australian locations, 2022)

2.6 Bushfire

Fire weather is largely monitored in Australia using the Forest Fire Danger Index (FFDI). The FFDI indicates the fire danger on a given day based on observations of temperature, rainfall, humidity and wind speed. The frequency of the most dangerous 10 per cent of fire weather days has increased significantly in recent decades across many regions of Australia, especially in the east including areas in the Tweed. The top 10% fire weather days in Tweed (i.e., the 90th percentile FFDI) for the period of 1950 to 2016 is between 0 and 20 (Dowdy, 2018) (Figure 2.13). These numbers increase further in Spring and early summer. For example, between August and November, Tweed can experience it's monthly top 10% fire weather days between 50 – 100 days (Bureau of Meteorology, n.d.). The present-day frequency of the highest 10 per cent of fire weather days has increased by 20 to 25 days when compared to 1985 (Figure 2.12), showing that the Tweed is experiencing its top 10% of its highest rated fire weather days more now than it has in the past.

The history of bushfires has been compiled into the spatial dataset 'NPWS Fire History - Wildfires and Prescribed Burns' which provide a record of fire history on National Park estate in the Shire (NSW Department of Planning & Environment, 2022). This dataset extends from 1968 to the present day and only includes NPWS land for both prescribed burns and wildfires.

The proportion of the Shire with declared National Parks and Reserves provides an indication of the extent of bushfire (i.e., excluding prescribed burns) that has occurred in the region (Figure 2.14). Since 1968, the area of fire has approximately equalled or exceeded 10km^2 on nine occasions. The period of 1991 to 1995 recorded 5 years in a row with significant fire activity, with 1991 having the highest fire damage of 37km^2, followed by 2019 with 25km^2. This period coincided with very dry conditions in the Tweed Shire (Figure 2.10).

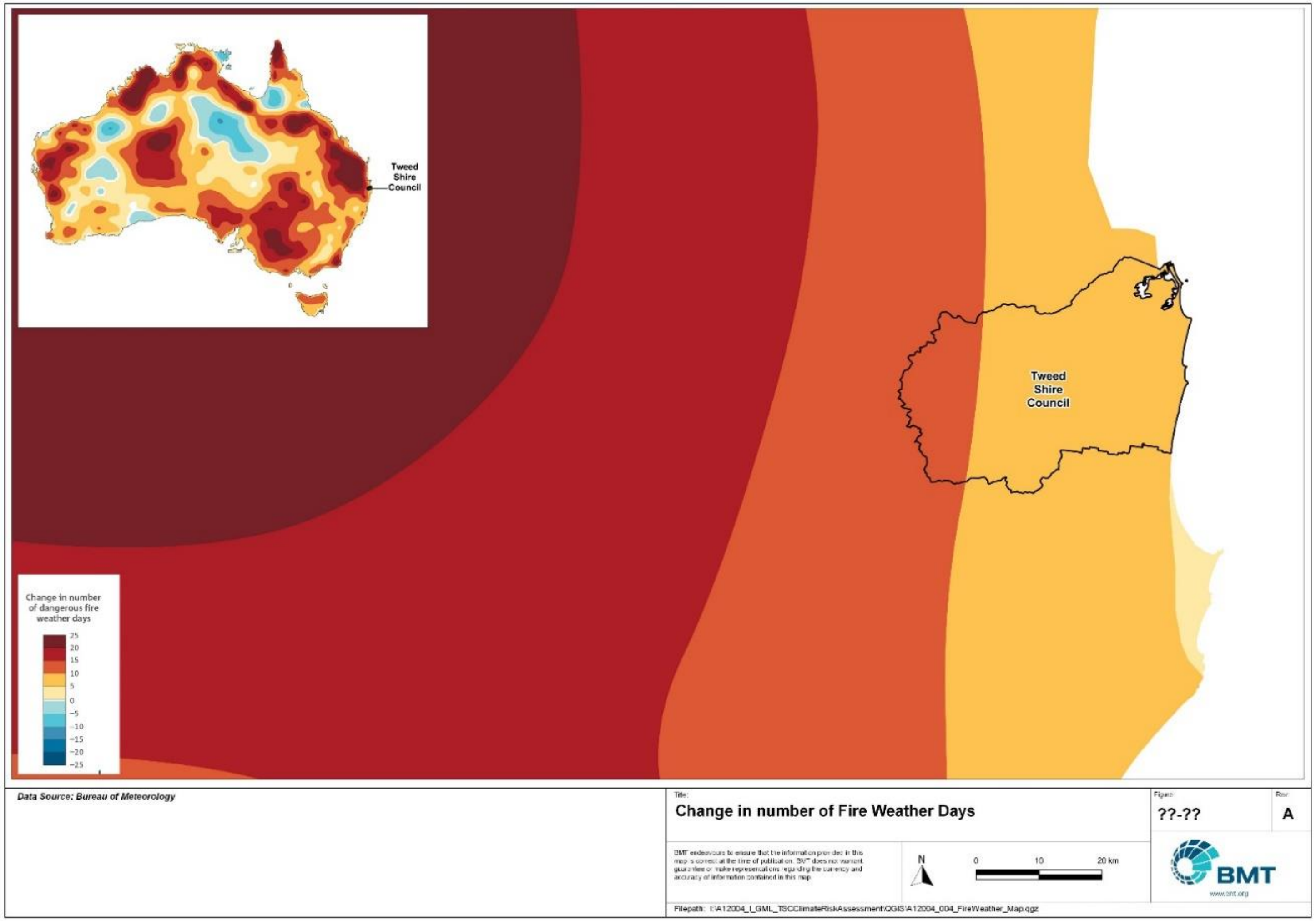


Figure 2.12 Change in number of dangerous fire weather days. Number of annual dangerous fire weather days in Tweed region has increased by 20 to 25 days (difference between two periods 1950-1985 and 1985-2020).

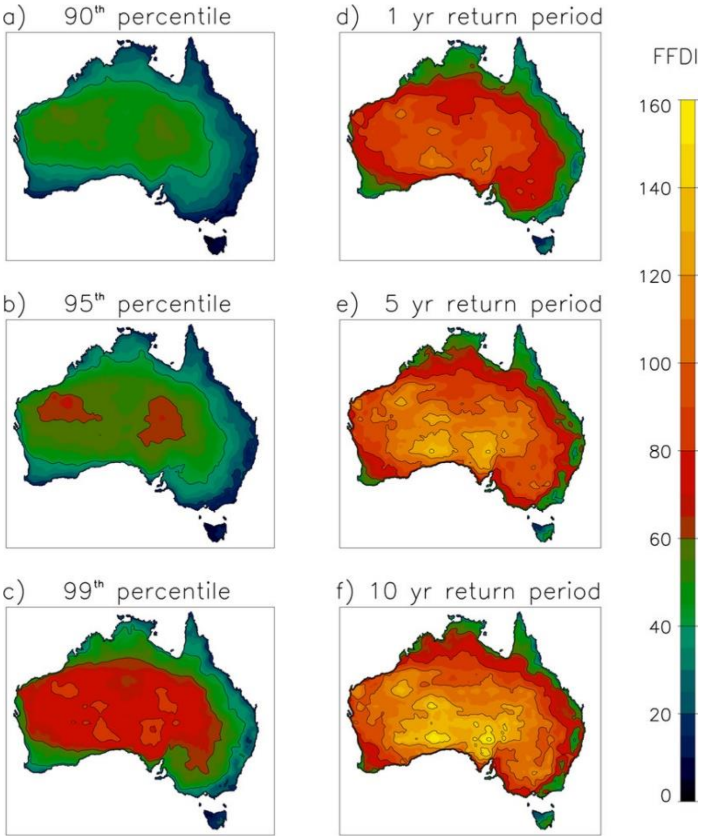


Figure 2.13 Extreme fire weather conditions throughout Australia

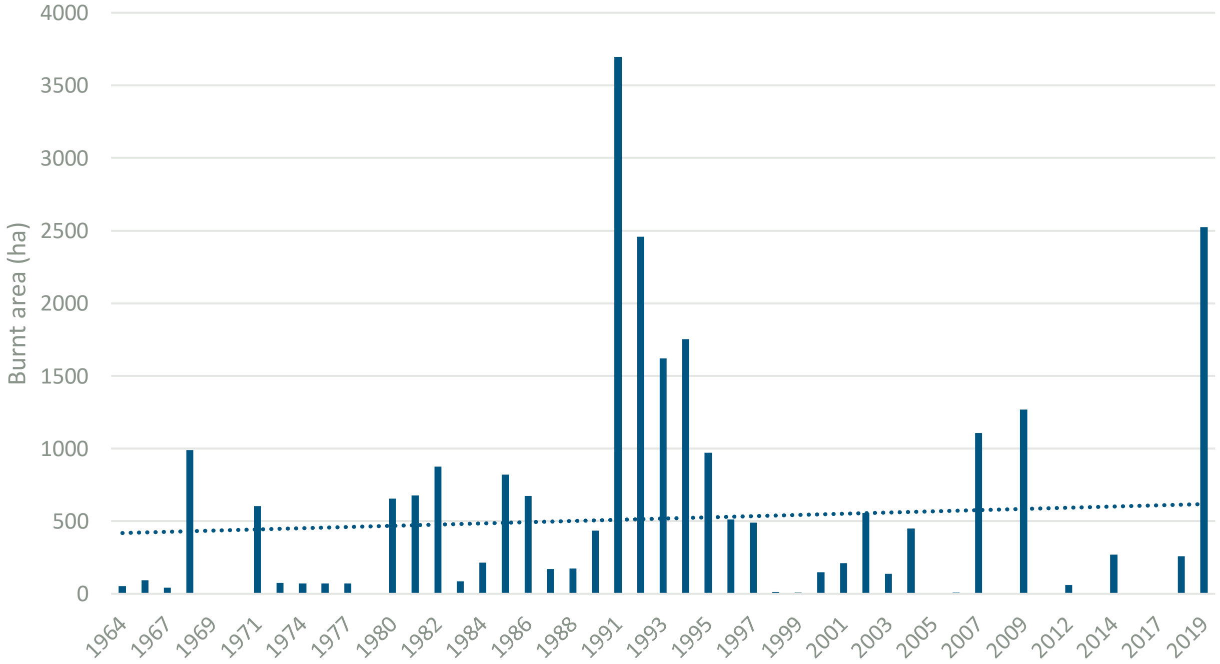


Figure 2.14 Bushfire annual burnt area in Tweed region. Data Source (NSW Department of Planning & Environment, 2022)

2.7 Hail and severe storms

Severe thunderstorms occur throughout Australia, every year and are most common from September to March in the spring, summer, and autumn seasons. They usually occur in the afternoon when temperatures are higher, and the atmosphere is unstable due to warming from the sun. Various effects are associated with severe thunderstorms, including tornadoes, wind gusts of at least 90 km/h and hail. Of these, hail is particularly prevalent along the eastern coast including Tweed. Severe thunderstorms have accounted for one-third of Australia's costliest natural disasters over the past 50 years, according to the Insurance Council of Australia (ICA).

A significant event occurred on December 20, 2018, which began as a warm, humid day for much of eastern Australia. Over the course of the day, a cold front that was positioned across the country moved north-eastward. Over the next few hours multiple waves of severe thunderstorms produced heavy rainfall, gusty winds, and very large hail for the Sydney and Central/East Coast regions including in the Tweed. Multiple reports of grape to golf ball size hail were found in the Tweed region as per BoM Hail database (BoM, 2020). Multiple hail events happened in 2018 and Figure 2.15 shows the frequency of hailstorms for 2018 along the Central and North Coast. (Verisk, 2019)

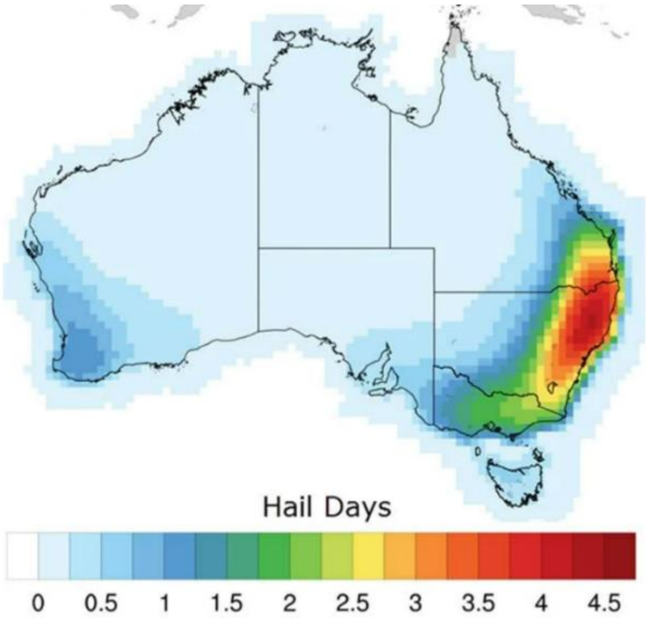


Figure 2.15 Frequency of hailstorms for 2018 and their distribution along the Central and North Coast. (Verisk, 2019)

The severe storms archive by BoM includes a record of hailstorms that have been observed across Australia. Since 2000, BoM has recorded 18 hailstorms in the Tweed Shire Council area. The majority of these storms have been recorded at Murwillumbah (10 hailstorms) and the others adjacent to Uki, Kingscliff, Tweed Heads, Condong and Pottsvile. The hailstorm on the 5th of November 2000 recorded the largest hail sizes out of the records with 6 cm hail and two tornadoes recorded (BoM, 2020).

3 Extreme events and impacts in the Tweed Shire

Extreme Floods

Extreme rainfall can be perceived in both a positive and negative light where rainfall can break droughts but if leading to flooding, can have devastating impacts. Floods typically occur from heavy rainfall when natural watercourses cannot contain the additional water volumes. Riverine flooding occurs in low-lying areas adjacent to rivers and streams. Flash flooding, otherwise known as overland flooding, occurs when short, intense bursts of rainfall overwhelm drainage systems and water cannot runoff quickly enough.

Flooding impacts can be vast and multifaceted. Immediate impacts include loss of life, damage to property, damage to agriculture, infrastructure, impacts to the economy and the environment. The longer-term impacts for communities can include long-term displacement, emotional and mental health, illness from water borne diseases, and economic impacts such as slow recovery for underinsured people and increases in insurance costs.

The Tweed River runs from Mount Burrell and flows north where it connects to the ocean at Tweed Heads. A variety of data have been gathered about flooding in the Tweed River over the past several decades. Three flood gauges within the Tweed River with long historical datasets that are quality assured are: Barneys Point in the lower Tweed River estuary (near Chinderah), Murwillumbah and Tumbulgum approximately mid-way between Barneys Pont and Murwillumbah. These three gauges have nominated levels indicating minor, moderate and major floods. The height of flooding is recorded in relation to the Australian height datum (AHD) which is the official vertical datum for Australia. AHD passes through the approximate mean sea level (MSL) realised between 1966 and 1968 at coastal tide gauges.

The data show that flooding at these sites has occurred at the following occasions.

- minor flooding above 2.2m AHD has occurred at Barneys Point (Water level gauge 558102 in 1974, 2017 and in 2022.
- major flooding at Tumbulgum has occurred in 1987, 1988, 1989 (x2), 1991, 2001, 2012, 2013, 2017 and in 2022 (Water level gauge 558014).
- major flooding at Murwillumbah has occurred in 1974, 1978, 1989, 2017 and 2022 (Water level gauge 058186).

Figure 3.3 shows the weekly total rainfall recorded in and around Tweed Shire up to 2nd March 2022. These weekly falls were significant and resulted in the highest flood levels on record at Murwillumbah and exceeded the 1954 peak level which was the highest previously recorded. The Tweed River at Murwillumbah peaked at 6.5m – 200mm higher than 2017 – Murwillumbah narrowly escaped more widespread flooding as the CBD levee only overtopped at a few locations for a limited time. Tumbulgum was one of the hardest hit localities in the Tweed, with the river peaking at 4.8m – 800mm higher than 2017.

Uki is also located along the Tweed River, upstream of Murwillumbah. The flood gauge at Uki has recorded data between 1967-81 and 1995-2022. In 2022, this flood gauge recorded the largest discharge volumes on record with a 2,557 m^3/sec (Alluvium, 2022). This is equivalent to a 75 year annual recurrence interval event (Figure 3.1).

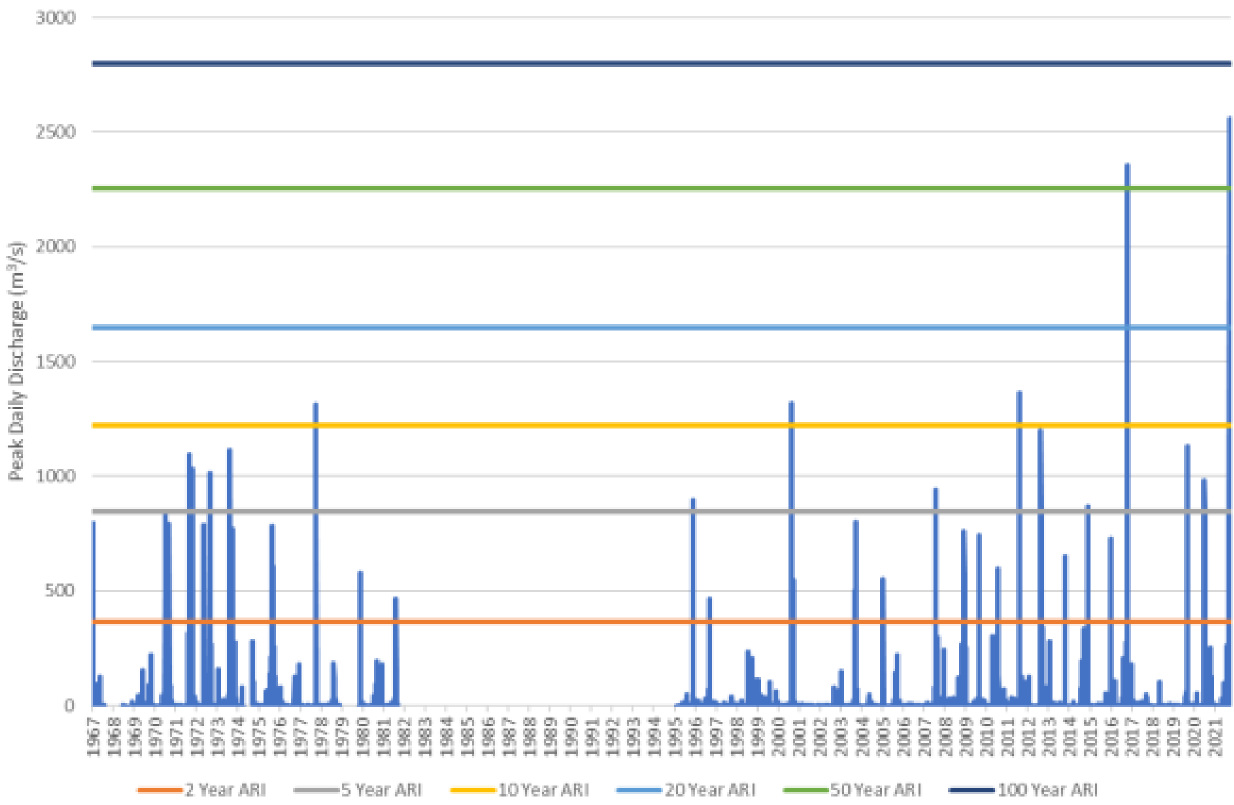


Figure 3.1 Uki flow series from 1967-1981 and 1995-2022 (Alluvium 2022)

The Oxley River is a perennial river in the Tweed catchment and stretches from Tyalgum in the west to Byangum in the east where it joins the Tweed River. Eungella is along the Oxley River and is one of the hydraulic reference stations maintained by BoM. Eungella gauge flow data are available from 1958 to 2018. This dataset shows that there has been multiple peaks on record with the highest monthly stream flow recorded in June 1967 (Figure 3.2). Within June of 1967, the highest flow recorded was 52,428 ML in a single day on the 12th of June. Other significant flow peaks were recorded in January 1974, April 1988/9, May 1996, January 2012 and March 2017.

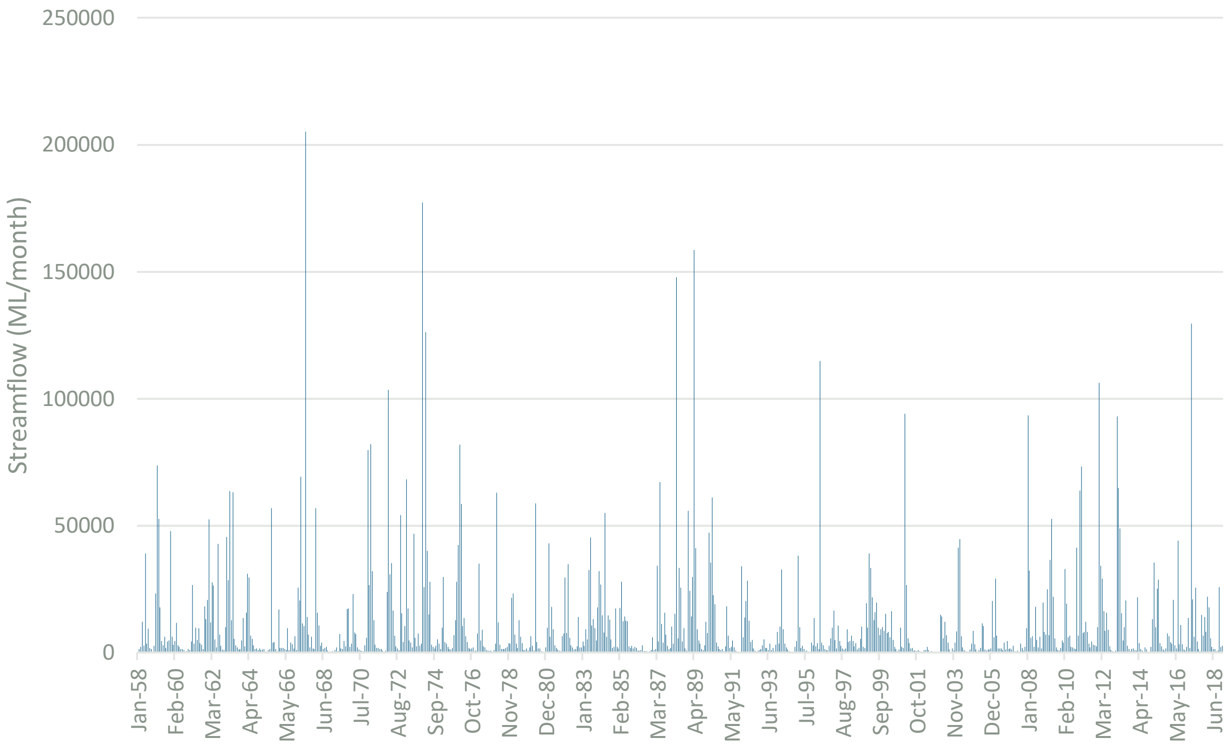


Figure 3.2 Oxley River streamflow at Eungella (Source: BoM gauge 201001, Accessed at http://www.bom.gov.au/water/hrs/#id=201001&panel=trend-explorer&control-0=)

Flood impacts in the Tweed

Recently, the 2017 and 2022 floods had significant impacts on the Tweed Shire and its community, damaging public and private assets, leading to loss of life, impacting the natural environment, and causing massive disruptions to livelihoods and wellbeing. Figure 3.4, Figure 3.6 and Figure 3.5 provide an indication of the extent of the flooding and the impacts from it.

Key impacts from the 2022 flood were:

- The largest flood levels on record at Murwillumbah.
- 500 homes left uninhabitable,
- more than 2,100 homes damaged,
- 1,600 people requiring temporary accommodation,
- total Council infrastructure damage bill estimated at $100 million,
- more than 26,000 tons of flood waste, 1,440 tonnes of asbestos and 75,000 tonnes of mud debris collected.

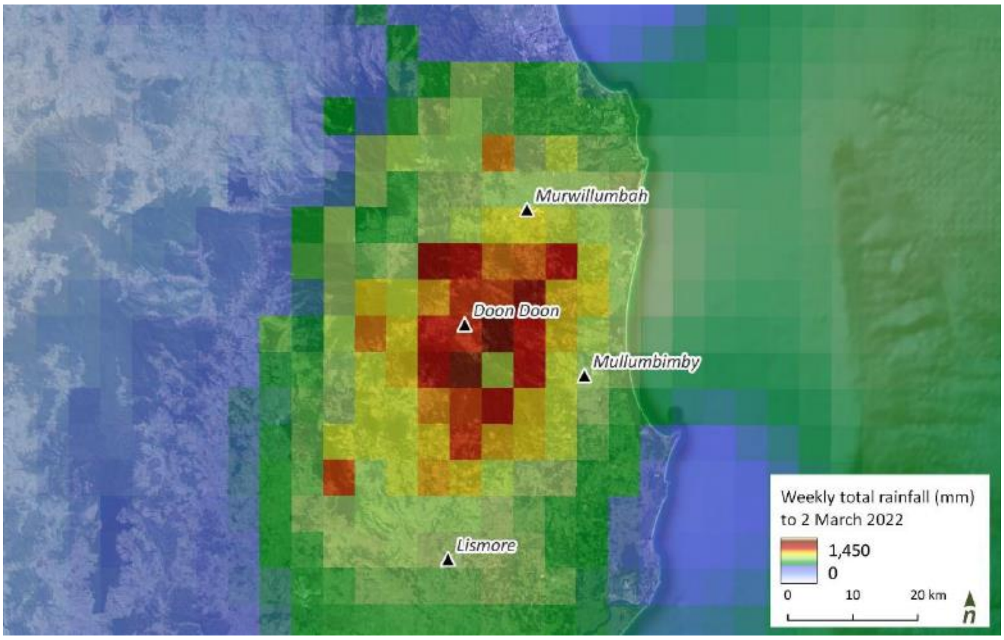


Figure 3.3 Total weekly rainfall grid for week up to the 2nd of March 2022 (Source: Alluvium, 2022)

Figure 3.4 Damage examples from Flood 2022. Formation of a chute channel across the floodplain and significant bank retreat up to edge of Kyogle Road. (Source: Alluvium, 2022)

Figure 3.5 The Tweed River at Murwillumbah peaked at 6.5m – 200mm higher than 2017 – and narrowly escaped more widespread flooding. Source: Tweed Shire Council

Figure 3.6 Flooding in Tweed Valley Way, Source: Tweed District Rescue Squad Accessed at https://www.tweedvalleyweekly.net.au/flood-warning-issued-tweed-river/

Key impacts from the 2017 flood included:

- rainfall caused record peaks at Uki, Chillingham, Murwillumbah and Tumbulgum river gauges.
- Six people died.
- More than 2,100 homes flooded.
- Over 18,000 tonnes of household waste were collected.
- 30% of Council's fleet, workshop and stores were lost at Murwillumbah depot resulting in up to $7M worth of damage.

Drought

Drought is a recurring part of the Australian landscape and despite this, is one of the most feared and costly climate challenges (Bureau of Meteorology (BoM), n.d.). The impacts of drought can be widespread on the environment, people and the economy. The agricultural sector particularly can experience impacts through reduced water availability, crop failure and stock losses. Environmentally, drought impacts water sources, soil quality and the success and survival of flora and fauna communities. Droughts can also increase the risk of bushfires, dust storms, and land degradation. Communities suffer during drought across in numerous ways including resulting mental health issues, reduced availability and quality of food and water and reduced air quality. Droughts can also cost people, businesses, and governments where the impacts may be locally restricted to the drought area or more widespread to areas outside of the drought affected area. A range of sectors can also be impacted in different ways such as agriculture, energy production, tourism, and recreation.

Major droughts that have had widespread impacts on Australia include the drought of 1982–83 (referred to as the 'Great Dry'), and 1997–2010 (Millennium drought).

The drought between 1982-83 was experienced across Australia in every state and territory excluding Tasmania (Gibbs, 1984). The most severe impacts were felt in NSW. This drought resulted in 58% of NSW experiencing first decile rainfall (in the top 10% of lowest rainfall recorded) (Heathcote, 1988). This drought had large impacts to the agricultural industry with large-scale losses of crops and livestock. A total of 86 million sheep and 14 million cattle died as a result, wheat production fell by 37%, with similar falls in barley, oats, rice, cotton and sugar (Australian Disaster Resilience Knowledge Hub, 2011). Dust storms caused the loss of millions of dollars' worth of topsoil.

The Millennium drought also affected the whole of Australia and has been described as the worst drought on record for southeast Australia (van Dijk et al., 2013). The years between 2001 and 2009 were the longest uninterrupted series of years with below median rainfall in southeast Australia since at least 1900. El Niño contributed largely to this drought which ended when La Niña conditions resulted in high rainfall in 2010.

More recently, a major drought was experienced between 2017 to 2019. This drought had the greatest impact in NSW and southern QLD. Nationally, the gross domestic product was reduced by 0.7% and in NSW was reduced by 1.6% (Wittwer & Waschik, 2021).

Analysing historical annual rainfall patterns for Tweed indicated that the major drought years occurred in 1902, 1915, 1961, 1986 and 2019 (Figure 3.7) which are in the 10th decile meaning they are drier than 90% of the years on record. This recent drought of 2019 is further emphasised in drought indicator data which shows December 2019 as an intense drought (Figure 3.8).

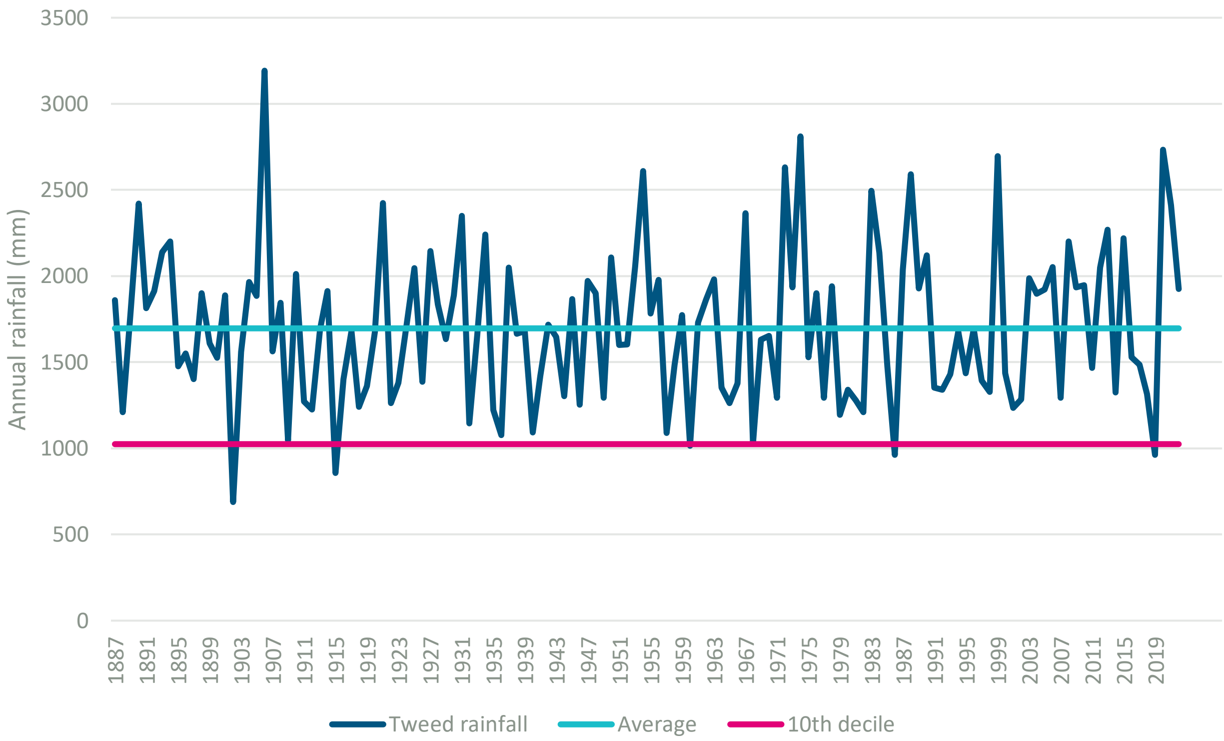


Figure 3.7 Annual rainfall at Tweed Heads Golf Club (BoM station 58056) showing 10th decile values to highlight drought years

The Department of Primary Industries published a nationwide Combined Drought Indicator (CDI) assessment parameter that allows for location specific trends to be compared and individually assessed. The CDI comprised of six categories where the lowest is non-drought up to the highest category where the affected area is classified with intense drought.

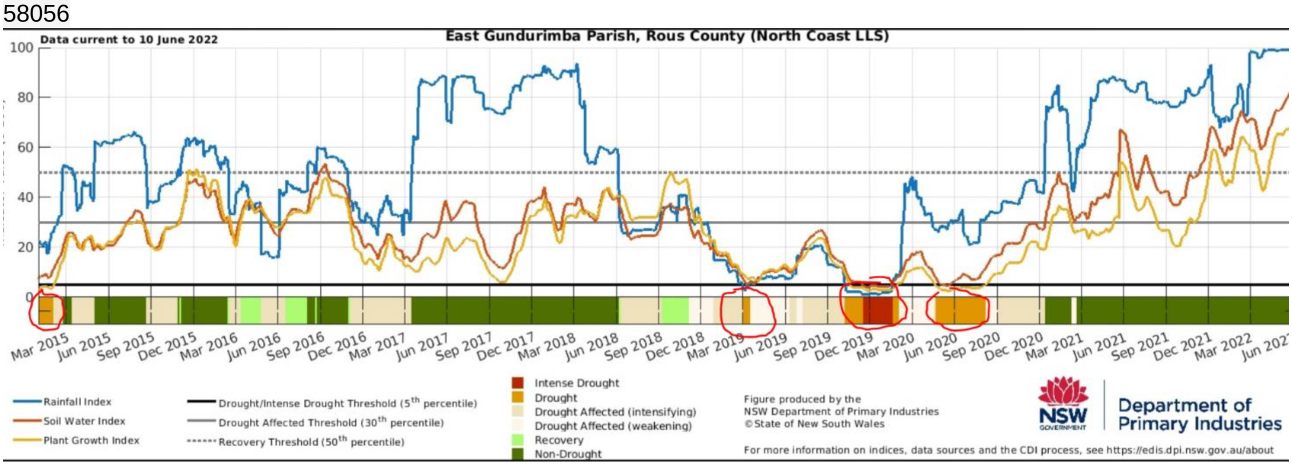


Figure 3.8 Drought indicator for North Coast (source: DPI)

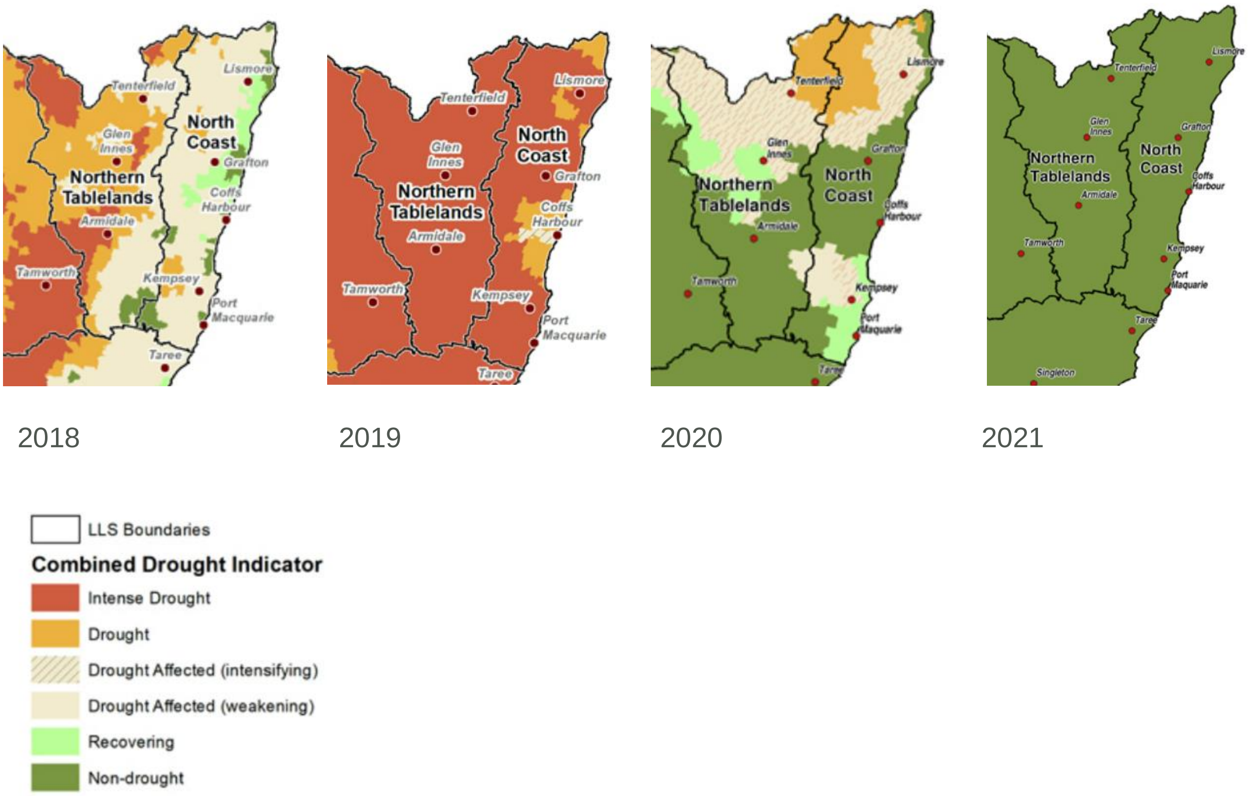


Figure 3.9 Drought conditions in the NSW North Coast between 2018 and 2021

Figure 2.10 shows the rainfall variability of the Tweed area and there are several years over the time of rainfall measurement when annual rainfall or monthly maximum rainfall are low, indicating drought conditions. Drought conditions can be highly variable, illustrated by the sequence of conditions between 2018 – 2021 (Figure 3.9). The drought conditions in the Northern Coast district and specifically in Tweed Shire were classified as drought affected but with a weakening effect in 2018. In the following year, the CDI identified the Tweed as experiencing intense drought, at a maximum of the CDI range. The whole region shifted towards an intensified drought affected area. In 2020 there was a slight decline in the severity of the drought, but Tweed Shire remained in the intensified drought category. In 2021 the whole North Coast area was classified as a non-drought affected area. Figure 3.9 illustrates that changes can occur rapidly. There is no gradual and gentle change, but it is a more extreme year-by-year phenomenon (Industries, 2022). Drought impacts in the Tweed

During January 2020, all of NSW was drought-declared. This led to water restrictions across the state, including in Tweed Shire. During the 2019/2020 water restrictions, the most significantly affected water users were businesses that derive their income from using large amounts of water outdoors, usually at other people's homes. Examples are car detailers, window cleaners, high pressure cleaners, dog washers, carpet cleaners. Council introduced a permit system to enable such businesses to keep operating, despite the restrictions in force. Approximately 90 permits were issued. Businesses were required to register their details with Council and log their water use on every job. The permit system reportedly alleviated significant potential stresses on these businesses.

Commercial and industrial properties using water indoors were not affected by the restrictions. Large industrial water users were asked to reduce their consumption if they could, without affecting their production rates.

Operationally, without water restrictions, the Tweed Shire water supply would have had about 12 months of water left. Imposing restrictions was likely to extend this by about 4 months. Fortunately, it rained in early 2020 and this was not tested.

The biggest impact on Council's infrastructure was at Tyalgum. Water had to be carted from the Tweed Shire water supply to the village of Tyalgum. During this time, the residents of Tyalgum reduced their average water consumption to about 140 litres per person per day.

In a response to the drought in 2019/20 the experiences and lessons learnt were used to develop the Tweed Drought Water Restrictions Policy. The Tweed Drought Water Restrictions Policy "covers a range of restrictions for all sectors connected to the public water supply and aims to minimise impacts on the community while reducing unnecessary water use as the restriction level increases". In broad terms the Policy focuses on reducing firstly outdoor water use, then residential water use and finally business water use.

- Outdoor water use is targeted first because:
- public health risks are not increased by reducing outdoor water use
- it is not feasible to enforce restrictions on indoor water use and leakage
- studies have found that many people reduce water use inside their homes as well when outdoor drought water restrictions are in place

Early reductions to residential sector water use are more severe than for business and commercial premises because:

- the residential sector accounts for the majority of usage in the shire
- there is less direct financial impact to the residential sector
- business and commercial premises and water users rely on the water supply to continue operating
- business and commercial premises should reduce water use but be allowed to operate as normally as possible, for as long as possible, without undue hardship
- the water efficiency of non-residential water users is specifically targeted under other programs and many of these premises are already efficient water users
- setting specific targets for business is not feasible because of the many variables affecting business water use such as type, size, occupancy, age etc.

A review of water demand by Tweed Shire Council found that by 2070 water demand is predicted to increase across its three service districts which includes a substantial increase in water connections. The three service districts are expected to have the following increase in demand by 2070 (Hydrosphere Consulting, 2020):

- Tweed: an increase of 8,400 ML/a (89%) to 17,872 ML/a
- Uki: an increase of 25 ML/a (42%) to 83 ML/a
- Tyalgum: an increase of 28 Ml/a (88%) to 59 ML/a

Sea level rise, saltwater ingress, and impact on water supply

Increased sea level and tidal anomalies have caused saltwater to overtop the weir at Bray Park. The Tweed River supplies town water to most of the Tweed Shire population, particularly the growing urban areas of Tweed Heads and the Tweed Coast. Water for the town water supply is extracted at Bray Park Weir, an artificial tidal barrier constructed on the Tweed River to prevent saltwater being transported upstream into the freshwater supply. Higher than expected tides (such as the 420 mm above predicted tides in August 2017) resulted in saltwater overtopping the weir (Tweed Shire Council, 2017b).

The saltwater contaminated the Tweed's freshwater. At this stage it was noted that the natural flow of the Tweed River would normally work against the tide and keep saltwater out of the weir, however, the coincident river flows were low (Tweed Shire Council, 2017b). Similar or greater intrusion events will potentially become more frequent with predicted sea level rise longer periods of low flows associated with climate change.

The saltwater ingress caused the raw water provided to the Bray Park Water Treatment Plant and the water supply to be contaminated. Although the level of salt contamination of the drinking water supply was not high and did not cause a health risk, immediate water restrictions were implemented. Council extracted the heavier salt laden water from the bottom of the weir and provided a continual release from the upstream Clarrie Hall Dam to refresh the weir pool.

Figure 3.10 Saltwater ingress in Bray Park Weir in 2017 (Source: Tweed Shire Council)

Bushfires

Like other hazards, bushfires can result in a wide range of impacts to the environment, community and economy.

Fire-management issues are a major threat to the Tweed Coast koala population due to, i) high intensity bush fires killing individual koalas, ii) peat fires causing widespread collapse of koala habitat, and iii) fire exclusion resulting in progressive koala habitat decline and displacement.

Tweed currently has approximately 4,470 ha of bushfire prone land which affects 16,054 properties or approximately 47% of all Tweed properties. Of those properties 5383 land parcels are within rural areas where approximately 20,000 Tweed residents live. Impacts to the community can be direct including loss of life, injury and damage or destruction of property. These may lead to mental health issues or short-term stressors but indirectly can result in smoke related illness and impacts to water availability and quality. Bushfires impact the economy through damage to agriculture, infrastructure, and assets.

The Tweed region is temperate to subtropical and although it can experience high rainfall it is also very seasonal with the dry months in August to October resulting in the bushfire season spanning from September to November. Within the Far North Coast area approximately 460 bushfires, grass fires scrub fires have been recorded (Far North Coast Bush Fire Management Committee, 2017). The main sources of bushfires are legal or illegal fires, arson and lightning strikes.

In Tweed, since 1968, the area of bushfire has approximately equalled or exceeded $10km^2$ on nine occasions. The period of 1991 to 1995 recorded 5 years in a row with significant fire activity, with 1991 have the highest fire damage at $37km^2$ (Figure 3.12), followed by 2019 with $25km^2$ (Figure 3.11). This period coincided with a very dry conditions in the Tweed Shire (Figure 2.10).

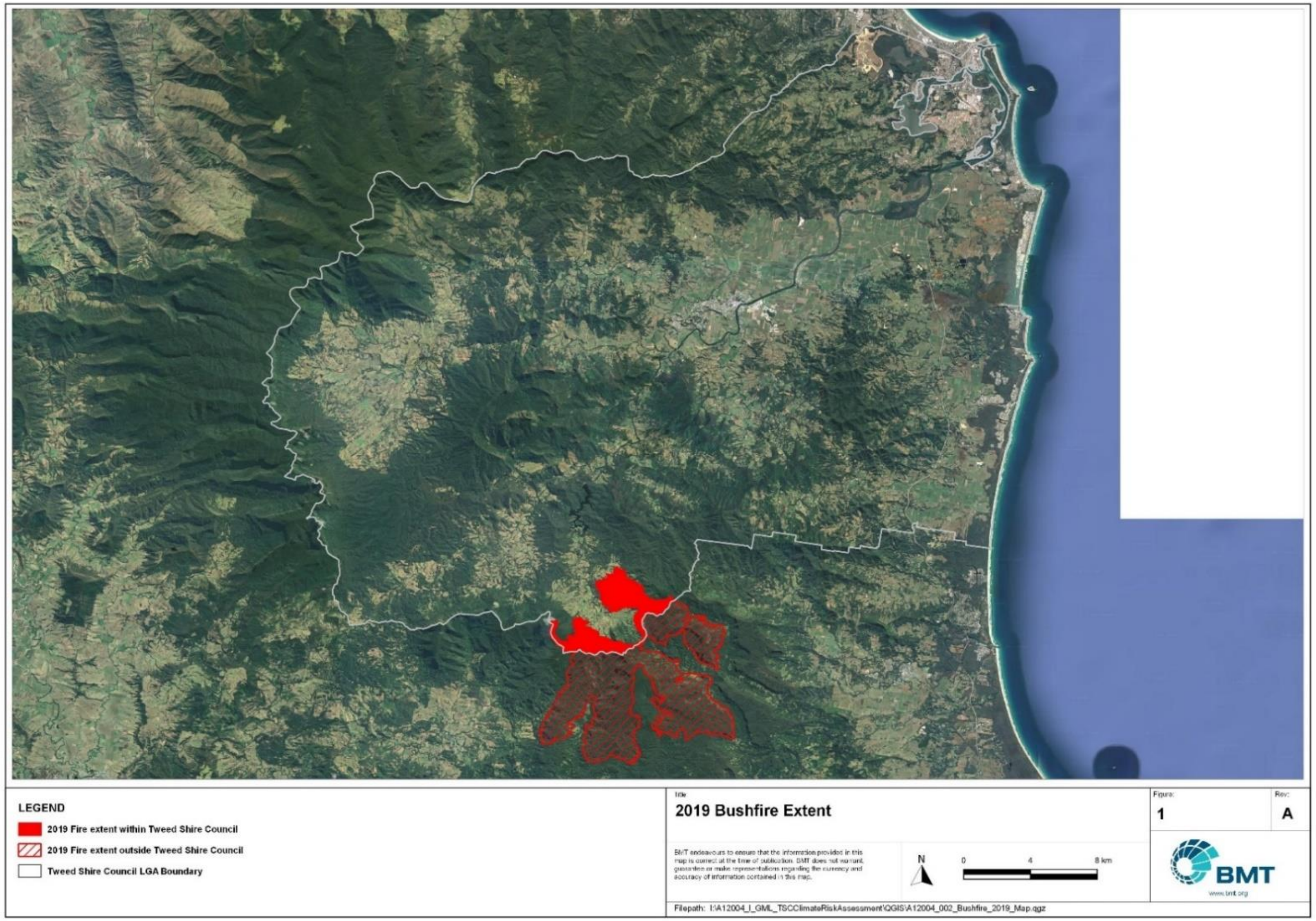


Figure 3.11 2019 Bushfire burnt area. Data Source (NSW Department of Planning & Environment, 2022).

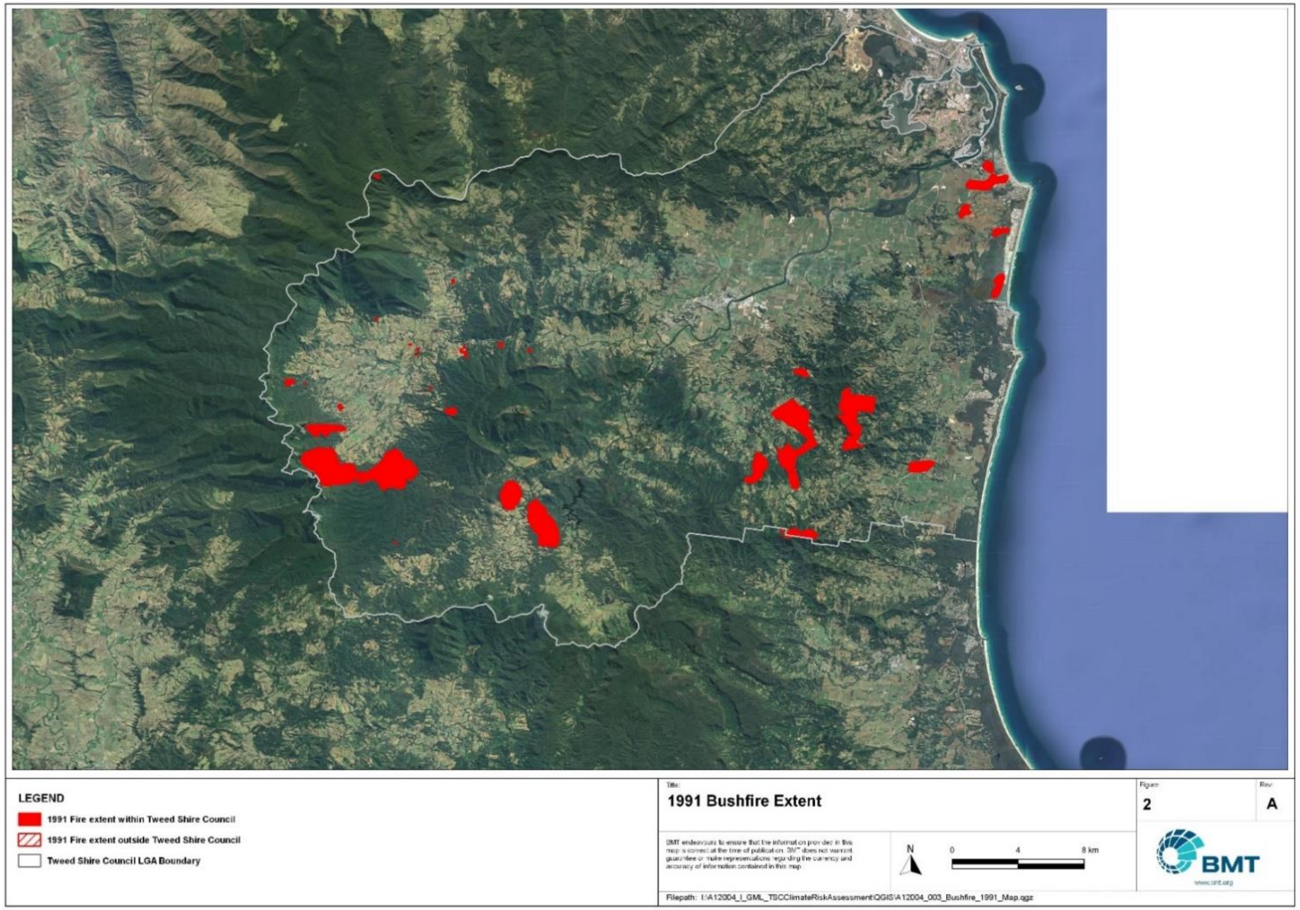


Figure 3.12 1991 Bushfire burnt area. Data Source (NSW Department of Planning & Environment, 2022)

4 Climate Change: Future projections

The greatest challenge in estimating how our climate will change in the future is to predict future human behavior: how will population grow, how will economies evolve, to what extent humanity will adopt sustainable practices (a shift to less carbon intensive fuels, lower meat consumption, reduction in deforestation etc.)? To address this challenge, scientists have developed future scenarios of change. Perhaps the best known of these at present are the RCP scenarios, as shown in Figure 4.1. RCP stands for Representative Concentration Pathways, and the four in Figure 4.1 range from RCP8.5, which is the highest level of greenhouse gases in the atmosphere, through to RCP2.6, which implies significantly lower emissions. At present, in terms of greenhouse gas emissions, humanity is tracking somewhere between RCP6.0 and RCP8.5.

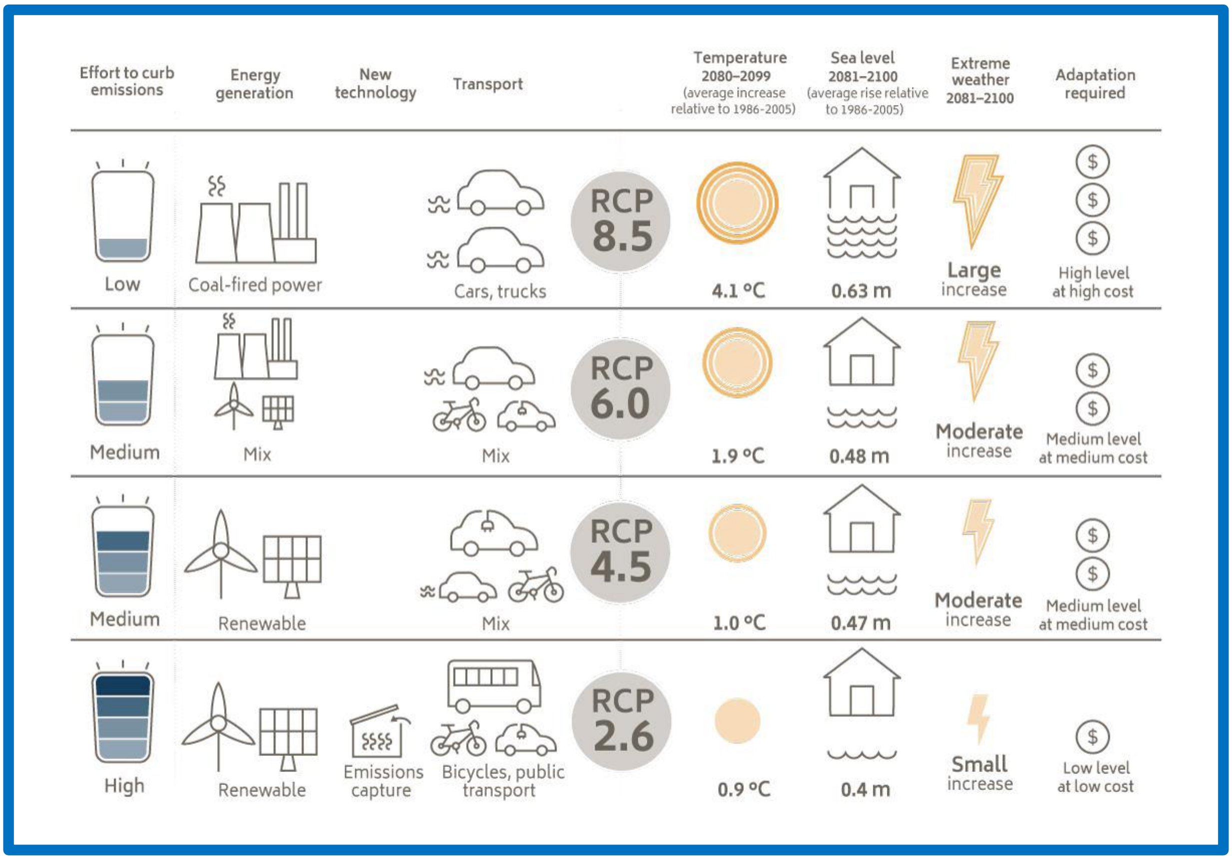


Figure 4.1 The Representative Concentration Pathways. Infographic taken from CoastAdapt. https://coastadapt.com.au/sites/default/files/infographics/15-117-NCCARFINFOGRAPHICS-01-UPLOADED-WEB%2827Feb%29.pdf. Accessed 9 October 2021

4.2 Temperature

The mean annual number of days with maximum temperatures greater than 30°C is currently 30 days in the Tweed. Under a high emission scenario this is likely to increase to 52, 74 and 134 days by 2030, 2050 and 2100 respectively. This will also increase the heatwave conditions in the Tweed. For example, the average of longest run of days in each year with maximum temperature greater than 30°C is currently 6 days in the Tweed. This is likely to increase to 9 days and 13 days by 2030 and 2050 respectively (Figure 4.2) and up to 28 days towards the end of the century.

Figure 4.2 Projection of temperature and heatwave conditions in the Tweed. Source: CoastAdapt using data from CSIRO.

International and Australian experiences show that prolonged hot days increase the incidence of illness and death – particularly among vulnerable population groups such as people who are older, have pre-existing medical conditions or those with a disability.

More severe conditions indicated by the number of days over 35°C will also increase in the Tweed. On an average between1981 and 2010 there was 0.83 days with such severe conditions. Under a high emission scenario (RCP 8.5) this is likely to increase by 2, 3, 6 and 12 days by year 2030, 2050, 2070 and 2090 (Figure 4.3).

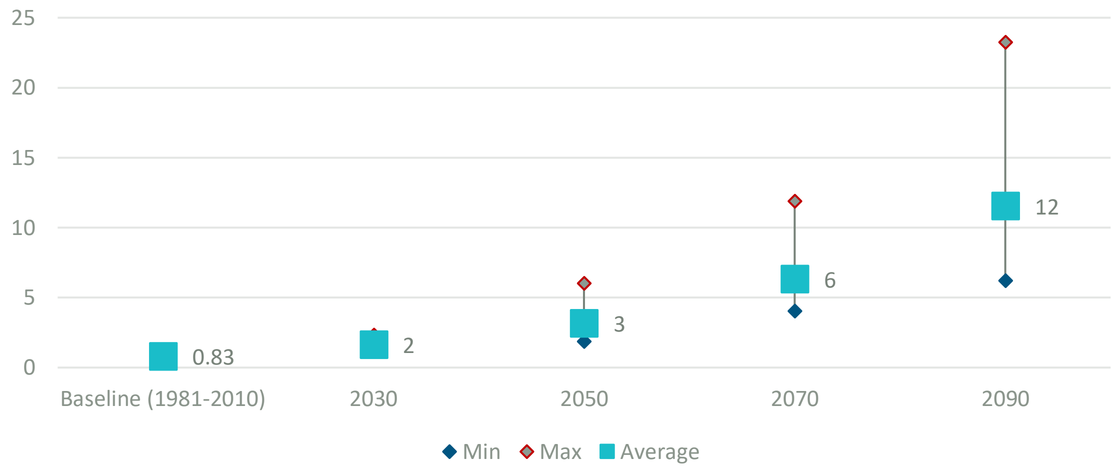


Figure 4.3 Annual average number of days over 35°C in the Tweed under RCP 8.5. Source Climate Change In Australia, Threshold Calculator by CSIRO. Teal rectangular boxes show average values and orange points shows the maximum possible values. For example, in 2050, there can be up to 6 days annually where temperature can be over 35°C

Highly urbanised areas create an environment that is divergent from the surrounding rural areas. Research has found that due to urban structures like buildings - along with roads, pavements, roofs and diminished vegetation cover – cities become warmer as more heat is absorbed in the materials during day and then released at night, which increases night-time temperatures. This creates an Urban Heat Island effect (UHI) not just on these surfaces but also in the atmosphere. This is more prominent during summer as temperatures rise. Figure 4.5 shows the distribution of land surface temperature in the Tweed (summer 2019) which shows built up areas with higher temperatures compared to surrounding non-built-up areas.

It is at night though, when UHI has its most negative influence on atmospheric heat extremes. Heat absorbed in urban structures during the day is slowly released after sunset compared to heat in vegetated areas. This results in much higher temperature shifts in the air overnight than in equivalent rural areas. Therefore, night-time minimum temperatures are also critical. Currently there are 0.43 days annually (between 1981 and 2010) where night-time minimum temperatures do not go below 25ºC in the Tweed. However, this is likely to increase to 1, 4, 12 and 24 nights in 2030, 2050, 2070 and 2090 (Figure 4.4).

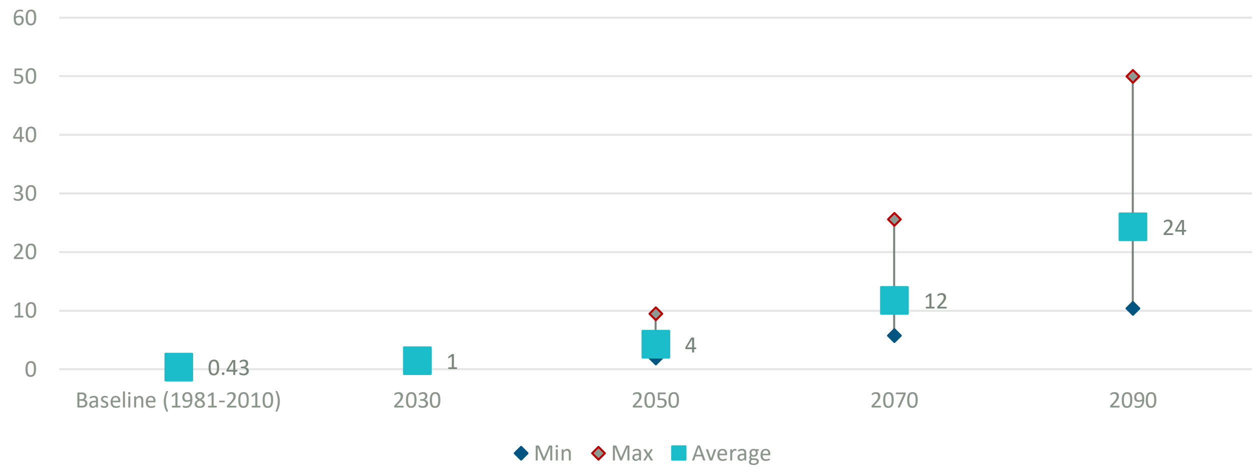


Figure 4.4 The annual number of nights where temperature will not come below 25°C in the Tweed under RCP 8.5. Source Climate Change In Australia, Threshold Calculator by CSIRO. Teal rectangular boxes show average values and orange points shows the maximum possible values. For example, in 2050, there can be up to 50 nights annually where temperature will not come down below 25°C.

Figure 4.5 Land surface temperature at Tweed Heads illustrating that built up areas have elevated temperature compared to non-built-up areas. Source: Landsat thermal imagery analysis between November 2019 and February 2020.

4.3 Rainfall and drought

For the Tweed Shire the majority of climate-based rainfall models agree that autumn and spring rainfall will increase, and winter rainfall will decrease in the near future (2030) and the far future (2070). However, the number of very wet days will increase. That is, when it rains, it is likely to rain heavily (Figure 4.6). This has significant implications for Tweed as high rainfall intensity in recent years has resulted in significant flooding in the region.

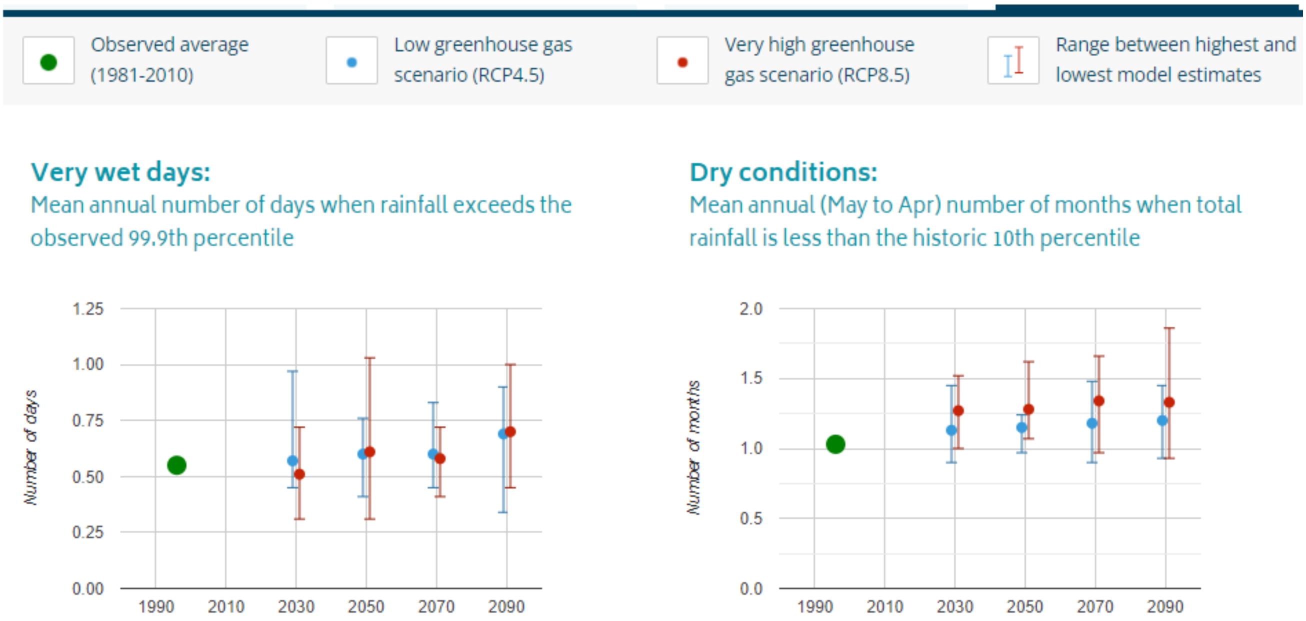


Figure 4.6 Projection of average rainfall and intensity in the Tweed Shire Source: CoastAdapt using data from CSIRO.

In general, Global warming is expected to increase the frequency of extreme El Niño events (below average rainfall) and extreme La Niña (above average rainfall) events (CSIRO & BoM, 2015).

4.4 Bushfire

Increased average temperatures and longer-term reduction of average rainfall and associated drying can create perfect weather conditions for bushfire. These conditions will increase he number of dangerous fire weather days and lead to a longer fire season for eastern Australia including the Tweed Shire. The Forest Fire Danger Index (FFDI) is used in NSW to quantify fire weather. The FFDI combines observations of temperature, humidity and windspeed. Fire weather is classified as severe when the FFDI is above 50 and most of the property loss from major fires in Australia has occurred when the FFDI has reached this level. Severe fire weather is projected to increase during summer and spring in the region by 2070. These increases are being seen during the peak prescribed burning season (spring) and peak fire risk season (summer). These conditions are likely to be experienced more in inland areas of the Tweed where there is dense vegetation.

Figure 4.7 shows the present-day FFDI at three locations on the NSW North Coast. The closest meteorological station to Tweed is at Lismore where the annual average FFDI is 4.9 days and the number of days where FFDI>50 is 0.3. By 2070 this number is likely to increase by a further 0.3 days (Figure 4.8). Although these changes in severe fire weather are relatively small in magnitude, they are projected to occur during prescribed burning periods (spring) and the peak fire risk season (summer) which means they may be influential.

Average FFDI					
Station	Annual	Summer	Autumn	Winter	Spring
Lismore	4.9	4.1	3.1	5.3	7.1
Casino	6.4	5	4.1	6.8	10
Coffs Harbour	3.3	2.8	2	4	4.3
Number of severe fire weather days (FFDI>50)					
Lismore	0.3	0	0	0.05	0.25
Casino	2.05	0.1	0	0.5	1.45
Coffs Harbour	0.25	0.1	0	0	0.15

Figure 4.7 Baseline FFDI values for meteorological stations within the North Coast Region.

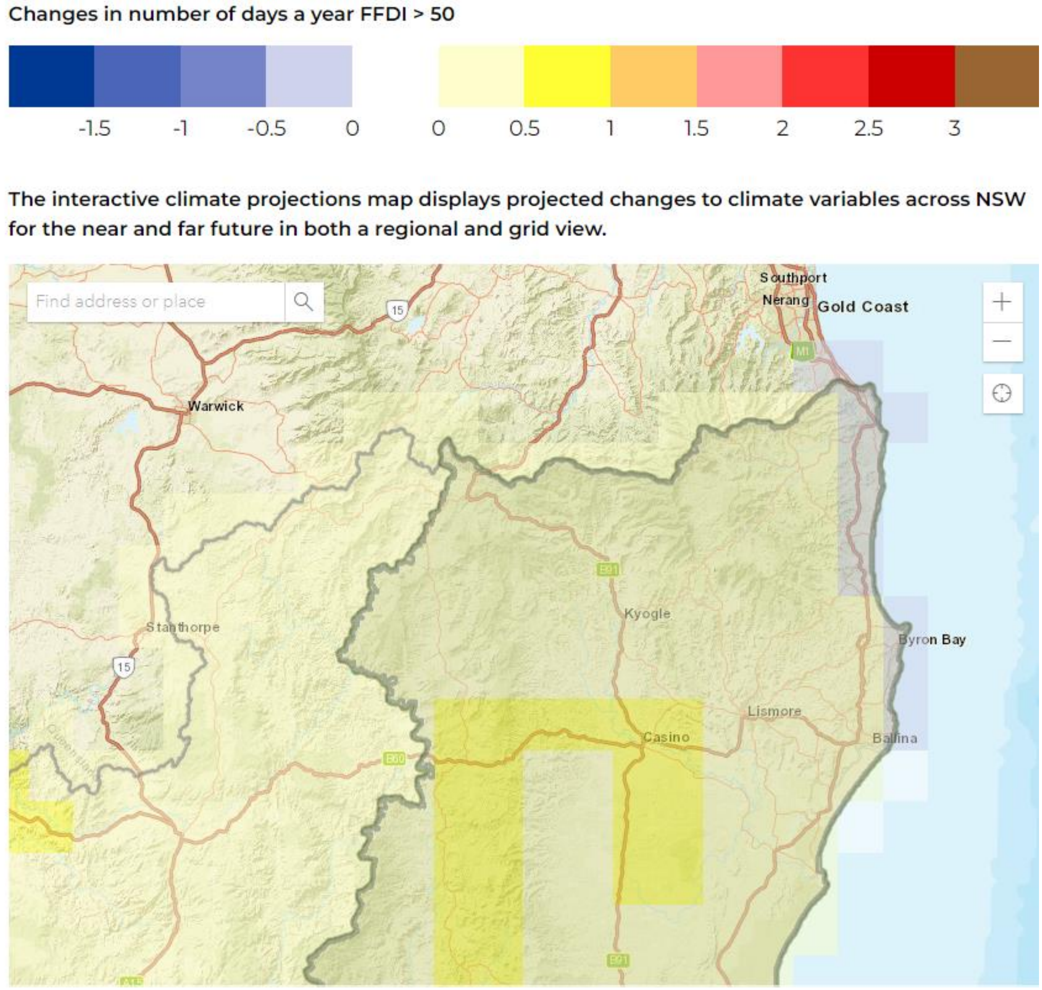


Figure 4.8 Changes in Forest Fire Danger Index (FFDI) in the Tweed region. Source: NARCliM NSW DPE.

4.5 Sea Level Rise

Climate change is a direct cause of rising sea levels. There are two principal contributing factors. First, warming causes the water in the oceans to expand, and hence the levels to rise. Second, the melting of land-based ice sheets and glaciers adds water to the oceans. A third relatively small effect is that any changes in the hydrological cycle have the potential to add volume to the world's oceans.

Global mean sea levels increased by 0.2m between 1901 and 2018. The average rate of rise has increased over time: between 1901 and 1971 it is estimated to have been 1.3 mm/year, but this increased to 1.9 mm/year between 1971 and 2006, with a further increase of 3.7 mm/year between 2006 and 2018. At the same time, the oceans are becoming more acid as they absorb carbon dioxide from the atmosphere, posing a risk to corals and to certain shell-forming animals (IPCC 2021a)

Satellite observation since 1993 shows that sea level has risen approximately 0.1m around Tweed (Figure 4.9). This trend is likely to continue with expected rise of 0.27m by 2050 and 0.66m by 2090 (Figure 4.9 and Figure 4.10). This can result in frequent inundation in some areas in Tweed as shown in SLR inundation maps created by CSIRO (Figure 4.11). The SLR inundation maps in Figure 4.11 are based on a high emissions scenario (RCP 8.5) of 0.77 m of SLR by 2100 (note this is different from 2090 projection of 0.66m). Sea-level rise (SLR) is combined with the nominal Highest Astronomical Tide (HAT) for the region to give an inundation level of 2.15 m above mean sea level.

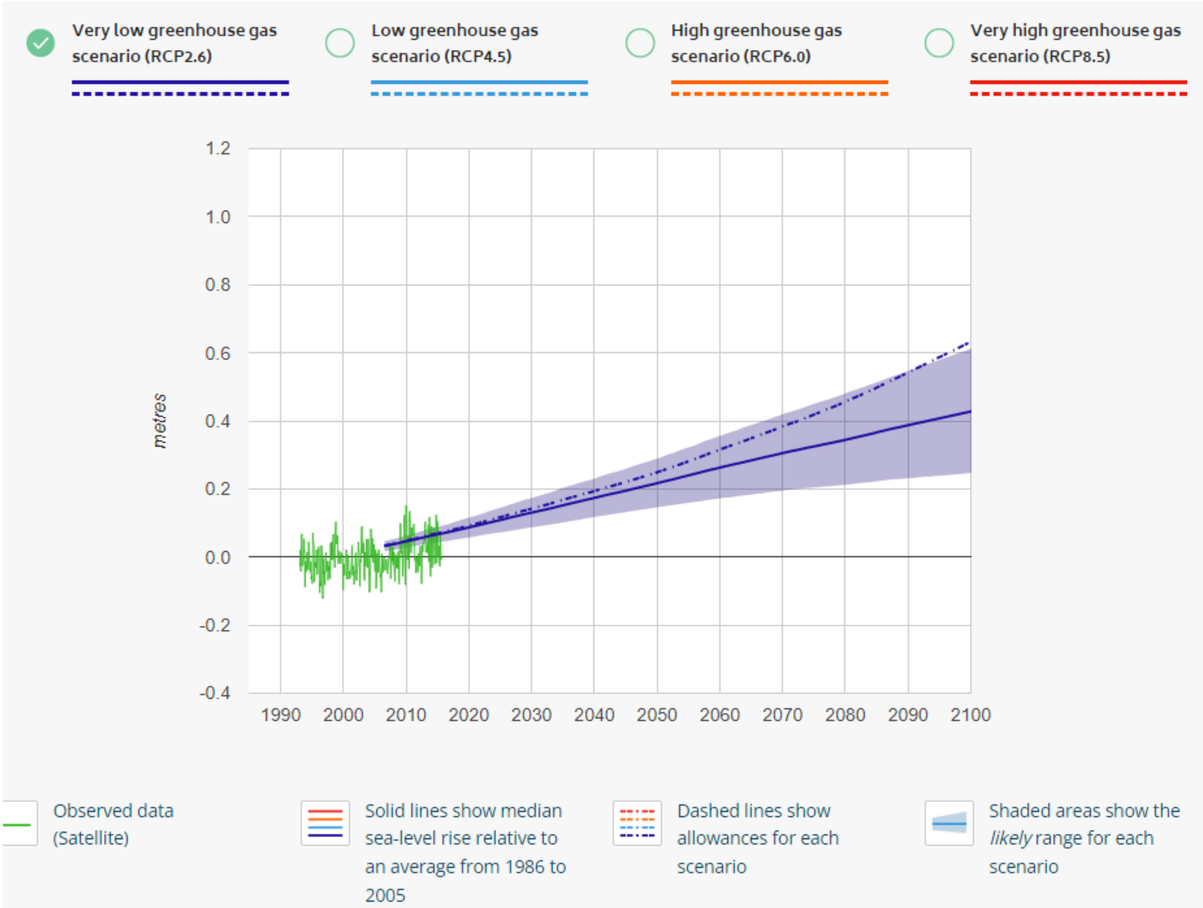


Figure 4.9 Sea level rise projections for the Tweed region under a very low emission scenario (RCP 2.6). Source: CoastAdapt using data from CSIRO.

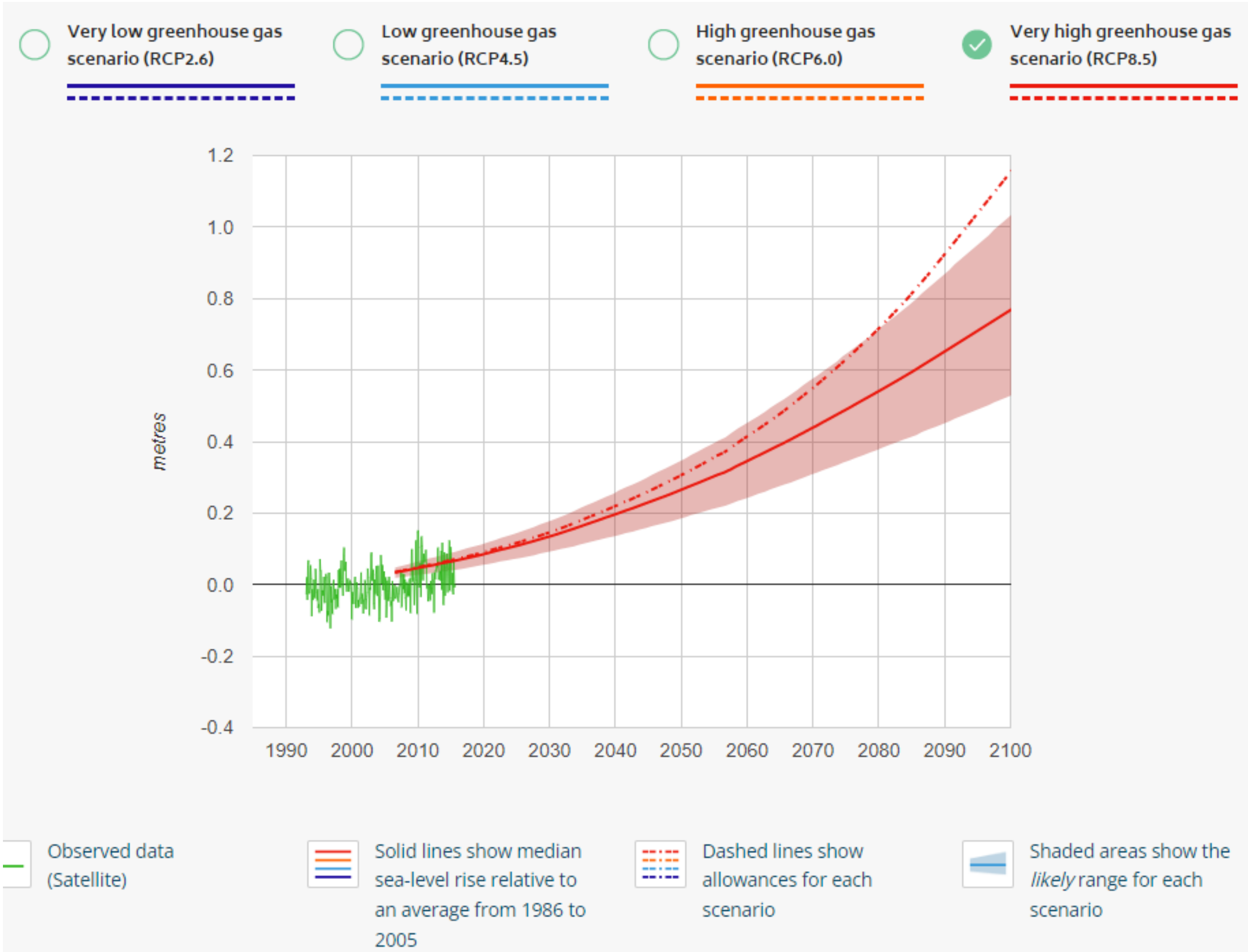


Figure 4.10 Sea level rise projections for the Tweed region under a very high emission scenario (RCP 8.5). Source: CoastAdapt using data from CSIRO.

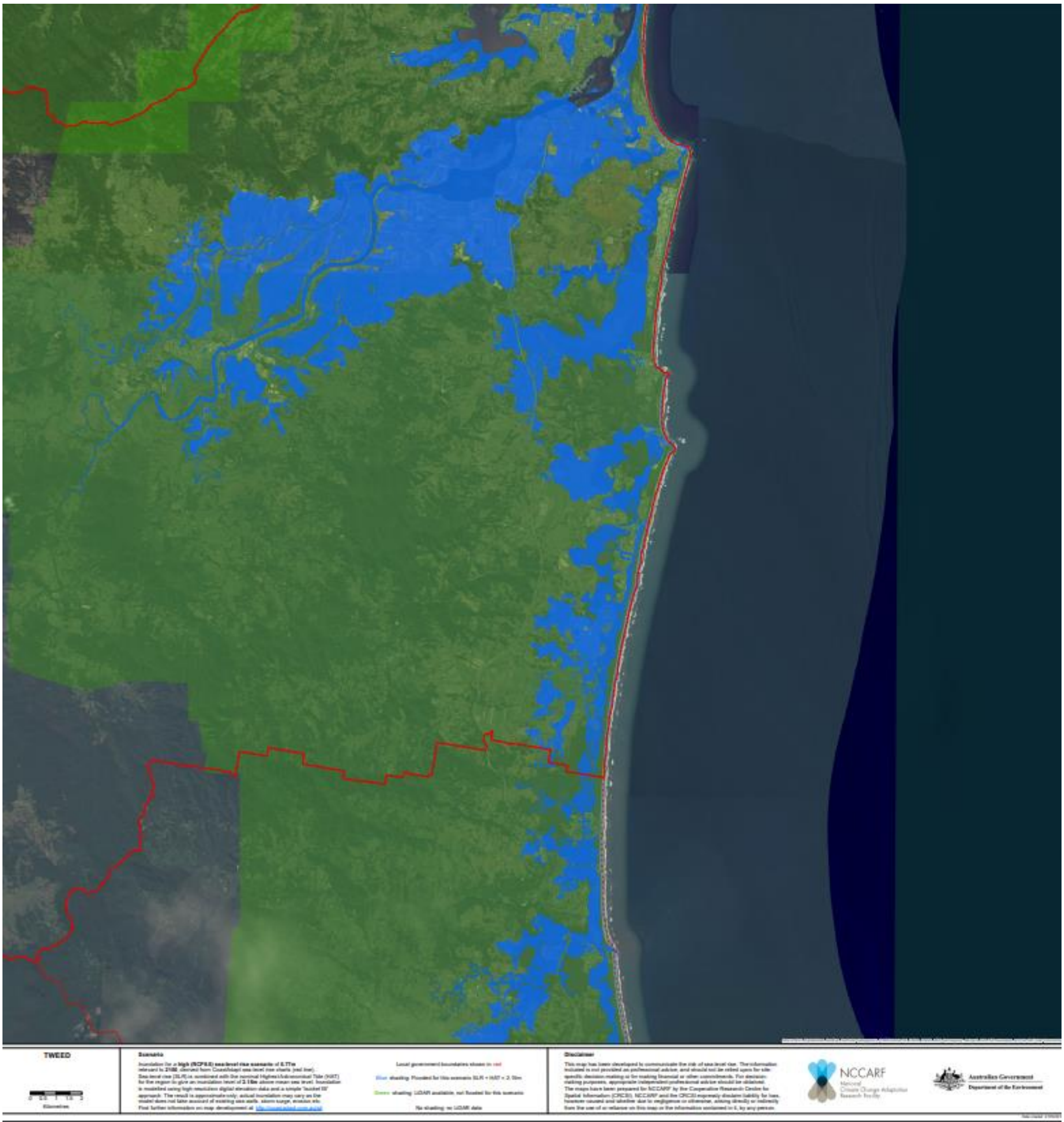


Figure 4.11 Sea level rise projected inundation map for Tweed Shire under a high emission scenario. Source CoastAdapt

4.6 Summary of climate change projections in the Tweed.

Table 4.2 Summary of climate change projections in Tweed.

Hazard	Present day climate	Future climate (High emission scenario)
High temperature (days over 30ºC)	• 30 days on average annually • In the last 34 years, coastal areas of Tweed have had an average of 16.6 days per year of temperatures above 30ºC while inland areas (Murwillumbah) in the past 46 years had an average of 56.6 days per year over 30ºC. • January has the highest average number of days over 30ºC for both areas.	• 2030: 52 days • 2050: 74 days • 2100: 134 days
Heatwave (continuous run of days over 30°C)	• 6 days average annually • 11 of the last 13 years have had >8 days of heatwave conditions	• 2030: 9 days • 2050: 13 days • 2100: 28 days
Rainfall (annual average)	• 1510 mm with February and March having the highest monthly rainfall averages for inland (Murwillumbah) and coastal areas respectively. • Highest monthly rainfall recorded was 702 mm in February 2020	• 1.6% increase by 2040 • 8.2% increase by 2080 • Less rain in Summer & Winter and more in Autumn and spring. • Very wet days will increase.
Bushfire	• The frequency of the most dangerous 10 per cent of fire weather days has increased significantly in the Tweed region. This increase varies from 20 to 25 days compared to 1985.	Severe fire weather (annual average days where FFDI>50) is currently 0.3 days in the region which is projected to increase during summer and spring by 0.1 days by 2040 and 0.3 days by 2070
Sea level rise	• Tweed region: increased 0.1 m since 1993 • Global mean sea levels increased by 0.2 m between 1901 and 2018	Mid-range of SLR projections are below. 2030:0.14 m 2050: 0.27 m 2100: 0.66 m High range of SLR projection at 2100 is 0.88m

5 Impacts of climate change on the Tweed's ecosystems and its community.

5.1 Ecosystem

Climate change is expected to have a range of impacts on the environment and associated ecosystems. Key impacts for the Tweed Shire include:

- heatwave impacts for flying foxes and other wildlife (including koalas, black cockatoos, bees and butterflies)
- the impacts on forests from drought, bushfires, and sea level rise
- changes to coastal wetlands (mangroves, saltmarsh and brackish water systems)
- landslides and loss of mature trees
- impacts of flooding such as erosion and disturbance of riparian areas, flood debris impacting water quality and ecosystems, and disturbance of habitat for wildlife
- changes in range for marine sea turtle nesting
- loss of foreshore and dune habitat
- changes to the distribution and abundance of species in the marine and terrestrial environments.

Here are some of these implications for the Tweed as a result of some of these impacts.

Heatwave impacts for flying foxes

Flying foxes play an important role in the Australian landscape including pollination and seed dispersal, both of which increase the resilience of ecosystems to environmental change. It is expected that environmental, social and economic shifts from climate change will impact wildlife, particularly though extreme events. Flying foxes are susceptible to heat stress resulting from extreme heat events. Heat stress occurs in flying foxes when temperatures reach 38°C and particularly when temperatures exceed 42°C (Queensland Government, 2022). The susceptibility of flying foxes to heat stroke is also related to the relative humidity, the species (some species are more susceptible than others) and their metabolic activity. As described in Section 4.2, the number of heatwaves is predicted to increase in the future increasing the exposure of flying foxes to extreme heat. Other wildlife also experiences heat-related mortality (including koalas, black cockatoos, bees and butterflies).

Heat related mortality in flying-foxes has been well documented in Australia due to their conservation significance and the visibility of the impacts at their daytime camps. Some of the key heat-related mortality events include:

- 1994-2008: Welbergen et al., 2008 estimates that 30,000 flying foxes have died in 19 heat waves across Australia
- 2009: Black Saturday bushfires in Victoria resulted in 5,000 dead flying foxes in Victoria
- 2013: heatwaves resulted in 10,000 flying fox deaths

- 2015: The worst heat related flying fox mortality was recorded in 2015 in South-East Queensland where a single hot day (temperatures up to 44.6°C) resulted in 45,000 flying fox deaths. These deaths were recorded in 52 of the 162 colonies that were assessed with the black flying fox (*Pteropus alecto*) accounting for 96% of the deaths.

Impact of drought and bushfires on rainforests and cloud forests

Rainforests and cloud forests are diverse ecosystems that contain a range of unique species of fauna and flora and provide a multitude of ecosystem benefits. The rainforests of the Tweed are part of the world heritage listed Gondwana Rainforest. The ecosystems of the Gondwana Rainforests contain significant and important natural habitats for species of conservation significance, particularly those associated with the rainforests which once covered much of the continent of Australia. It is expected that climate change will have a multitude of impacts on rain forests through both changes in every day climatic conditions and natural disasters. As described in Sections 4.3 and 4.4, there is likely going to be an increase in frequency in droughts and bushfires in the region which will impact rainforests and cloud forests. This is supported by research from Baumen et al. (2022) who have already recorded that an increase in atmospheric water stress is increasing tropical tree mortality. This study observed a mortality in a plot of rainforest trees to double, which has been attributed to a decrease in atmospheric moisture. With an increase in drought frequency predicted with climate change, this may increase the mortality of rainforests further in the future. Local species throughout the Tweed region are likely to be impacted due to drought and reduced water availability, particularly in species such as Antarctic Beech (*Lophozonia moorei*), Nightcap Wattle (*Acacia orites*) and brush box (*Lophostemon confertus*).

As atmospheric moisture decreases, this increases the potential likelihood and severity of bushfires. The Department of Planning, Industry and Environment (DPIE) (2020) estimated that approximately a third of NSW rainforest was burnt in the 2019/20 bushfire season. This included a wildfire within the Mt Nardi National Park adjacent to the Tweed Shire Council LGA.

With changing climatic conditions, the extent of rainforests may reduce or change in response to new climatic gradients and increased frequency of extreme weather events.

Impacts of sea level rise on coastal wetlands

Coastal wetlands (including seagrass, salt marsh, mangroves and freshwater environments) evolve due to the complex interaction of physical and ecological processes. Sea level rise, and its acceleration, will change the spatial distribution of coastal wetlands. In some areas sea level rise will influence tidal wetlands to migrate landward, however it has been predicted that saltmarsh will significantly reduce in area, being squeezed between rising tides and adjacent landforms. Fresh water wetland extent may reduce due to saltwater intrusion into the groundwater table and droughts reducing freshwater availability. An important factor to consider on the low-lying Tweed River floodplain will be the issue of drainage retardation, as rising sea levels affect flood gate opening times on existing drains.

Coastal wetlands in the Tweed are likely to be impacted by sea level rise. When this is extended to consideration of all estuarine, wetland and floodplain communities.

Under all emissions scenarios considered in the IPCC6 report, coastal wetlands will likely face high risk from sea-level rise in the mid-term, with substantial losses before 2100. These risks will be compounded where coastal development prevents up shore migration of habitats or where terrestrial sediment inputs are limited, and tidal ranges are small. Loss of these habitats disrupts associated ecosystem services, including wave-energy attenuation, habitat provision for biodiversity, climate mitigation, and food and fuel resources. Near- to mid-term sea-level rise will also exacerbate coastal erosion and submersion, and the salinisation of coastal groundwater, expanding the loss of many different coastal habitats, ecosystems, and ecosystem services.

Landslides and loss of mature trees

Climate change will likely have an effect on the location, frequency and severity of landslides through changing precipitation patterns and subsequent changes in soil moisture. Mature trees take many years to grow, if not decades, therefore losing these in a landslide is not only detrimental to the ecosystem but the loss of mature trees may also make an area more unstable and prone to landslides in the future.

Changes in range for marine sea turtle nesting

Climate change has the potential to threaten marine turtles at all stages of their lifecycle. These impacts include altering sea temperatures (change ocean currents and the location/quality of marine habitat), increase sea levels may erode beaches making them not viable nesting locations and changes in temperature of beaches may alter gender ratios resulting in a shortage of male turtles. The Tweed provides feeding, foraging and nesting habitat to marine turtles and therefore, changing climates may impact turtle habitat into the future. Higher sea-levels can lead to loss of beaches because of inundation, which can impact turtle nesting.

Loss of foreshore and dune habitat

The loss of dune vegetation is a major trigger for dune erosion. Dune vegetation traps windblown sand and holds it on the foredunes. The exposed, dry sand is easily mobilised by high-velocity winds and large volumes of sand can be rapidly transported, sometimes forming large depressions in the dunes termed blowouts. Downwind from blowouts, drifting sand can smother the surrounding vegetation and cover roads and properties. Dune vegetation also contains many native species and is valued as habitat and for its own intrinsic biodiversity. Beaches and dunes are important feeding, breeding and roosting grounds for sea turtles and shorebirds. Sea level rise can induce erosion of dunes resulting in loss of foreshore and dune habitats in the Tweed.

Changes to the distribution and abundance of species in the marine and terrestrial environments.

Tweed Shire’s coastal areas contain a wide range of freshwater wetlands, which support a high diversity of plants and animals and provide many important ecosystem goods and services to people. These wetlands are subject to high levels of exposure to changes in climatic drivers due to their position in the landscape. As low-lying ecosystems at the interface of terrestrial, marine and freshwater realms, these wetlands experience changes both directly and via the effects of changes in other connected ecosystems. Freshwater wetlands are also typically exposed to a wide range of extreme events, including floods, droughts and fires, all of which are expected to change in frequency and intensity. Coastal freshwater biota are likely to be especially vulnerable to climate change impacts due to their high likelihood of exposure and sensitivity to the key drivers expected to change, as well as the high level of non-climatic pressures which they face.

Climate change is already changing and will continue to change the distribution of terrestrial and marine species along the east coast of Australia with species moving southwards as the climate warms and as the East Australian Current strengthens. These changes will gradually influence ecosystems in the area.

In the coastal marine environment and intertidal and subtidal coastal habitats, ocean acidification is likely to result in further ecological impacts by reducing the growth and survival of the many organisms which rely on dissolved carbonate to build their shells or skeletons, with significant ramifications for the food webs which rely on them. Ocean acidification may also directly affect the development and metabolism of non-calcifying marine organisms.

In terrestrial coastal ecosystems, e.g., dunes and headlands, CO2 fertilisation may lead to vegetation thickening and encroachment of grasslands by shrubs.

Changes to catchment runoff and associated effects on receiving waters

Changes in the frequency and intensity of extreme events will further affect coastal ecosystems in all realms both directly, e.g., via mechanical damage to organisms or effects on sediment dynamics, and indirectly, e.g., by influencing the quantity and quality of terrestrial runoff entering coastal ecosystems.

Heavy rainfall often results in turbid flood plumes that reduce available light for seagrasses (Longstaff and Dennison, 1999; Campbell and McKenzie, 2004; McKenzie et al., 2012). Elevated nutrient levels transported to the nearshore environment by floods can promote phytoplankton and epiphyte growth, further limiting the light and oxygen available to seagrasses (McKenzie et al., 2012).

Longer periods of drought and reduction in rainfall has been noted to be influencing the physical dynamics of ICOLLS at times because of reduced flows causing them to open to the sea less frequently (Scanes et al., 2020). Reduced inflows for long periods will also result in nutrient and sediment plumes from estuaries being closer inshore and therefore closer to shoreline habitats. This may have implications for the health of these systems.

Changes to fire seasons and fire severity

Hotter dryer conditions on the coastline that result from climate change will result in altered fire regimes which is likely to affect vegetation communities in these coastal ecosystems and the habitat they provide to fauna.

Cumulative stressors

Cumulative stressors and extreme events are projected to increase in magnitude and frequency and will accelerate projected climate-driven shifts in ecosystems and loss of the services they provide . These processes will exacerbate both stress on systems already at risk from climate impacts and non-climate impacts like habitat fragmentation and pollution. Increasing frequency and severity of extreme events will decrease recovery time available for ecosystems (high confidence).

5.2 Impacts to communities

The NSW Government commissioned Integrated Regional Vulnerability Studies (IRVA 2016) for the North Coast which identified a number of key climate change impacts to the community of the Tweed region. Some of the highlights are summarised below.

Population demographics

Population demographics are an important driver of vulnerability to climate change impacts in the Tweed Shire. Major demographic trends in the region that are influencing vulnerability include an aging population, population growth driven by retirees and migration, loss of youth, seasonal fluctuations and the relatively large alternative community lifestyle. The population trends between 2016 and 2021 for the Tweed region are shown in Figure 5.1.

Australia as a whole has an aging population due to decreased birth rates and longer life expectancy. By 2031 the NSW population over the age of 65 is projected to increase from 15% at present, to 20%, while for the North Coast this will increase from 20% to 30% (DPE 2014). An aging population alters the vulnerability profile of the area as people over the age of 65 years are generally more vulnerable as they are more susceptible to heatwave impacts, typically require more health services, have higher mobility issues and lower economic capacity to recover.

Disabilities

People with long-term health conditions or disabilities are considered vulnerable populations as they are more susceptible to natural disasters such as heatwaves, floods etc. and require more health services and may have limited mobility or difficulty evacuating. In the 2021 census in the Tweed Shire region, 59% of people reported having a long-term health condition which is significantly higher than the NSW or Australian proportion (48% and 49% respectively). Vulnerable social groups have complex needs and providing services that meet these needs is expensive.

Migration

People migrating from other countries or locations in Australia lack local knowledge and therefore may not be aware of local hazards and events and on tried and tested ways of responding to them. Residents emigrating from major cities and large centres have high expectations around delivery of government services. These expectations are often not matched by the level of service available on the North Coast, making them less resilient.

Having a high tourism industry also means the Tweed Shire may have large influxes of people which poses significant challenges for the region as infrastructure and services need to meet the peak demand, yet the costs of providing for the demand must be met locally. Transient school student numbers associated with workers and families temporarily relocating to the North Coast for the staged upgrade of the Pacific Highway made education planning difficult as school funding is tied to permanent student numbers. Climate change is likely to add complexities to these existing pressures.

Housing

The majority of dwellings (84.9% of dwellings) in the Tweed are separate houses or townhouses with only a small percent (12.8% of dwellings) being units or flats. Communities have a preference for single houses on larger blocks which increases the land required to meet the housing demand. The desire for larger blocks impacts the regions natural resources and landscape by impacting adaptive capacity of natural systems. The limited space in coastal towns also constrains the ability to move gravity fed sewerage treatment and pump stations out of flood and inundation areas.

Economy

The socio-economic status of people and communities impacts their ability to respond and recover to natural disasters. The Tweed personal, family and household income is significantly less than both the NSW and Australian median weekly incomes. For example, the Tweed median weekly household income in 2021 was $1,296 compared to the NSW and Australian median weekly income of $1,829 and $1,746 respectively,

Insurance

Climate change impacts (repeated extreme events) and adaptation responses were identified as putting upward pressure on costs and leading to loss of revenue to the state government, community and businesses on the North Coast. These increasing costs are linked to increased costs of maintenance and insurance, increasing the costs to businesses and the community changes in insurance premiums leading to potential of under-insurance of private assets.

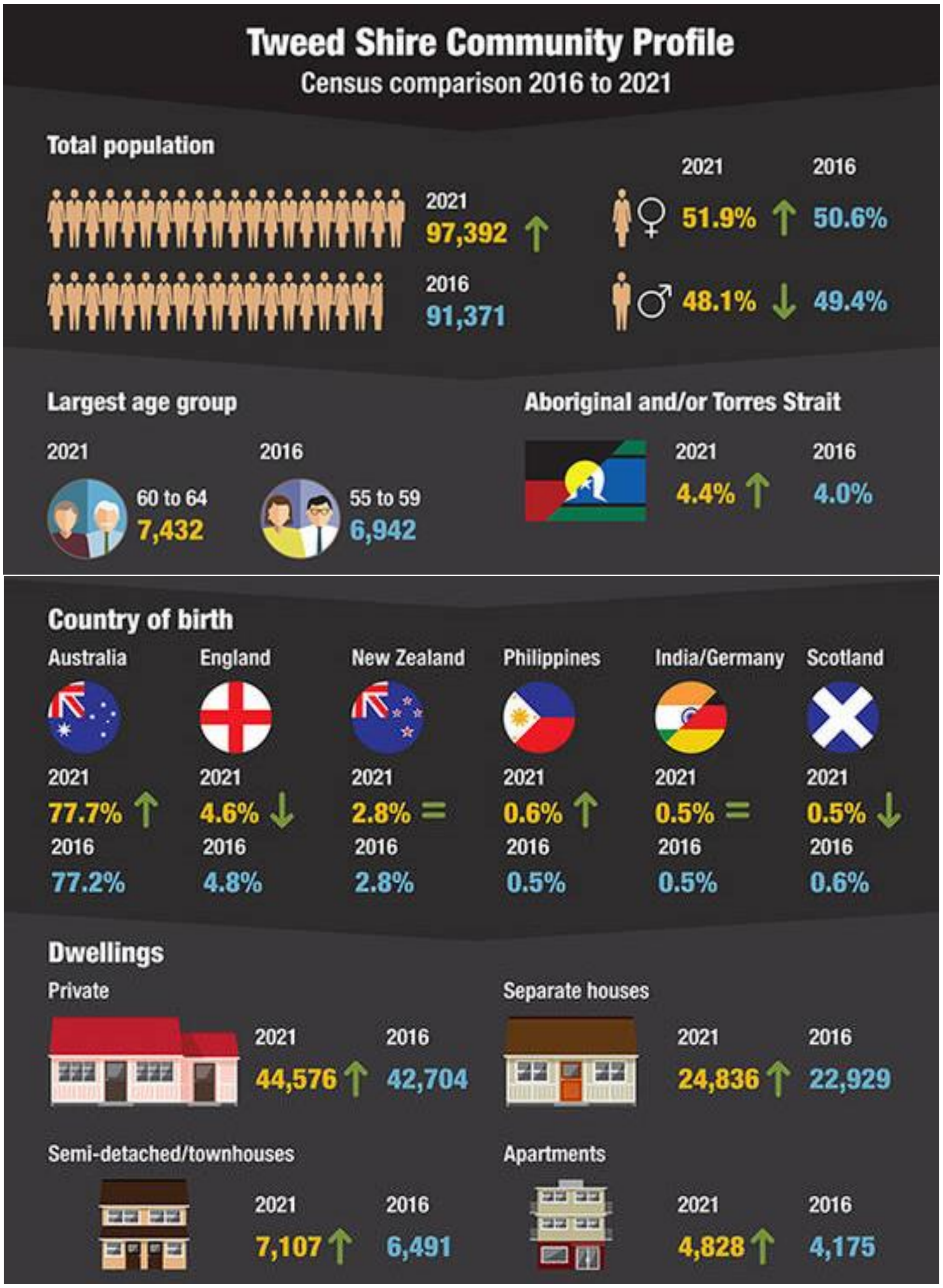


Figure 5.1 Change in community profile between 2016 and 2021 in the Tweed (Source: Tweed Shire Council 2022)

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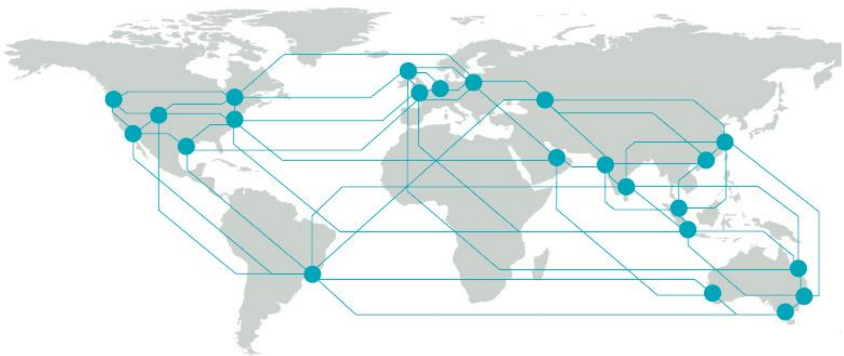

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