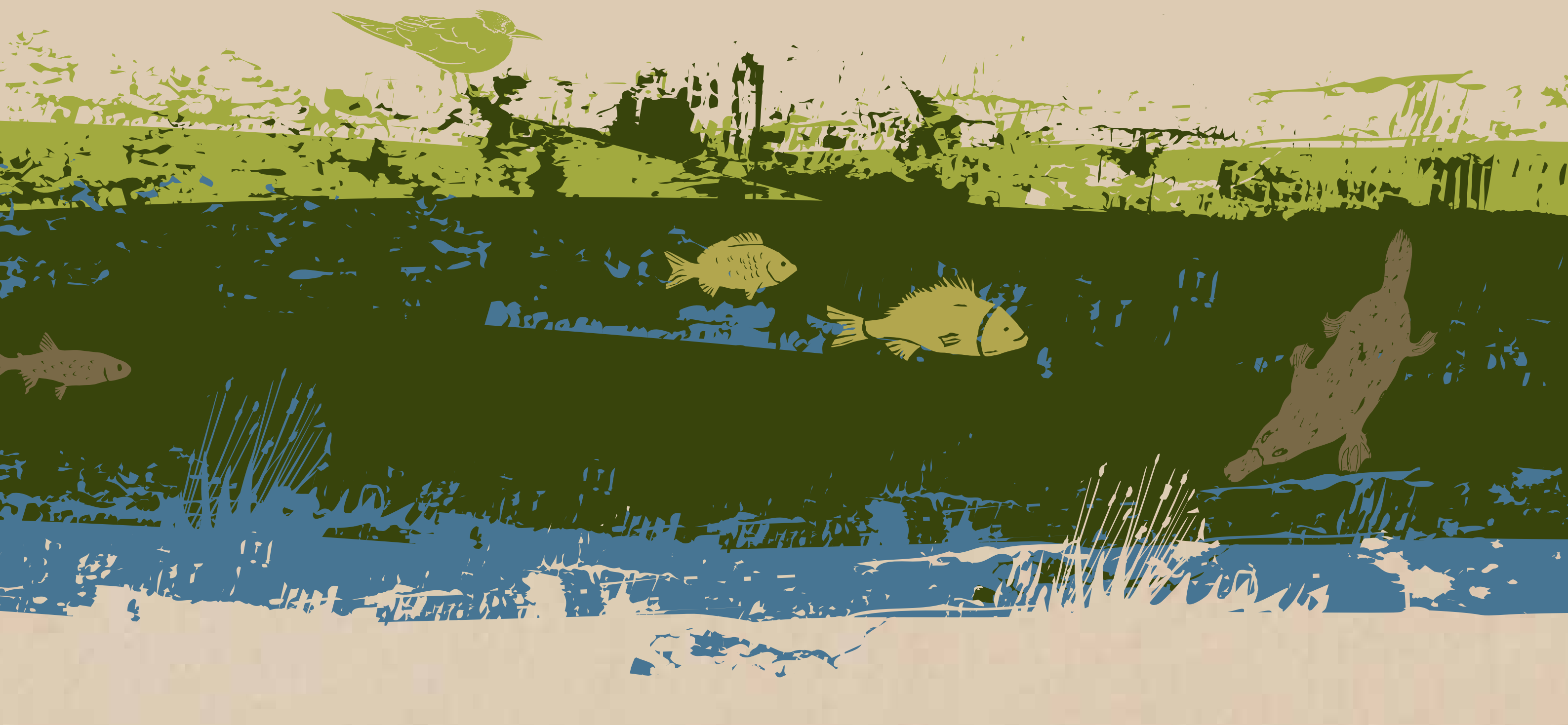
CORANGAMITE CMA

EstuaryWatch

Data Analysis and Interpretation

Painkalac Creek Estuary

2007-2013



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Special thanks to the volunteers of the Painkalac Creek EstuaryWatch group as without all their hard work this report and subsequent work would not be possible.

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Introduction

The Painkalac Creek Estuary is a beautiful coastal lagoon system located in south-west Victoria along the Great Ocean Road at the township of Aireys Inlet (Figure 1). The Painkalac Creek begins in the Otway ranges at an elevation of 430m in the deeply-dissected rolling hills at the north-eastern end of the Otway Ranges, it flows mostly in an easterly direction for 20.3 km and it enters Bass Strait, on the south-west side of Aireys Inlet. The Painkalac Creek has a total catchment area of 6,133 ha, including the creek's main stem and the Distillery Creek sub-catchment, which meets Painkalac Creek about 4 km upstream of the estuary mouth and 200m south-west of the Old Coach Road crossing. The estuary is approximately 3.6 km long, has an area of 16.2 ha and is classified as a wave dominated strand plain (Ozcoasts, 2013.) It opens intermittently but the majority of the time its closed to the sea.

Discharges from the Painkalac Reservoir (Figure 2) largely control river flow to the estuary. The Painkalac Creek passes through the reservoir site at 29.79m above sea level approximately 7 km upstream of the estuary mouth. The Painkalac Creek reservoir was constructed in 1978 and has a capacity of 532 ML and supplies the townships of Aireys Inlet and Fairhaven. The reservoir's catchment extends to 11 km west and has a total area of about 3,420 ha.

Barwon Water's current bulk entitlement allows a maximum harvest of 317 ML a year from the reservoir through the bulk entitlement (Aireys Inlet) Conversion Order 1997 (Barwon Water, 1997). Under the bulk entitlement, the maximum diversion rate allowed is 2.94 ML/day. Passing flows are specified as March to November, the lesser of 0.5 ML/day of inflow and December to February, entire flow. Therefore, no storage of water is permitted during the December to February period, and the passing flow during this period must match the inflow to the reservoir. Some of these summer passing flows are not attainable if inflows are above 3-5 ML/day due to the size of the outlet pipe, unless the reservoir is at capacity, whereby flows are directed over the spillway.

The upper catchment of Painkalac Creek above the reservoir is entirely forested being within the Great Otway National Park. Below the reservoir the lower part of the Painkalac Creek valley was largely cleared of woody vegetation early in the 1800s and much of the cleared land is used for grazing. The estuary floodplain has been largely cleared of vegetation and is also used for grazing. Additionally, the encroachment of the Aireys Inlet township, surrounding the estuary, resulted in residential development within the floodplain which is constantly at threat of flooding during times of high water levels.

The environmental values associated with Painkalac Creek Estuary include a diverse range of plant, bird, reptile, frog, and fish communities. Many of these organisms are dependent on a range of different physico/chemical variables often observed in an estuarine environment, such as river flow, flooding, changes in salinity, salt wedge movement and good water quality.

Many plant communities require periodic flooding and variable salinities to establish and maintain their community structure within the estuarine environment. Many plant species, particularly those associated with saltmarshes display the ability to cope with extremely high salinities often found on the fringes and depressions of the floodplain. Several of these species require periodic flooding and inundation of freshwater to promote seed development and success of juvenile recruitment. Thirteen Ecological Vegetation Classes (EVC's) have been used to describe the estuary vegetation at Painkalac Creek (Australian Ecosystems Pty Ltd, 2010) of which three are listed as endangered in the Otway Plain Bioregion (DEPI, 2014). The importance of the diversity of the estuarine vegetation has a major role in providing habitat and food sources for the animals that inhabit this environment.

There has been at least 50 terrestrial vertebrate species recorded in the area surrounding the Painkalac Creek Estuary, comprising 12 mammals, 34 birds, two reptiles and two frogs. Up to 200 bird species have been recorded in the Painkalac Creek valley over time (SCS, 2010). This number is likely to be a conservative estimate due to the availability of a diverse range of habitat in the estuary environment that could maintain a variety of vertebrates. The Great Egret was the only bird species listed as vulnerable, though there is potential food and habitat available for the endangered Orange-bellied Parrot.

Introduction

There are at least 15 species of fish that are likely to occur within the Painkalac Creek Estuary *(Doeg et al., 2007)* at some stage in their lifecycle, these fish can be divided into three broad groups *(Lloyd et al, 2008)*:

- Estuarine residents - specialised fish that complete their entire lifecycle within the estuary, these fish may tolerate variable salinities.
- Estuarine dependent - these fish are dependent on the estuary to complete one part of their lifecycle such as spawning, shelter, feeding, or as a nursery for their young. These fish may be marine or freshwater species for most of their lives.
- Estuarine opportunists - these fish may be freshwater or marine species that use the estuary opportunistically to exploit the resources of the estuary and are likely to visit the estuary on a regular basis.

The Painkalac Creek Estuary has no fish species listed as vulnerable, though it may be possible for Australian Grayling to enter the estuary. However, viability for successfully inhabiting the creek is very low due to the long periods of low flow and the barrier created by the reservoir *(Doeg et al., 2007).*

These plant and fish communities are dependent on the estuary dynamics and are generally capable of surviving extreme changes often observed in estuaries.

The Painkalac Creek Estuary has high recreational values for the Aireys Inlet community and visitors to the region. Recreational fishing is popular in the estuary with catches of Estuary Perch, Black Bream, Mullet, Flounder and Luderick. There are several fishing platforms installed along the estuary banks for this activity. Canoeing and paddle boarding is also popular, particularly at the estuary mouth. Other passive recreational pursuits include walking, sightseeing, bird watching and relaxing.

The management of the estuary and its surrounds involves coordination between several management agencies including:

- Corangamite Catchment Management Authority (CCMA)
- Surf Coast Shire (SCS)
- Great Ocean Road Coast Committee (GORCC)
- Parks Victoria (PV)
- Barwon Water
- Department of Environment and Primary Industries (DEPI)
- Southern Rural Water
- Western Coastal Board
- Victorian Coastal Council (VCC)
- Environmental Protection Authority (EPA).

The need to understand the estuary's functions, health, and risks posed by flooding and potentially poor water quality has led to increased research into the estuary and the Painkalac Creek system. This research identified the 'values' of the Painkalac Creek and risks posed to these 'values', enabling better management of this fragile environment. There have been several studies and plans developed for the Painkalac Creek and the estuary conducted by the Surf Coast Shire (SCS) and the Corangamite Catchment Management Authority (CCMA) including:

- Painkalac Creek Estuary Management Plan (SCS)
- Environmental Flow Determination for Painkalac Creek (CCMA)
- Estuary Entrance Management Support System development (CCMA), a decision making tool incorporating environmental, social and economic values.

Introduction

In 2007 the Corangamite CMA set up the EstuaryWatch program on the Painkalac Creek Estuary. EstuaryWatch is a community based estuarine monitoring program, the aims of EstuaryWatch are to *'Raise awareness and provide educational opportunities to the community in estuarine environments, and enable communities and stakeholders to better inform decision making on estuarine health'.*

The EstuaryWatch Program enables a better understanding of the processes, ecology and community values of the estuary and whether they are changing over time. The program also raises awareness of the Painkalac Creek Estuary within the local community.

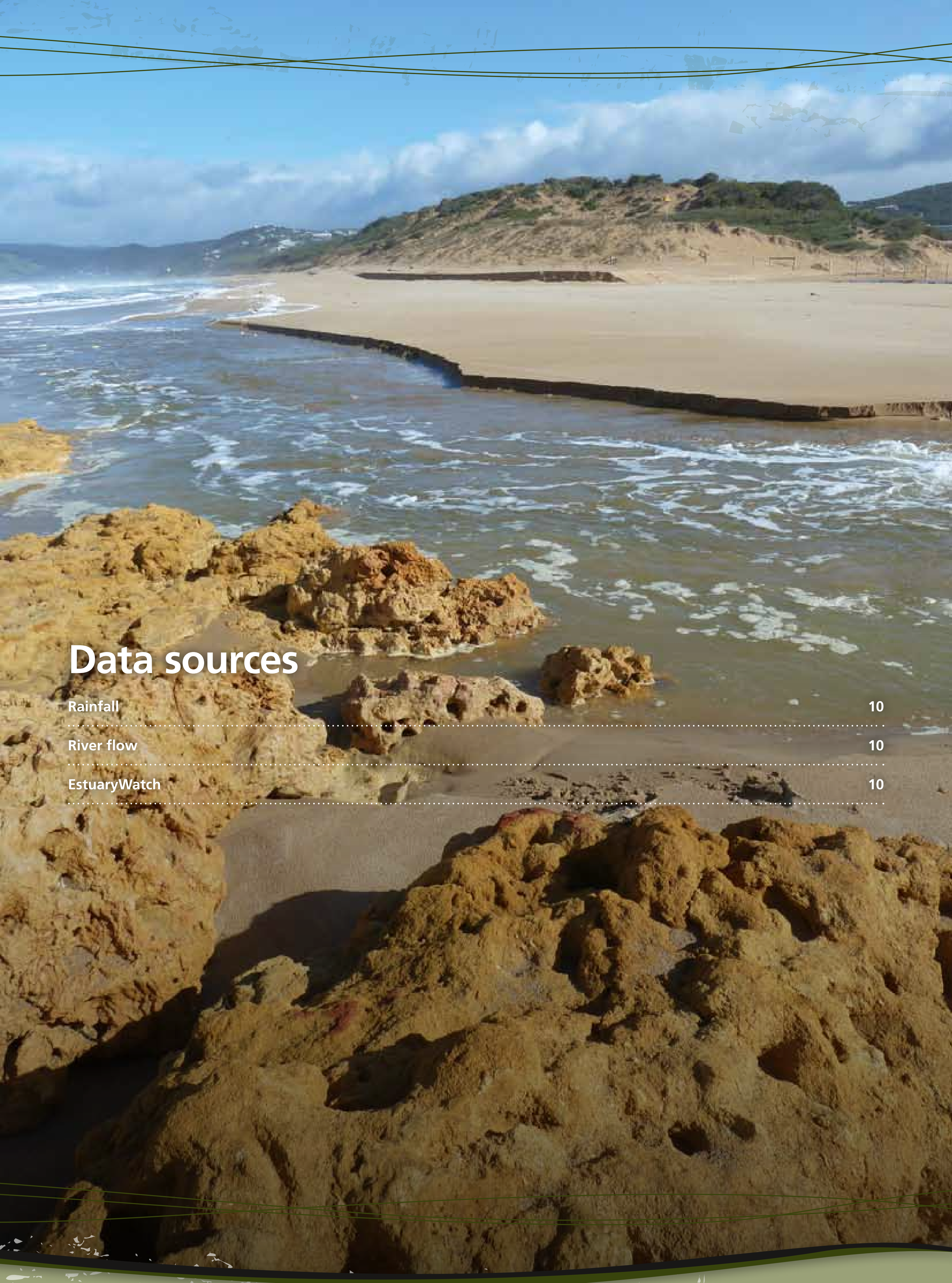
The following are some of the reasons why the community volunteers became involved in the EstuaryWatch Program:

- For the general health of the estuary. Also, I would like to look out for eels whilst I'm monitoring
- Because I care about the estuary. At the moment there is no data and conditions change so much
- It is important that we know and understand the estuary and also important that we contribute to its health
- The establishment of a database for the estuary that can be added to over the years is important
- I think the Painkalac Estuary is a great place and I want to see it maintained in good condition and EstuaryWatch will contribute to that
- I would like to get a good dataset of information on the estuary and to add to environmental management decisions that are made now and into the future
- I believe we need more information on the Painkalac Creek Estuary. Finding out what are relevant environmental flows for the estuary is important. It is important that we get this information now
- The estuary is valuable for the community and most people enjoy it
- When you are looking at entire catchment management the estuary represents the end of valley target. Therefore EstuaryWatch will provide us with important information useful for entire catchment management.

Since 2007 the Painkalac Creek EstuaryWatch team has collected and stored a significant amount of data on the EstuaryWatch online database. This report presents the analysis and interpretation of this data, along with other data sources including, rainfall and river flow.

Figure 1. Painkalac Creek Estuary with the locations of EstuaryWatch monitoring sites.

Figure 2. *Painkalac Creek catchment with the locations of the Painkalac Reservoir, Aireys Inlet weather station and gauging stations upstream and downstream of reservoir.*



Data sources

Data sources

Comprehensive sets of data are used in this analysis to assess the patterns and processes occurring within the Painkalac Creek Estuary. The data assessed include local rainfall, river flow, estuary depth, and the water chemistry parameters of salinity, electrical conductivity, temperature, dissolved oxygen, pH, and turbidity. Additional observational data is used to assist in the interpretation of the results. The data is sourced from the Bureau of Meteorology (rainfall), the Victorian Water Data Resource Warehouse (river flow), via their websites, and from EstuaryWatch. The EstuaryWatch data forms the major component of this study.

Rainfall

The rainfall data used in this study was obtained from the Bureau of Meteorology (BOM) website (BOM, 2013) for the Aireys Inlet weather station (Station No. 090180). This station was used as it has the most complete data set for stations in this region. Data was first recorded from this station in 1990 and the station is still recording today. A total of 19 years of daily rainfall data is assessed from 1995-2013. These records are displayed in millimetres per day (mm/day).

River flow

The river flow data was obtained from the Victorian Water Resource Data Warehouse website (VWRDW, 2013) for two locations on the Painkalac Creek. The site, *Painkalac Creek @ Painkalac Reservoir* (site code 235232) was chosen as it is the only monitoring station downstream of the reservoir. The location of this gauge station is approximately 150m downstream of the reservoir. Data was first recorded at this site in 1974. A total of 30 years of daily flow data are assessed (data from 1992-1999 was not assessed). The second gauging site assessed is *Painkalac Creek upstream Painkalac Reservoir* (site code 235257) and was selected as it is the only monitoring station upstream of the reservoir and enables a comparison between inflows and outflows to and from the reservoir. The location of this gauge station is approximately 5 km upstream of the reservoir. Data was first recorded at this site in 1999. A total of 14 years of daily flow data are assessed.

The river flow measurements at these sites are instantaneous measurements, from which average daily, monthly and annual records are computed by automated software at the Victorian Water Resource Data Warehouse. These records are displayed as Mega Litres per day (ML/day). There are some irregularities in the data from the two gauging stations due to possible equipment failure and in some cases deems interpretation not possible.

EstuaryWatch

The EstuaryWatch program involves community volunteers collecting environmental and observational data from six locations within the Painkalac Creek Estuary and entering this data onto the EstuaryWatch online database. More information on EstuaryWatch and the processes and procedures employed by volunteers can be obtained from the Corangamite Catchment Management Authority website (CCMA, 2012) and by following the links to the EstuaryWatch Program.

The locations of the six EstuaryWatch sites are displayed in Figure 1. Of the six sites, five sites are water quality monitoring sites (P1 (inactive), P2, P3, P4 and P5) and one site is for the photo point (Pp1) and mouth condition (PMC) assessments.

For further information on the mouth condition observational assessment a sample field entry sheet is available from the EstuaryWatch online database.

A total of 415 entries were available on the EstuaryWatch database at the time of this assessment, these entries are from all sites and include the parameters recorded during each depth reading. The site codes, site names, distance from the estuary mouth and number of times each site has been sampled is displayed in Table 1.

Data sources

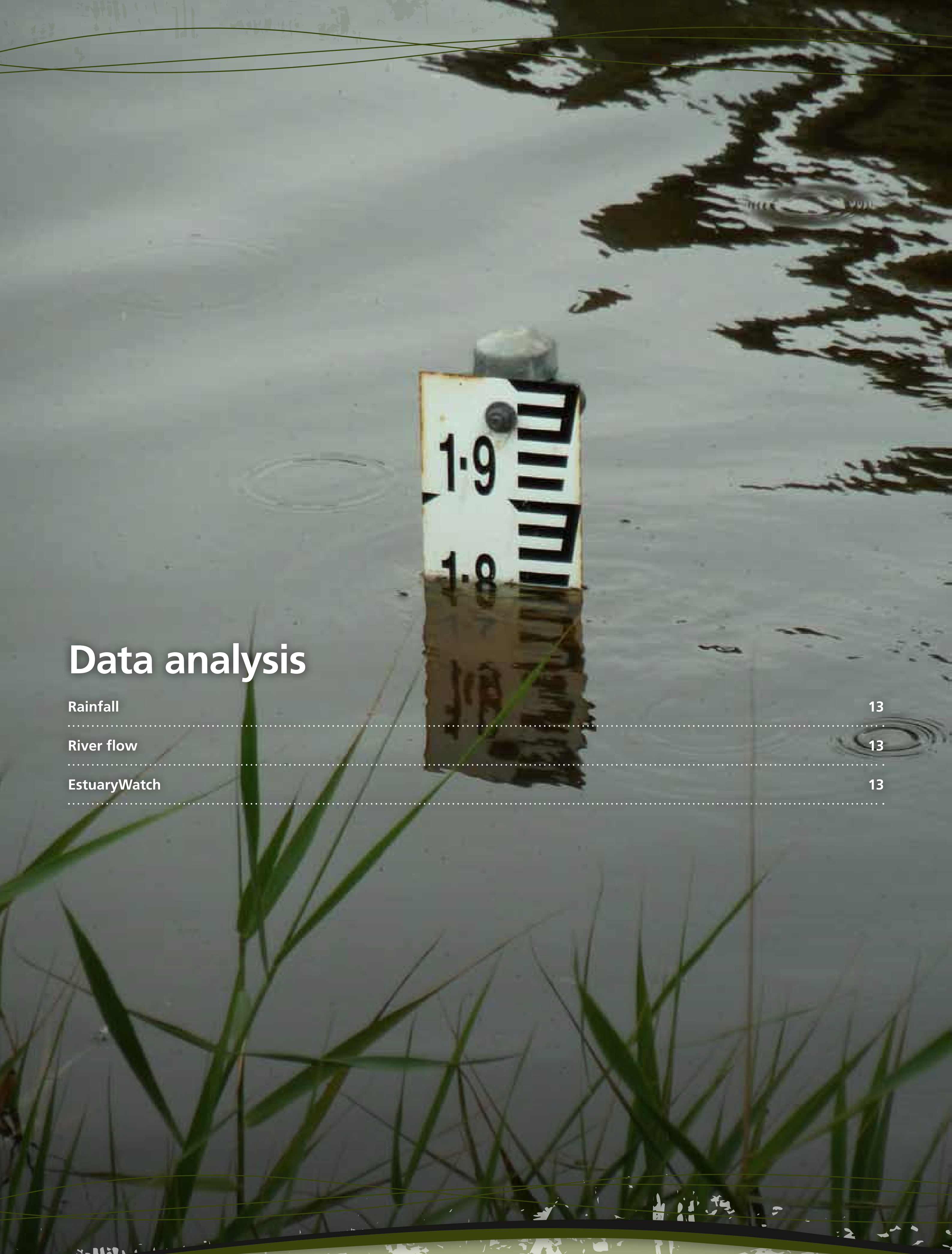
Table 1. The EstuaryWatch monitoring site names, the distance each site is from the mouth of the estuary and the number of times each site has been monitored.

Site code	Site name	Distance from estuary mouth	Number of times sampled
PP	Photo Point – Mouth Condition	0.1 km	133
P1	Estuary Mouth	0.23 km	1
P2	Great Ocean Road @ Aireys Inlet	0.86 km	84
P3	Coastal Court Fishing Platform	1.42 km	63
P4	The Bend	1.86 km	67
P5	Woods Property Fishing Platform	3.16 km	67

The data collected from the water quality sites include; depth (m) at time of sampling, turbidity (NTU), temperature (°C), dissolved oxygen (mg/L and % saturation), salinity (ppt) and more recently electrical conductivity (mS/cm). Turbidity and pH sampling is undertaken from the top (top 0.1m from surface) and bottom (within 0.1m of the bottom) of the water column.

Temperature, dissolved oxygen, salinity and electrical conductivity measurements are taken from the top and bottom and at 0.5m intervals from the water surface to the bottom of the estuary. This methodology enables the generation of profiles of the water column and an assessment of changes in the measured water quality parameters.


EstuaryWatch monitoring, site P3. Photo: Corangamite CMA



Data analysis

Data analysis

The initial data analysis involves assessing the trends and patterns within each data set. Further analysis involves assessing the relationships between the data sets enabling an interpretation of the physical and chemical processes occurring within the estuary. Additional assessment is performed to provide information around times of potential stress for organisms within the estuary i.e. estuary closures and openings (natural and artificial), times of low dissolved oxygen, salinity gradients and changes in pH.

Rainfall

Rainfall is the key component of any river system, the seasonality and variability in annual rainfall in south-west Victoria can lead to times of stress in systems reliant on rainfall, as do times of extreme rainfall, such as storm events that may lead to flooding.

The BOM records daily rainfall (mm), to determine the average monthly and average annual rainfall. This information is presented in a graph with an emphasis on the period of 2007-2013 for EstuaryWatch data assessment. Additionally, the average monthly rainfall is displayed as the percentage of total rainfall for the 18-year average, and for each year from 2007-2013, to indicate the seasonality and variability in monthly rainfall patterns.

River flow

The timing and volumes of water entering the estuary from Painkalac Creek influences estuary health and biota. River flow is the main factor determining the degree which marine derived salt water can penetrate the estuary, as well as being the main influence on the estuary's mouth condition.

The assessment on river flow is the average annual and monthly flows, to give an indication of the seasonality of the flow and display the relationship with catchment rainfall. The daily volume of water leaving the Painkalac Reservoir and entering Painkalac Creek is determined by the bulk entitlement, the size of the outlet pipe and the capacity of the reservoir. Once the reservoir reaches capacity flows are directed over the spillway.

EstuaryWatch

The EstuaryWatch data also presents very interesting information about the processes occurring within the estuary. The EstuaryWatch site P2 was selected for the long-term time series as this site has the best profile data in the lower part of the estuary *(pers. com Corangamite CMA)* and has the most comprehensive data set being sampled on 84 occasions. The top and bottom water data is displayed in time series enabling an assessment of seasonal variability in the water quality parameters, as well as displaying times of potential stress such as low dissolved oxygen. Also displayed are times when the estuary becomes stratified along a salinity gradient. The remaining sites are assessed in summary from 2007-2013.

The water column profile data is also assessed for each site giving an overview of the water quality conditions found throughout the estuary. These graphs display the seasonal variability associated with river flow and the marine tidal influence. This information is available on request.

Trends and patterns

Trends and patterns

Long-term rainfall

The average annual rainfall at the Aireys Inlet weather station for the last 18 years is 635mm. The highest annual rainfall was 901mm in 2001 and the lowest was 422mm in 1997. Figure 3 displays the rainfall record for the period from 1995 to the end of 2012, the years 1995, 2000, 2001, 2003, 2004, 2007, and 2010-2012 exceeded the average annual rainfall and the years 1996-1999, 2002, 2005, 2006, 2008 and 2009 a below average rainfall was recorded.

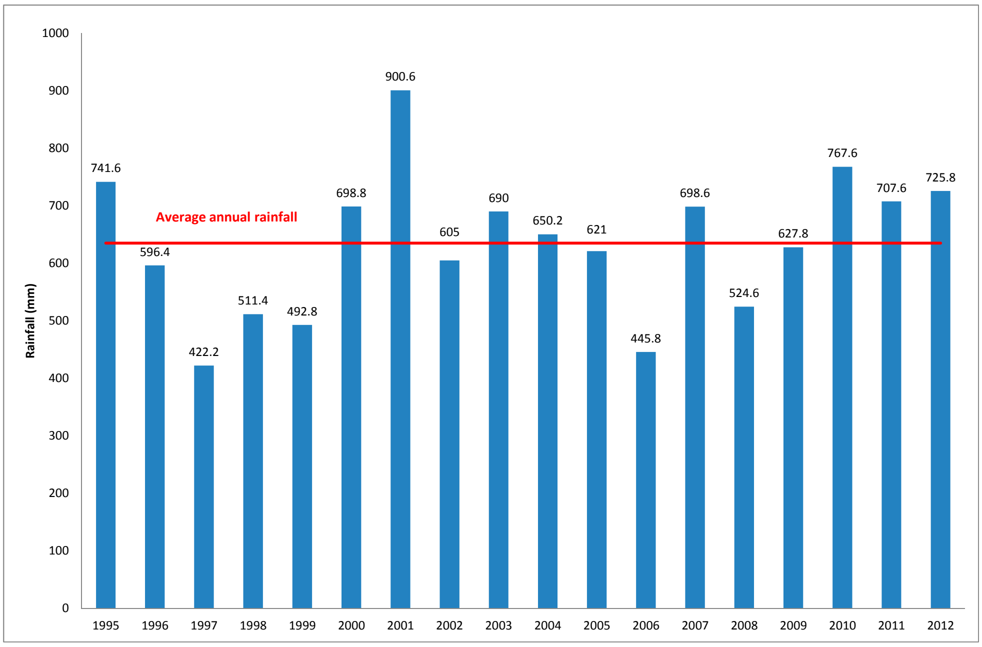


Figure 3. Average annual rainfall from BOM Station 090180 Aireys Inlet for the years 1995-2012. The red line indicates the 18 year average annual rainfall (635mm).

The timing of rainfall in this region follows a very seasonal pattern, using average monthly rainfall data for the last 18 years indicates winter rainfall accounts for 32% of total annual rainfall, followed by, spring 29%, autumn 21% and the lowest being summer, accounting for 18% (Figure 4). On average March is the lowest rainfall month and August is the highest.

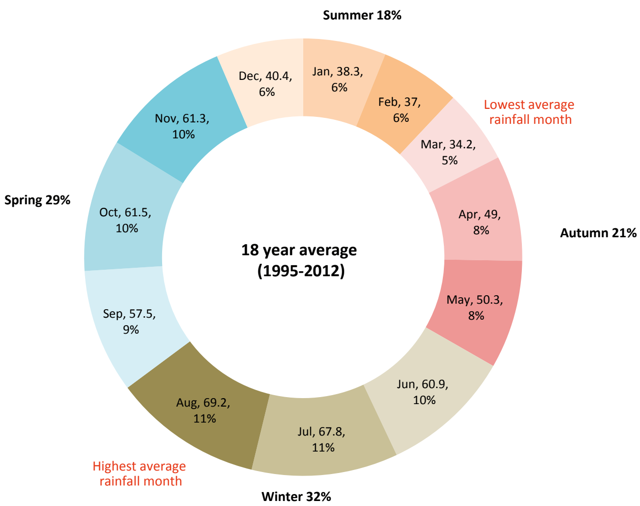


Figure 4. The average monthly rainfall percentage contributions for the 18 year average (1995-2012).

Trends and patterns

The variability in the seasonality of rainfall from 2007-2012 compared to the long-term average is also displayed in Figures 5-10. In January and February 2009, only 3% of annual rainfall was recorded. This would result in a significant flow reduction in the Painkalac Creek Estuary. During the same period in 2011, 28% of the annual rainfall was recorded due to an extremely high rainfall event that created major flooding in many areas across southern Victoria. Also the rainfall pattern in 2011 shows a markedly higher rainfall pattern in the first six months of the year due to this event.

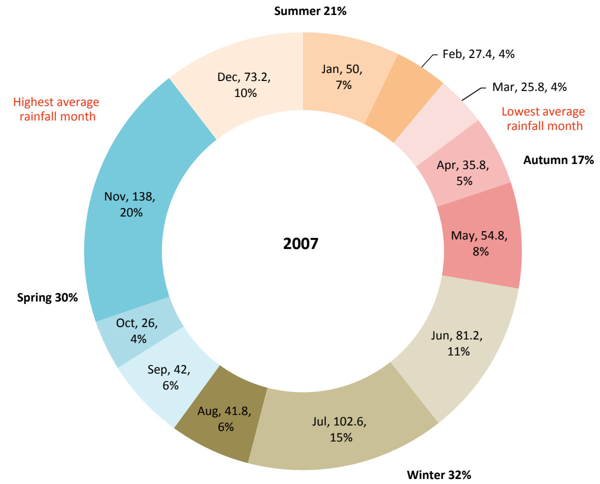


Figure 5. The monthly rainfall (mm) and the monthly and seasonal percentage contribution to the annual rainfall amount for 2007.

In 2007 the annual rainfall was 698.6mm. The highest rainfall season was winter (225.6mm) and the lowest rainfall season was autumn (116.4mm).

The highest rainfall month was November (138mm) and the lowest rainfall month was March (25.8mm)

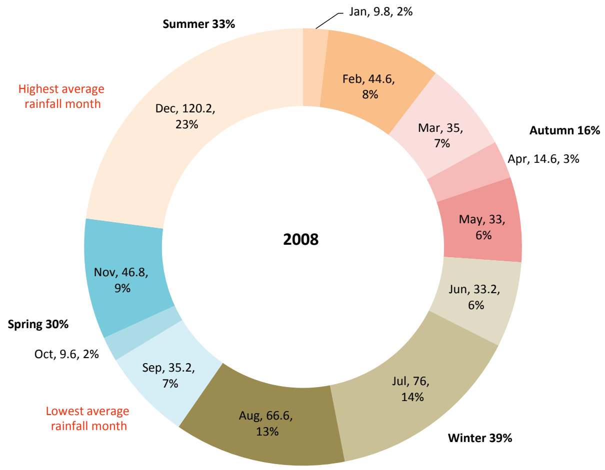


Figure 6. The monthly rainfall (mm) and the monthly and seasonal percentage contribution to the annual rainfall amount for 2008.

In 2008 the annual rainfall was 524.6mm. The highest rainfall season was winter (175.8mm) and the lowest rainfall season was autumn (82.6mm).

The highest rainfall month was December (120.2mm) and the lowest rainfall month was October (9.6mm).

Trends and patterns

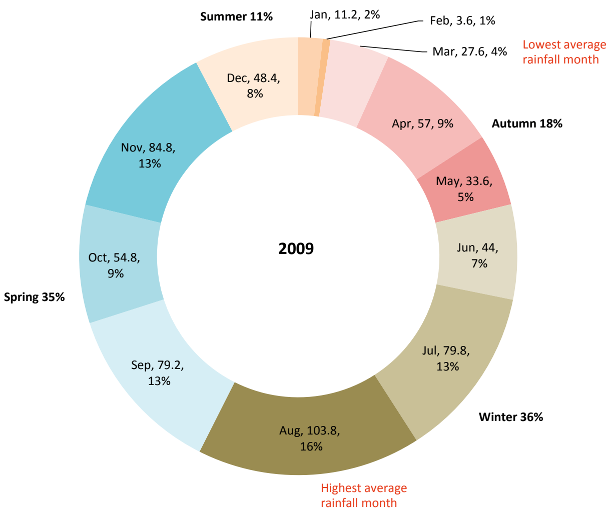


Figure 7. The monthly rainfall (mm) and the monthly and seasonal percentage contribution to the annual rainfall amount for 2009.

In 2009 the annual rainfall was 627.8mm. The highest rainfall season was winter (227.6mm) and the lowest rainfall season was summer (82.6mm).

The highest rainfall month was August (103.8mm) and the lowest rainfall month was February (3.6mm).

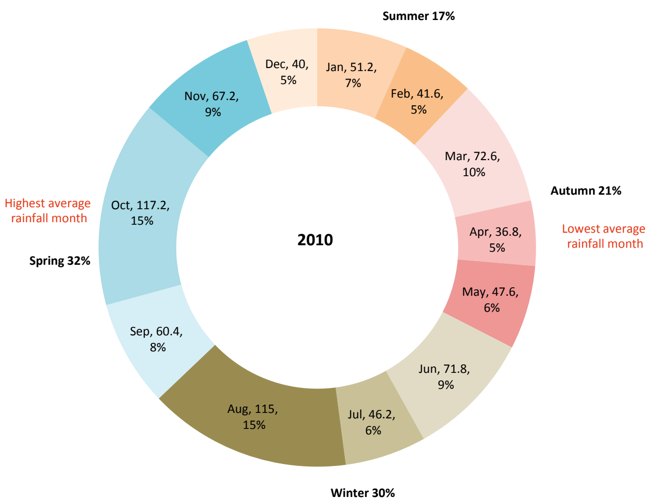


Figure 8. The monthly rainfall (mm) and the monthly and seasonal percentage contribution to the annual rainfall amount for 2010.

In 2010 the annual rainfall was 767.6mm. The highest rainfall season was spring (244.8mm) and the lowest rainfall season was summer (132.8mm).

The highest rainfall month was October (117.2mm) and the lowest rainfall month was April (36.8mm).

Trends and patterns

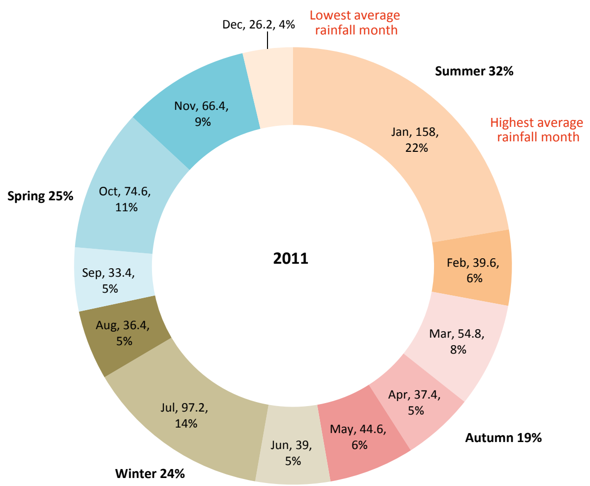


Figure 9. The monthly rainfall (mm) and the monthly and seasonal percentage contribution to the annual rainfall amount for 2011.

In 2011 the annual rainfall was 707.6mm. The highest rainfall season was summer (223.8mm) and the lowest rainfall season was autumn (140.4mm).

The highest rainfall month was January (158mm) and the lowest rainfall month was December (26.2mm).

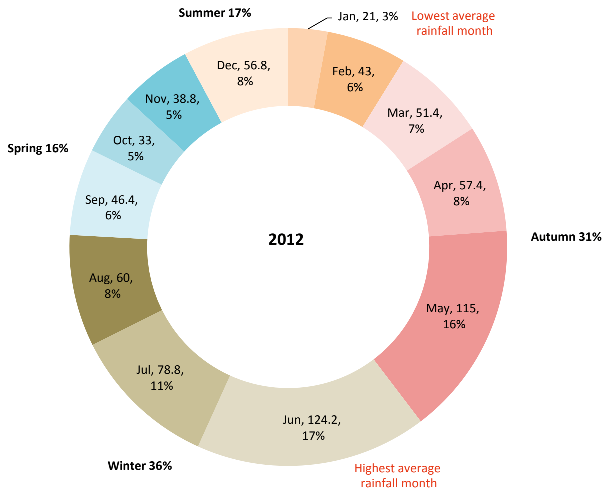


Figure 10. The monthly rainfall (mm) and the monthly and seasonal percentage contribution to the annual rainfall amount for 2012.

In 2012 the annual rainfall was 725.8mm. The highest rainfall season was winter (263mm) and the lowest rainfall season was spring (118.2mm).

The highest rainfall month was June (124.2mm) and the lowest rainfall month was January (21mm).

Trends and patterns

Long-term river flow

The average annual flow at the *Painkalac Creek @ Painkalac Reservoir* site (downstream of the reservoir) for the last 38 years (excluding 1992-1999) is 11.5 ML/day. The highest average annual flow was 46.1 ML/day in 1978. The lowest average annual flow was 0.2 ML/day in 2006 and 2008. Figure 11 displays the flow record for the period from 1975 to the end of 2012.

There was no average flow calculated from 1992-1999 due to missing data. From 1975-1991, seven years were below the average and ten years were above the average. From the years 2000-2012 only in 2001 was the average annual flow exceeded. The long-term average annual flow at the site *Painkalac Creek upstream Painkalac Reservoir* was not assessed as only 3 of the 12 years (2000-present) the site has been operating was average annual flow calculated, due to gaps in data collection.

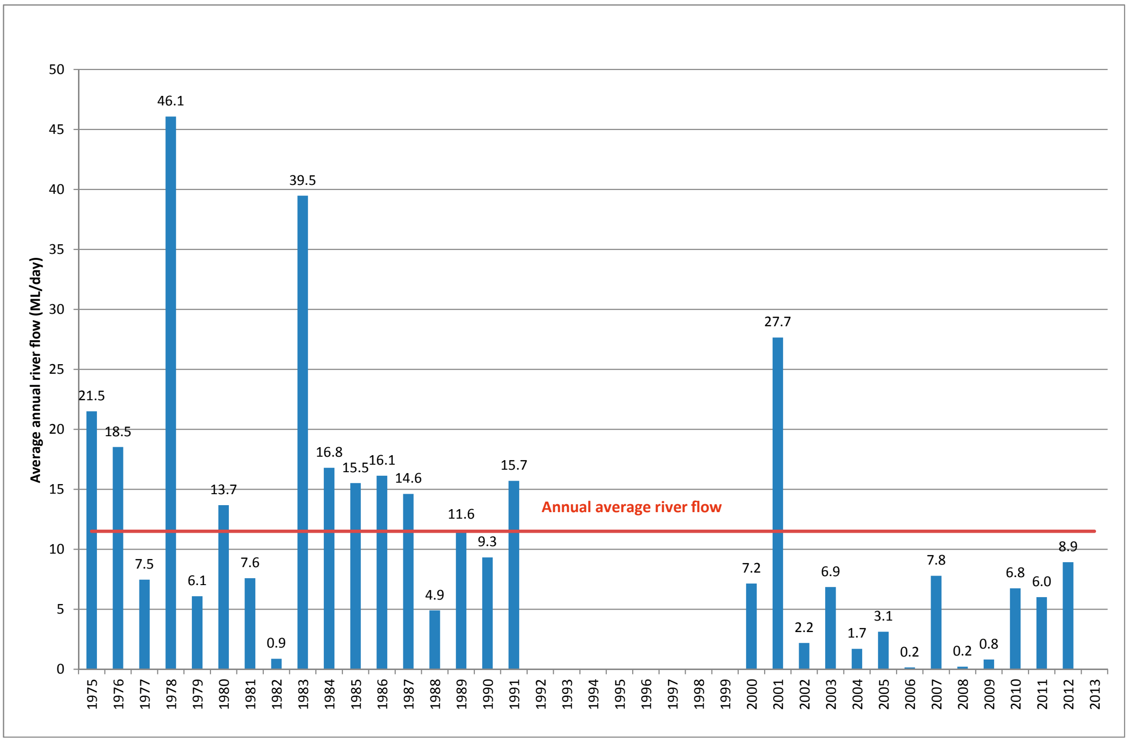


Figure 11. *The average annual flow (ML/day) from 1975-2012 including the annual average river flow (11.5ML/day).*

Trends and patterns

The flow within the Painkalac Creek follows a very seasonal pattern, using average monthly flow data from the last 38 years indicates spring flows accounts for 42.5% of total annual flow, winter 40%, autumn 9% and summer the lowest, accounting for 8%. The average monthly flow percentage contribution is displayed in Figure 12 (30-year average).

An additional assessment to display any variations or changes in the seasonality of river flow that may be due to the containment of water within the reservoir pre and post implementation of the Bulk entitlement (1997) is displayed in Figures 13.

There is evidence that reductions in flow have occurred in most months during the 2000-2012 period. The high value recorded for April during this period was the result of an extreme weather event during April 2001, the average monthly flow for this event was 158 ML/day.

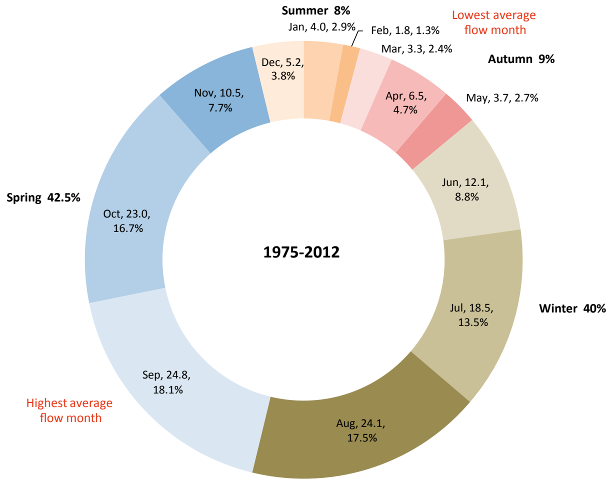


Figure 12. The average monthly river flow (ML/day) and the average monthly and seasonal percentage contribution to the annual river flow from 1975-2012.

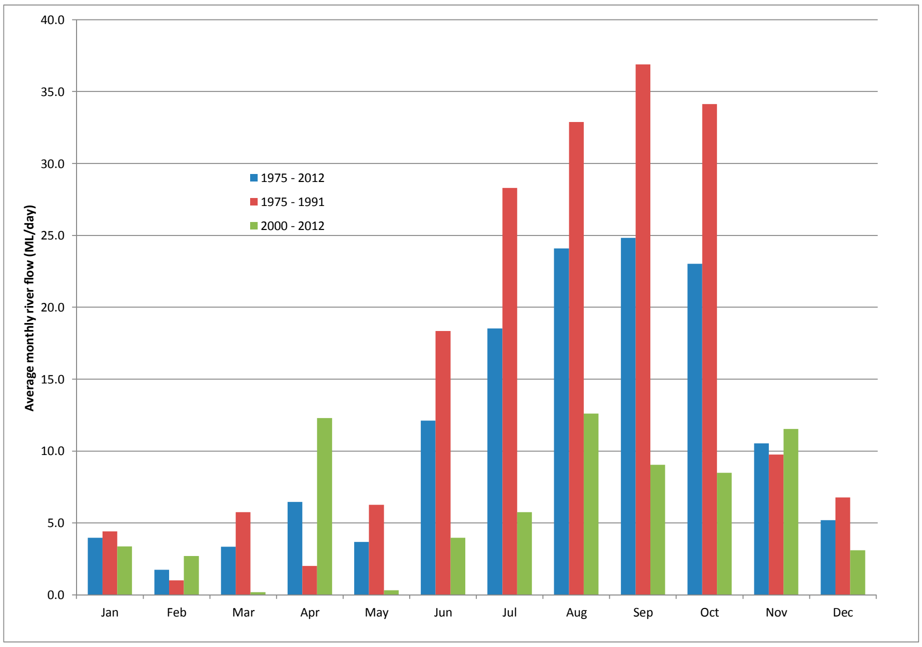


Figure 13. The average monthly river flows (ML/day) for the periods 1975-2012 (blue), 1975-1991 (red) and 2000-2012 (green).

Trends and patterns

Long-term EstuaryWatch data

Estuary mouth condition

The data collected by EstuaryWatch indicates that the Painkalac Creek Estuary is closed from the sea most of the time, shown in Figure 14. There is the potential for a minor opening to be missed as monitoring only occurs on a monthly schedule, though due to the relatively low flows and characteristics of the sand accumulation at the mouth this is unlikely. The amount of time the estuary mouth remains open after artificial openings is dependent on river flow.

The EstuaryWatch mouth condition information and the Estuary Entrance Management Support System (EEMSS) indicates the estuary mouth opened naturally on two occasions, and was artificially opened on 12 occasions from 2007 to mid-2013.

Figure 14 also displays increased rainfall and in some cases increased flow prior to most openings, this is explored further in the annual assessments.

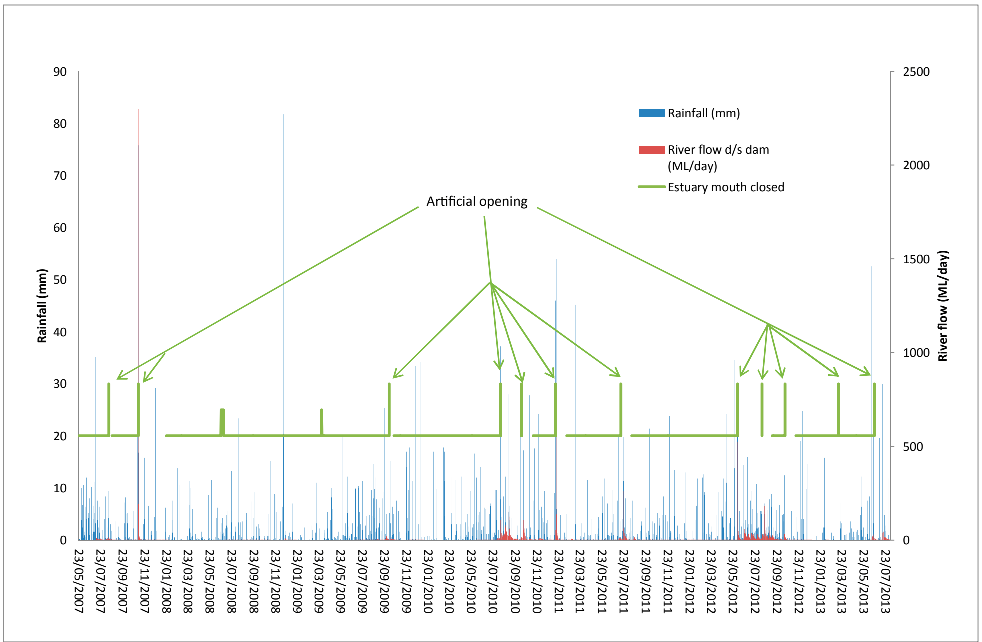


Figure 14. The Painkalac Creek Estuary mouth condition as recorded by EstuaryWatch. The horizontal green line indicates the estuary mouth is closed and the vertical lines indicate recorded openings from 2007-2013. Also included is the daily rainfall and average daily river flow.

Trends and patterns

Water quality monitoring site P2 – Time series

This section provides an assessment of the long-term water quality monitoring data. The data used in this time series assessment are from site P2 as this site presents the best depth profile in the lower section of the estuary, and uses the data collected from the top and bottom of the water column. The parameters assessed include depth, temperature, salinity, dissolved oxygen, turbidity and pH. This data is presented in time series and it should be noted that sampling is not continuous, it is undertaken on a monthly basis therefore each sampling event is not related to any other sampling event, as may be indicated using the line graph representation, to assess the long-term trends. Further assessments are given for the remainder of the EstuaryWatch sites describing the range of measurements recorded at each site.

Depth-water level

The water level at site P2 showed a gradual increase in depth when the estuary mouth was closed during times of increased river flow (Figure 15). Also displayed is the rapid drop in water level when the estuary is artificially opened. The water level also shows a decrease at times when the estuary mouth is closed and there is no river flow. This occurred several times during prolonged closures over the summer/autumn period and is presented later. The trend line in Figure 15 indicates there is a slight increase in depth over time (approx. 0.1m) suggesting there may be some minor scouring of the substrate sediment at this site. The depth ranged from a minimum depth of 1m to a maximum depth of 3.14m.

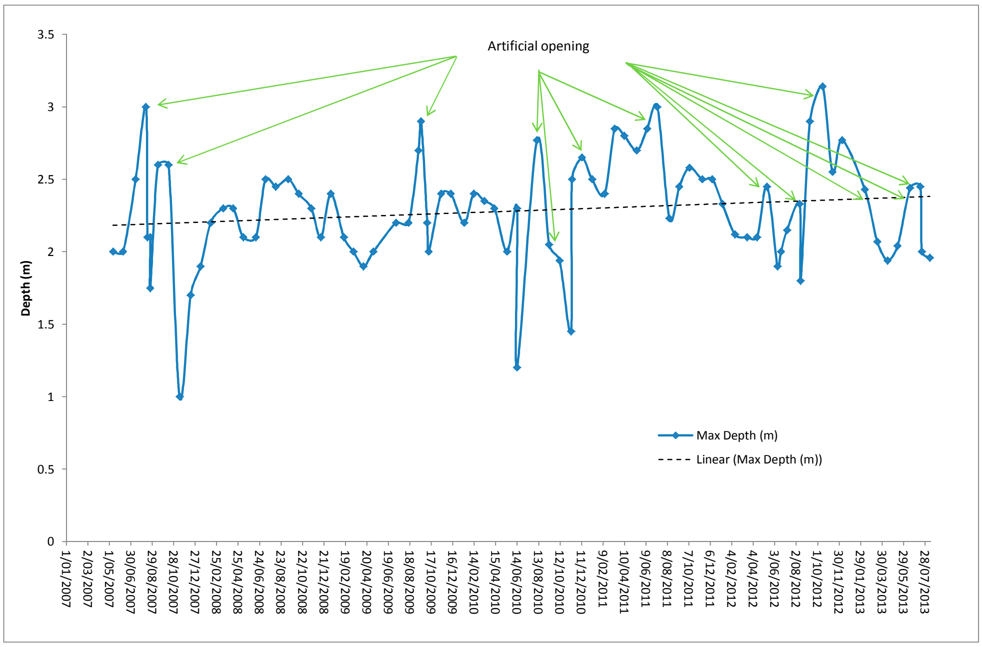


Figure 15. The water level (m) (depth) at EstuaryWatch site P2 from 2007-2013. Also indicated are the times the estuary mouth was artificially opened.

Trends and patterns

Temperature

The temperature at EstuaryWatch site P2 displayed significant seasonal variation in both the top and bottom waters with winter temperatures the coldest and summer temperatures the warmest as is displayed in Figure 16. Winter temperatures ranged from 7.7-13.9°C, and summer temperatures ranged from 16.8-27.9°C. During the summer months the bottom waters are often warmer than the top waters, this occurs at times when the estuary is stratified, the difference in temperature observed can be as much as 5.2°C and is likely due the lack of mixing. The causes of this difference in temperature may be from rainfall/river flow or from solar radiation penetrating the water column and warming the bottom substrate.

On some occasions this also occurred during the winter months with the largest difference being 6.2°C. During the winter months this is likely to be due also to the effects of stratification reducing mixing and the inputs of cooler rainfall/ river flows. The trend-line displayed is for the top and bottom water, two trend-lines for the top and bottom waters were initially assessed but were fundamentally the same.
This indicates over the longer period of time the average temperatures in the top and bottom waters are the same. This trend-line also indicates the temperature over the six years is constant.

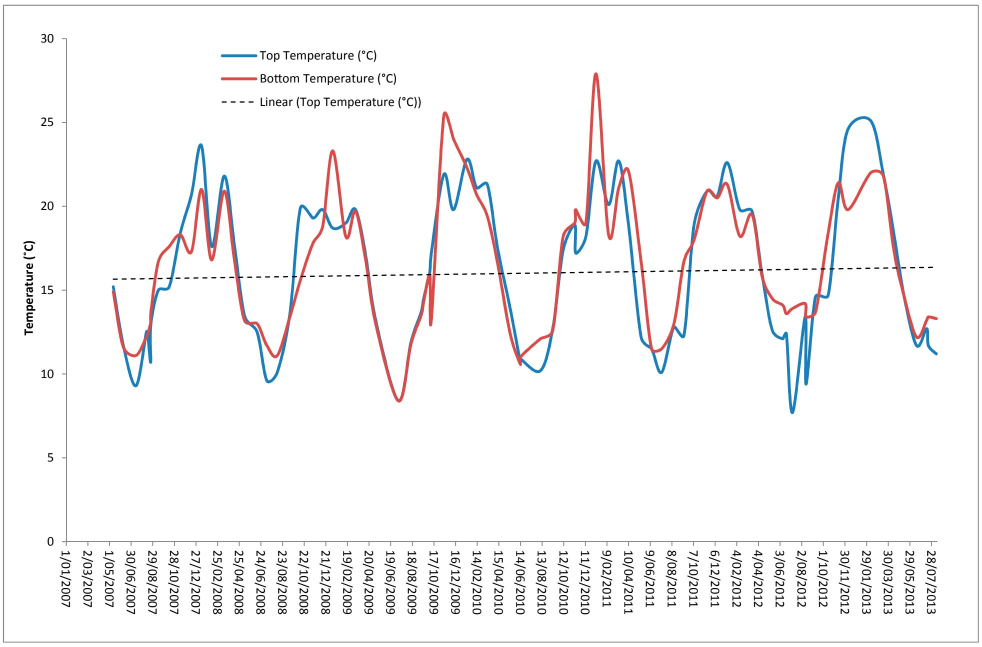


Figure 16. *The temperature (°C) at EstuaryWatch site P2 from 2007-2013. Also included is the trend-line.*

Trends and patterns

Salinity

The salinity from 2007-2013 at EstuaryWatch site P2 showed the estuary to be stratified along a salinity gradient at times of increased river flows and at times when the estuary mouth was opened. This can be seen in Figure 17 when the top and bottom waters show different salinities, when the top waters are mostly fresh and the bottom waters are of marine salinity or close to it. Also apparent here is the input of marine derived seawater following an estuary opening as is displayed by a sharp rise in bottom water salinity. The salinity time series also displays extended times when the estuary is fully mixed and not stratified, these times occur during periods of no flow or extremely low flows. When the estuary mouth is closed during the summer/early autumn period. This is displayed by the top and bottom waters having the same salinity. During the 2008 summer/autumn period the estuary experienced a time of slight hyper-salinity when the waters of the estuary had a greater salinity than commonly found in seawater. This was likely due to no, or extremely low freshwater inputs and increased evaporation during the summer period. This also corresponds with a time when the berm at the estuary mouth was breached resulting in sea water entering the estuary. The estuary water level was reported as being extremely low at this time. The salinity of the top waters ranged from 0.8-42.7 ppt, and the bottom waters ranged from 12.1-42.7 ppt. The trend-lines indicate the top waters becoming fresher over-time, this corresponds with the slight increase in river flows observed in more recent years. The bottom waters also show a slight reduction in salinity though this is only marginal.

Dissolved oxygen

The dissolved oxygen levels from 2007-2013 at EstuaryWatch site P2 show the effects of stratification within the estuary. This can be seen in Figure 18 where the top and bottom waters show different levels of dissolved oxygen. This corresponds with times of different top and bottom salinities. The effect of stratification inhibits mixing between the top and bottom waters and as the bottom waters are isolated from the surface, the consumption of oxygen by organisms and microbial activity results in oxygen depletion in the bottom waters. At times the bottom waters would be unsuitable for the survival of oxygen dependent organisms such as fish. The dissolved oxygen levels in the top waters ranged from 50-124% saturation, and the bottom waters ranged from 0-90% saturation. The increase in dissolved oxygen levels in the top waters corresponds with times of rainfall and increased river flow. Within the bottom waters increases in dissolved oxygen level are observed following an estuary opening, this is likely due to the returning high tide bringing freshly oxygenated seawater into the estuary.

Trends and patterns

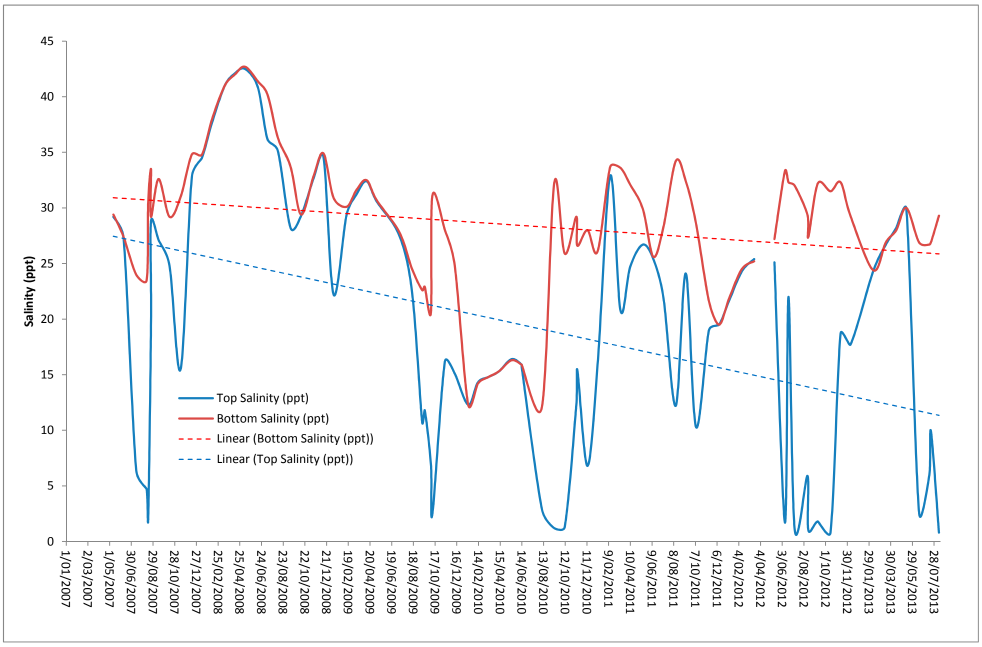


Figure 17. *The salinity (ppt) at EstuaryWatch site P2 from 2007-2013. Also included are the trend-lines for both the top and bottom waters.*

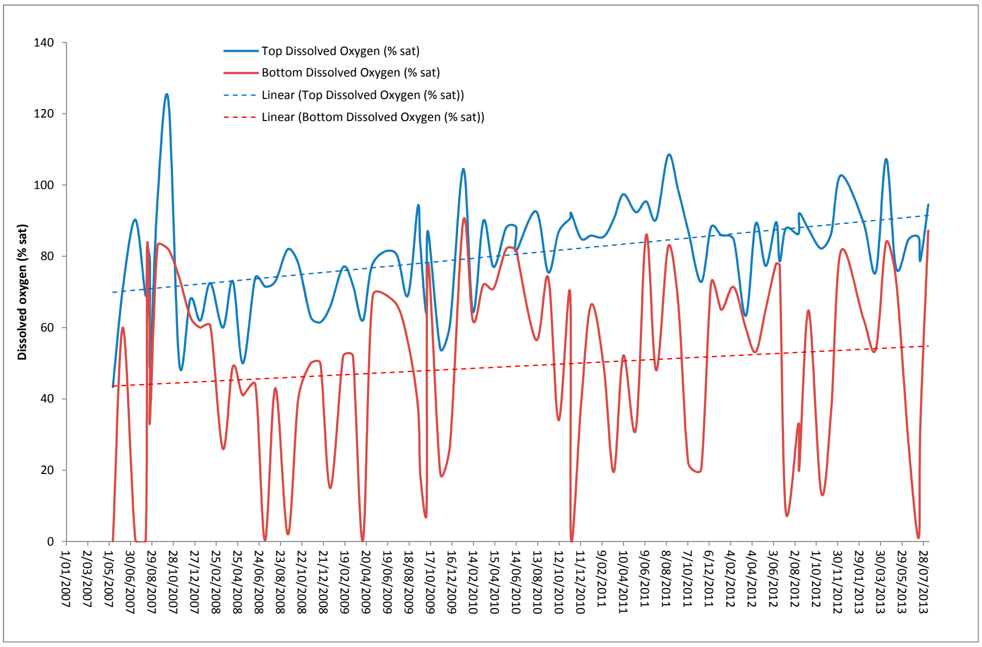


Figure 18. *The dissolved oxygen (% saturation) at EstuaryWatch site P2 from 2007-2013. Also included are the trend-lines for both the top and bottom waters.*

Trends and patterns

Turbidity

The turbidity levels from 2007-2013 at EstuaryWatch site P2 are displayed in Figure 19. The increases in turbidity levels in the top waters correspond with times of increased rainfall and river flows. Some increases in the bottom waters correspond with times of increased river flows and estuary openings. Both the top and bottom waters had a turbidity range of 10-30 NTU.

A measurement of 30 NTU is relatively low particularly during times of high rainfall and river flows, in comparison to other riverine/estuary environments. This may be the result of the Painkalac Reservoir which slows and contains influent river water from the upper catchment enabling suspended particles to settle out within the reservoir before this water is released into the Painkalac Creek in the lower valley.

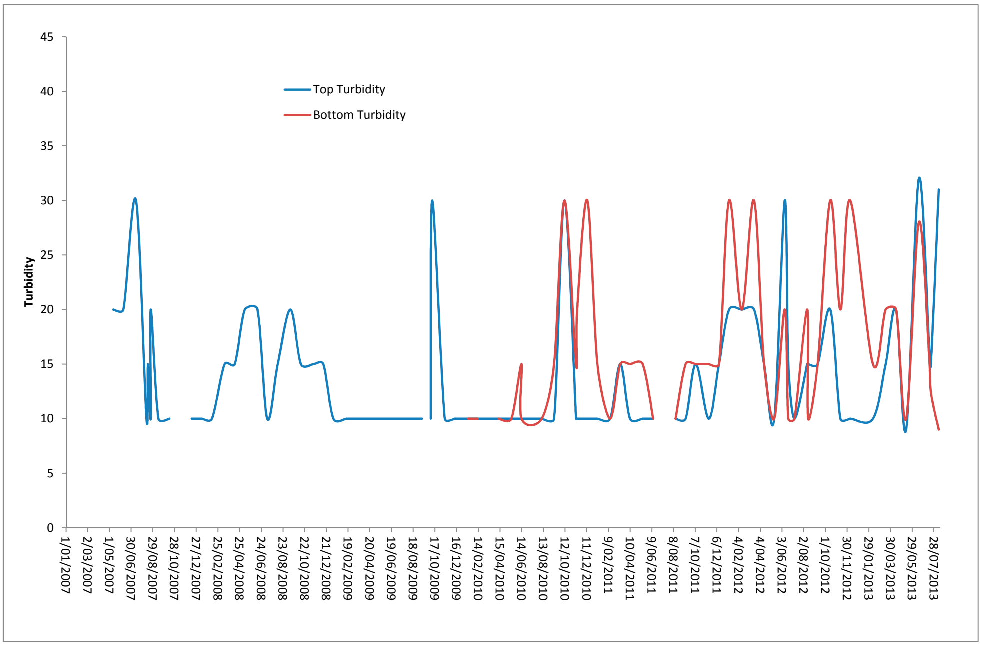


Figure 19. *The turbidity (NTU) at EstuaryWatch site P2 from 2007-2013.*

Trends and patterns

pH

pH measurements have only been recorded from late 2010. However, they do show some concerning factors. The pH in the top water on several occasion were 5.5 and 5.3, these values are quite low and should be considered for further investigation, as these levels may cause stress to organisms living in the estuary.

The expected range would be 7-8.5 for a healthy system. The pH of the top waters ranged from 5.3-8, and the bottom waters ranged from 6.2-8. The times of low pH values corresponds with high rainfall and river flow and may be the result of drainage of acid sulphate soil as often occurs in the neighbouring Anglesea River estuary catchment.

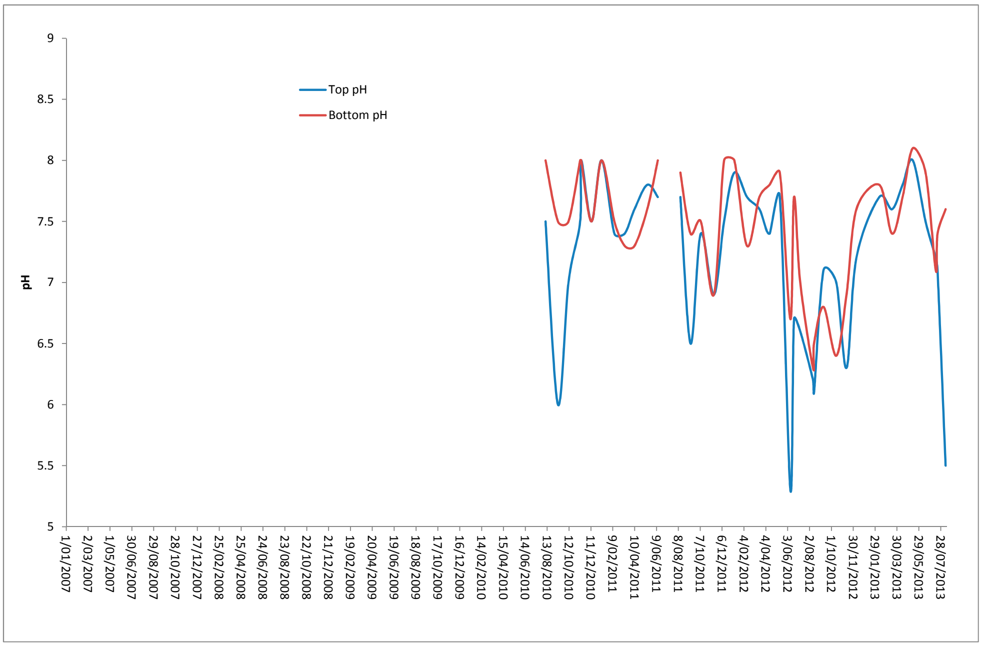


Figure 20. *The pH at EstuaryWatch site P2 from 2007-2013.*

Trends and patterns

Annual reviews

2007

The EstuaryWatch program was set up on the Painkalac Creek Estuary in May 2007. During 2007 the Painkalac Creek Estuary had two artificial estuary mouth openings on August 14 and November 4 (Figure 21). The data collected, following the August opening indicates the estuary remained open for only a short period, possibly one week (as monitoring is not performed daily this is an estimate from the mouth condition data). Following the November artificial mouth opening the estuary was open to the sea until mid-January 2008. The estuary may have closed sooner as the last mouth condition observation on December 15 reported the estuary as 'open'. The next observation was January 22 reported 'closed'. Assessing the salinity profile suggests the estuary may have closed in mid-December.

In 2007 the Painkalac Reservoir was at 100% capacity from July 9 to December 31 (Barwon Water, 2014). During the November event the estuary received flooding river flows with 2,300 ML/day recorded at the gauge station downstream of the reservoir (Figure 21). The effect of these openings on the water level within the estuary can be seen in Figure 22. Following both openings there is a sharp drop in water level. Also evident is the slow increase in water level within the estuary before each opening and the rise in turbidity (Figure 26). Following the closure of the estuary after the November opening the estuary experienced extremely low water levels. Though not evident in the site data, this information was gathered from comments included in the mouth condition data.

For the remainder of the time the estuary was isolated from the sea. The water temperature during the year displayed the expected seasonal pattern of being cooler during winter (Figure 23). Also displayed, during July-October, the bottom waters were warmer than the top waters, likely due to increases in rainfall and river flow and as a result of stratification.

Stratification was evident in the water column from June-August, and following the opening in August-December, this can be observed in the salinity profile (Figure 24). During the June to August period the stratification was significant with the top waters representing close to freshwater and the bottom brackish water. Whilst the estuary was stratified, the concentration of dissolved oxygen levels in the bottom waters were reduced to critical levels (Figure 25) which would have caused severe stress to marine dependent fish. Prior to the November opening the estuary did not display significant stratification, and dissolved oxygen levels remained in the healthy range.

The opening in August resulted in the return of seawater to the estuary upon the returning high tide, this can be observed with the sharp increase in salinity levels in the water being representative of sea water (Figure 24). Also apparent, is the complete breakdown of the stratification at this site with healthy dissolved oxygen levels (Figure 25).

Following the potential closure of the estuary in December, the estuary was completely mixed with no stratification, likely due to no river flow or rainfall, dissolved oxygen levels at this time showed a decline in levels.

Trends and patterns

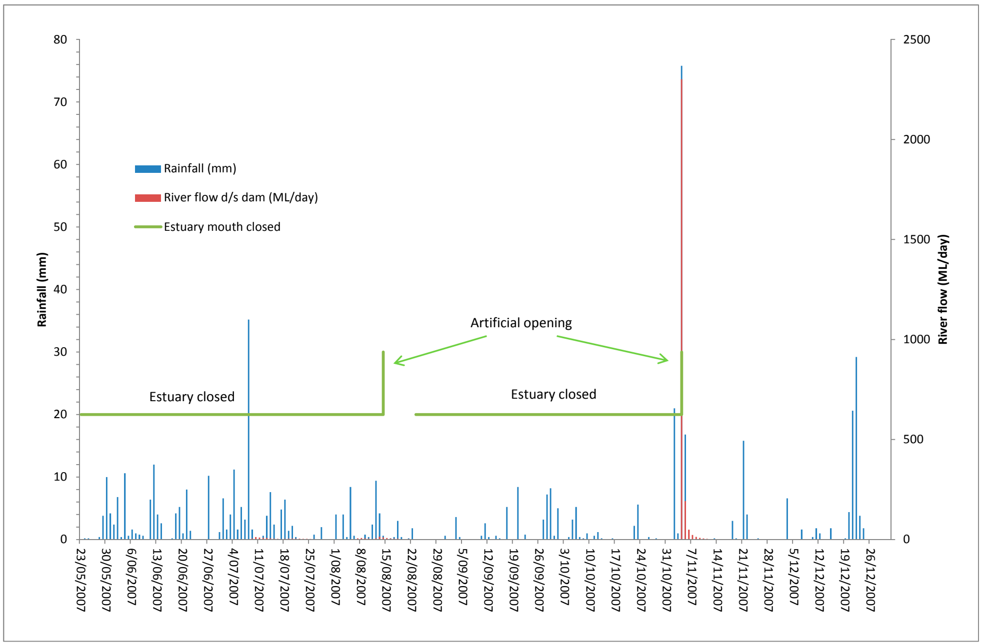


Figure 21. *Rainfall, river flow and estuary closures and openings during 2007.*

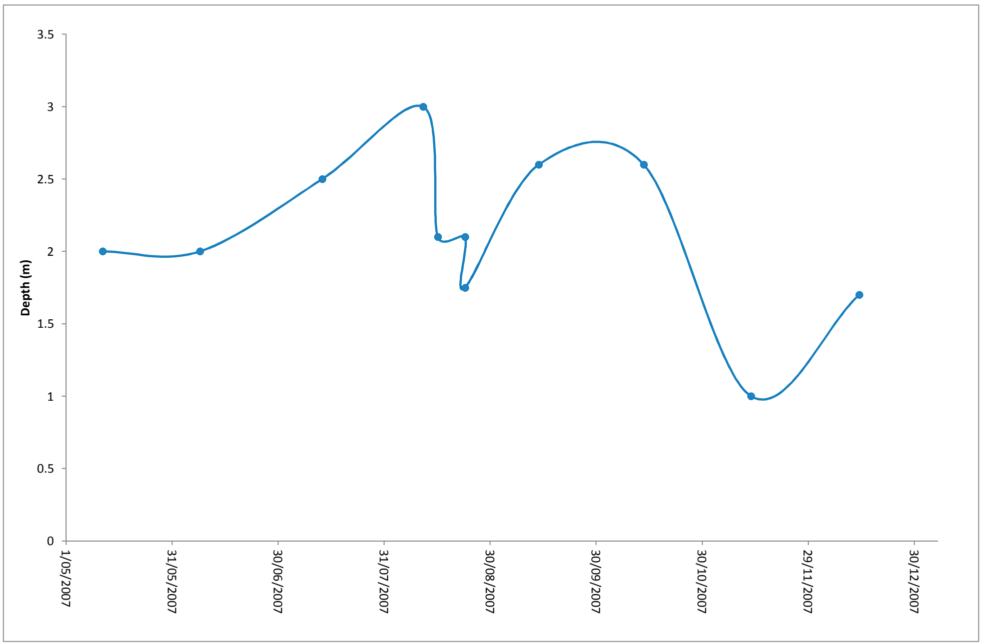


Figure 22. *Water depth at site P2 during 2007.*

Trends and patterns

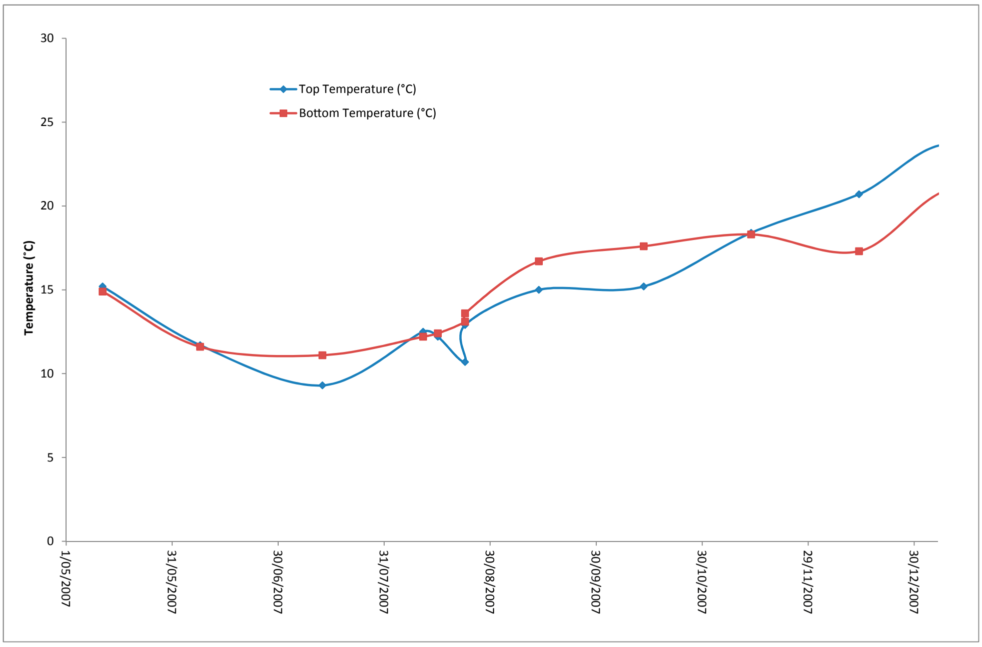


Figure 23. *Temperature (top and bottom) at site P2 during 2007.*

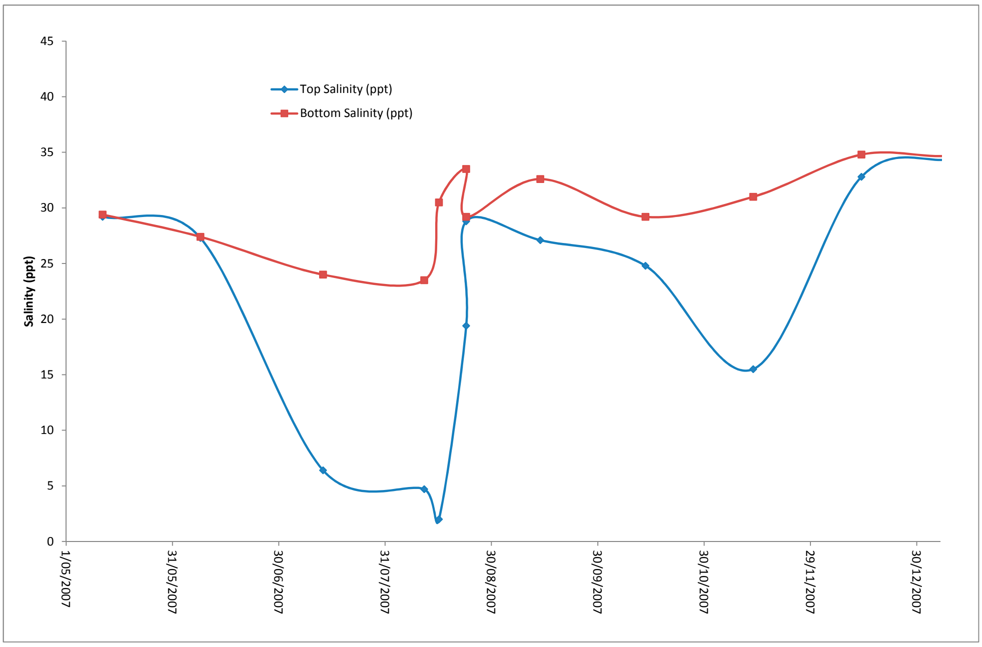


Figure 24. *Salinity (top and bottom) at site P2 during 2007.*

Trends and patterns

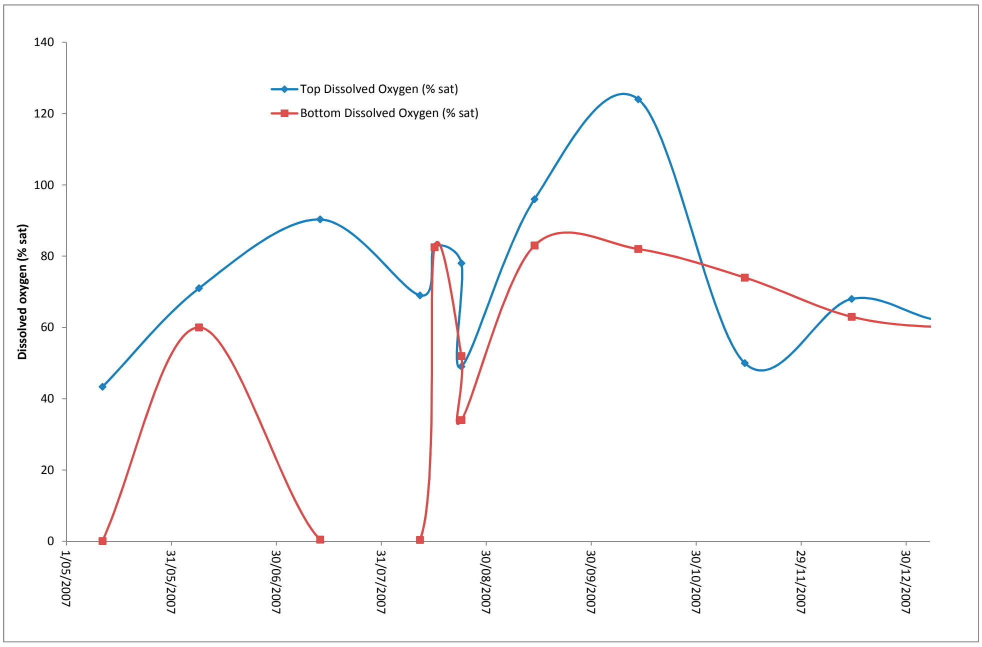


Figure 25. Dissolved oxygen (top and bottom) at site P2 during 2007.

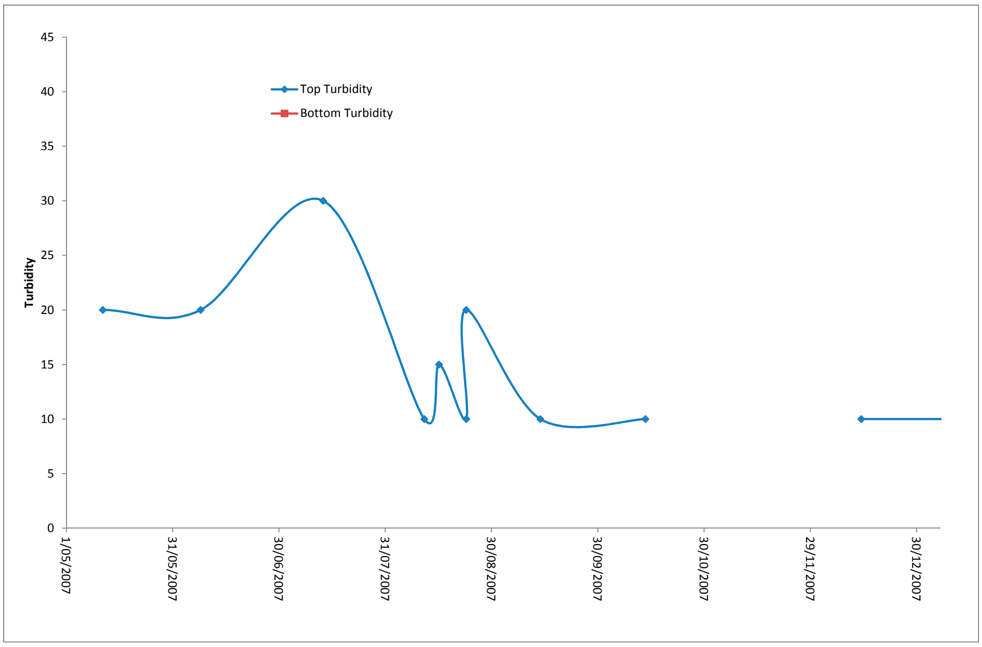


Figure 26. Turbidity (NTU) (top only) at site P2 during 2007.

Trends and patterns

2008

In 2008 the estuary was closed to the sea apart from one potential natural opening in June (Figure 27). This closure continued until October 2009. During the summer-winter period the estuary experienced extremely low water levels, recorded as being below the gauge board, this was not apparent in the depth readings at site P2 (Figure 28). Also during this time sea water was observed entering the estuary at high tide. Rainfall during 2008 was extremely low, as were the river flows, no river flow entered the estuary for the first half of the year. In 2008 the Painkalac Reservoir was at 100% capacity from January 1 to January 8 and December 15 to December 31 (Barwon Water, 2014).

The consequences of the estuary receiving no fresh water inflows during the first half of the year, and the only inflows being from the sea on some high tides resulted in the dramatic reduction in water volume in the estuary. This resulted in significant evaporation from the water surface further reducing water levels. This also increased the estuary's salinity resulting in a hyper-saline environment as can be seen in Figure 30.

During the first half of the year the estuary was mostly fully mixed and displayed no stratification. Some minor flow returned to the estuary during winter producing only slight stratification, during these periods dissolved oxygen in the bottom waters was reduced to critical levels (Figure 31). During this year top water dissolved oxygen remained fairly constant and near to healthy, whereas bottom waters displayed lower dissolved oxygen levels.

The temperature at this site displayed the expected season pattern (Figure 29).The turbidity levels in the top water remained fairly stable throughout the year showing a slight increase from summer to winter (Figure 32).

Sea water entering estuary at high tide, March 2008. Photo: David Flanagan

Trends and patterns

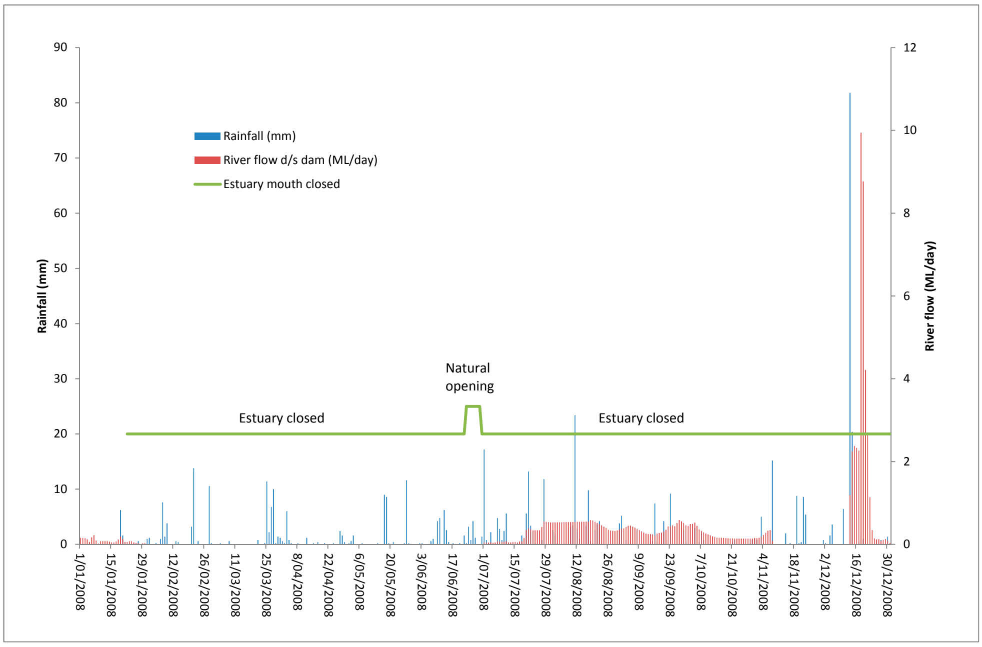


Figure 27. *Rainfall, river flow and estuary closures and openings during 2008.*

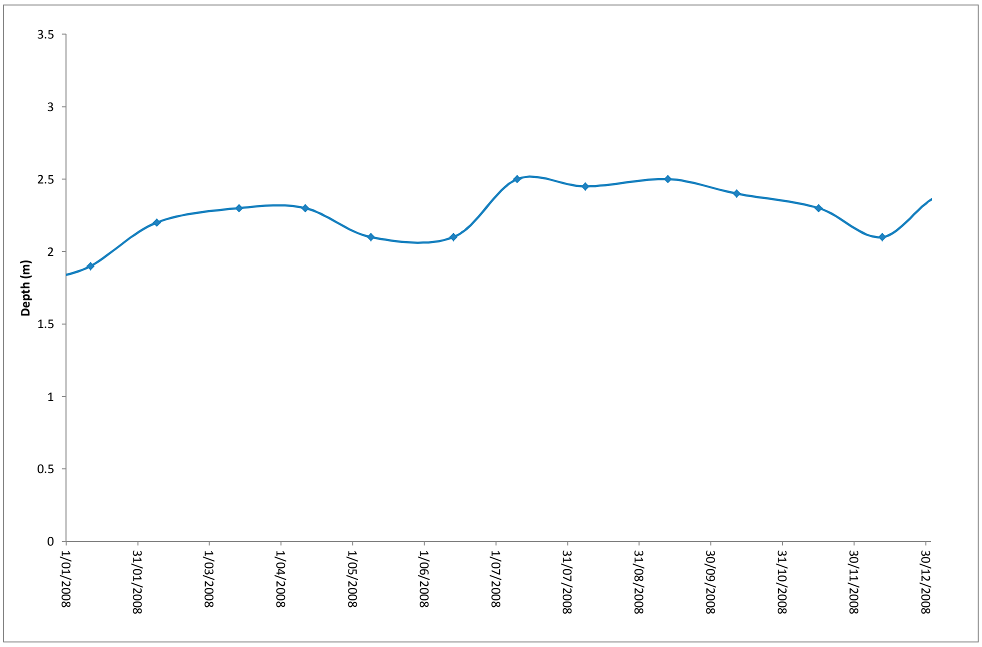


Figure 28. *Water depth at site P2 during 2008.*

Trends and patterns

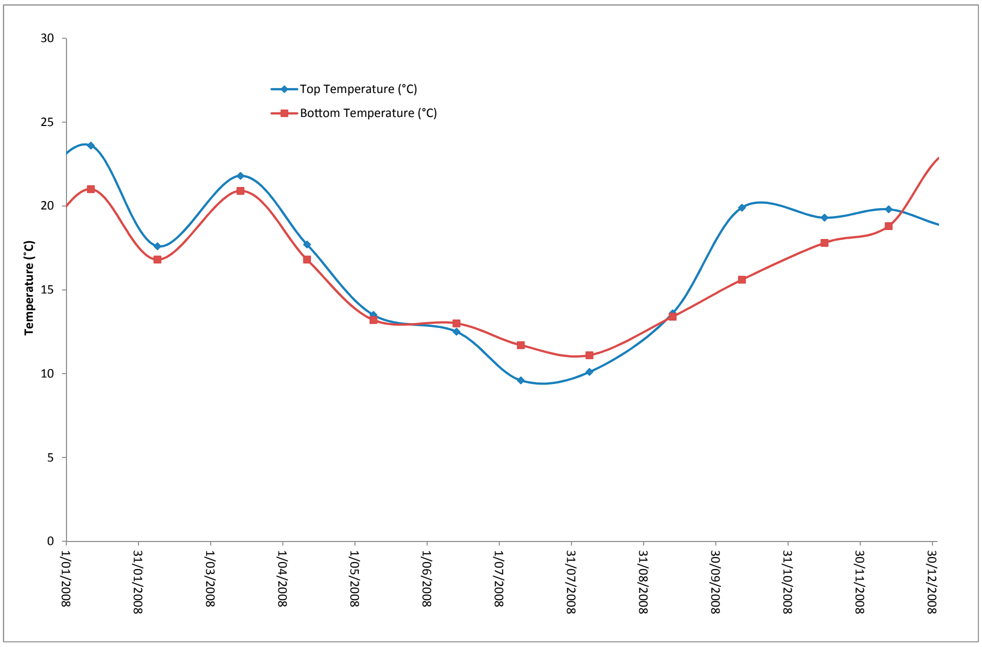


Figure 29. *Temperature (top and bottom) at site P2 during 2008.*

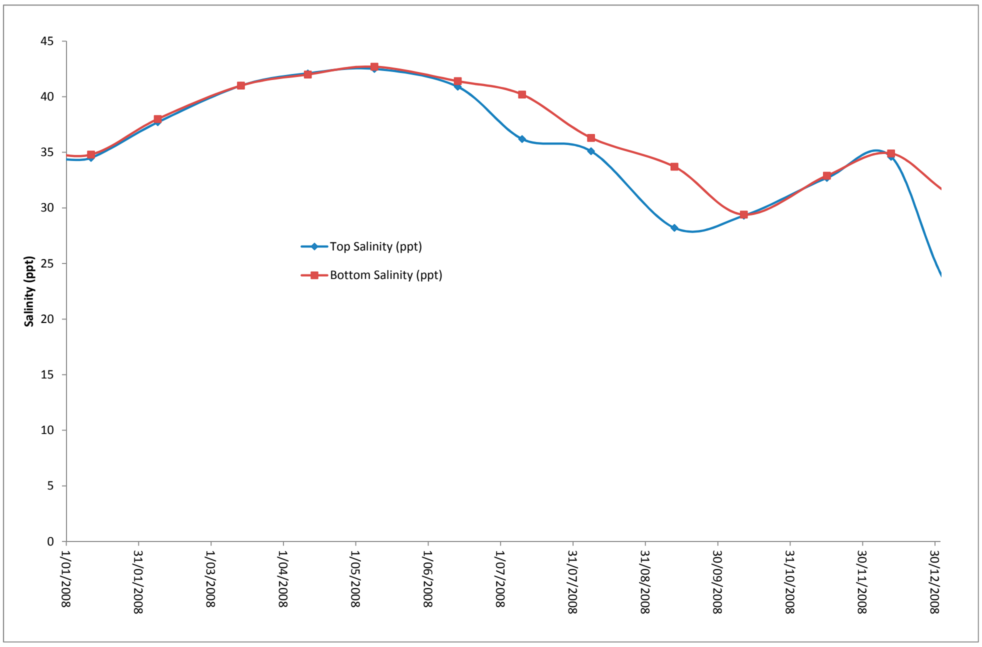


Figure 30. *Salinity (top and bottom) at site P2 during 2008.*

Trends and patterns

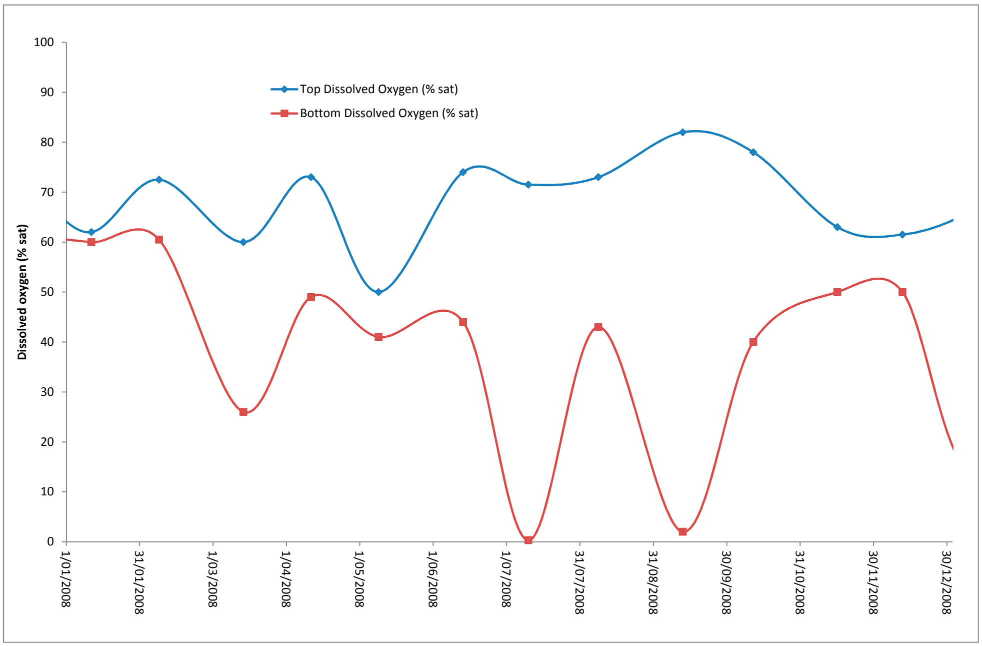


Figure 31. *Dissolved oxygen (top and bottom) at site P2 during 2008.*

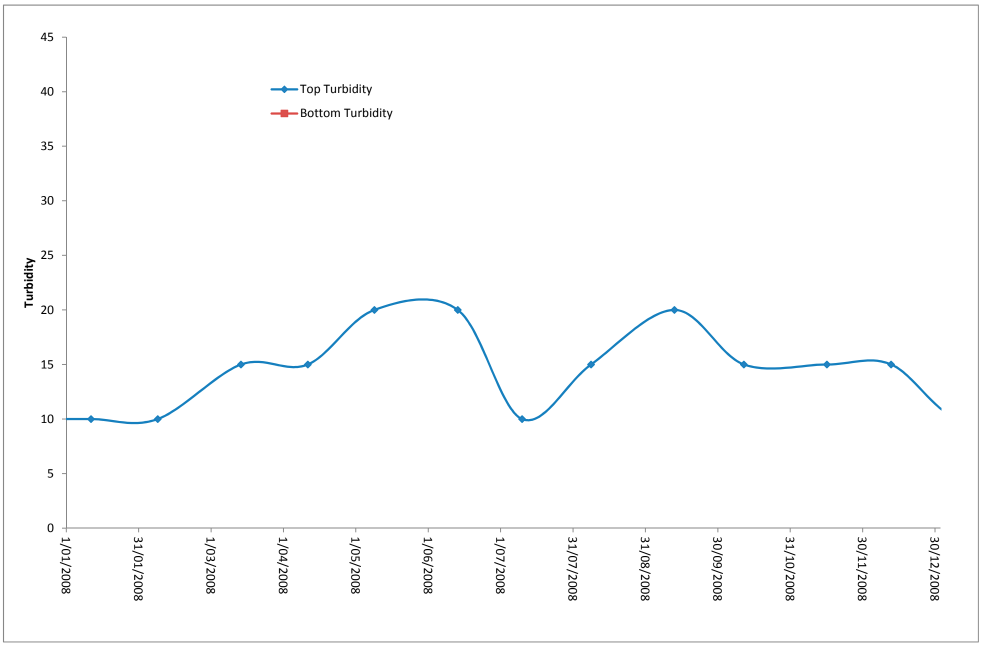


Figure 32. *Turbidity (NTU) (top only) at site P2 during 2008.*

Trends and patterns

2009

During 2009 the Painkalac Creek Estuary had one artificial estuary mouth opening on October 5 (Figure 33). And potentially one natural opening, this natural opening is likely to be an incorrect assumption as the water level at the gauge board was extremely low and may have been recorded due to inflows from the sea breaching the berm at high tide.

From the data collected, following the opening in October the estuary remained open for only a short period, possible eight days (as monitoring is not performed daily this is an estimate from the mouth condition data), after which the estuary mouth closed and the estuary became isolated from the sea. The estuary may have closed sooner as the last mouth condition observation to record the estuary as "open" was October 10, the next observation was October 18 reported 'closed'.

In 2009, the Painkalac Reservoir was at 100% capacity between August 30 and December 1 (Barwon Water, 2014). During the October event the estuary received moderate river flows with a maximum of 21 ML/day recorded before the opening, and a maximum of 9 ML/day after the opening (Figure 33). The effect of these river flows and the opening on the water level within the estuary can be seen in Figure 34. Following this opening there is a sharp drop in water level. Also evident, is the rapid increase in water level within the estuary before the opening and the rise in turbidity (Figure 38). Following the closure of the estuary after the October opening the estuary experienced low water levels. Though not evident in the site data, this information was gathered from the gauge board heights in the mouth condition data.

For the remainder of the time the estuary was isolated from the sea. The water temperature during the year displayed the expected seasonal pattern of being cooler during the winter (Figure 35). Also displayed is during January the bottom waters were warmer than the top waters. This is likely due to the bottom substrate being warmed by solar radiation and with stratification reducing the potential for the top and bottom waters to mix. This also occurs in December but is likely due to influent river flow and as a result of stratification.

Stratification was evident in the water column in August and September prior to the opening, and following the opening in November and December, this can be observed in the salinity profile (Figure 36). Prior to the opening, stratification was significant with the top waters representing almost fresh water and the bottom brackish water. The results of this stratification was seen to reduce the concentration of dissolved oxygen levels in the bottom waters to critical levels (Figure 37) which would have caused severe stress to marine dependent fish. Prior to the October opening, the estuary displayed slight stratification in January, resulting in low dissolved oxygen levels in the bottom waters. Very low dissolved oxygen levels in the bottom waters were also recorded in April and may be the result of the breakdown of organic matter close to the substrate. The estuary was not stratified on this occasion.

The opening in October resulted in the return of sea water to the estuary upon the returning high tide. This can be observed with the sharp increase in salinity levels in the bottom water being representative of sea water (Figure 36). Also apparent, is the return of healthy dissolved oxygen levels at this site (Figure 37). Further stratification was evident after the opening when the estuary closed again.

Trends and patterns

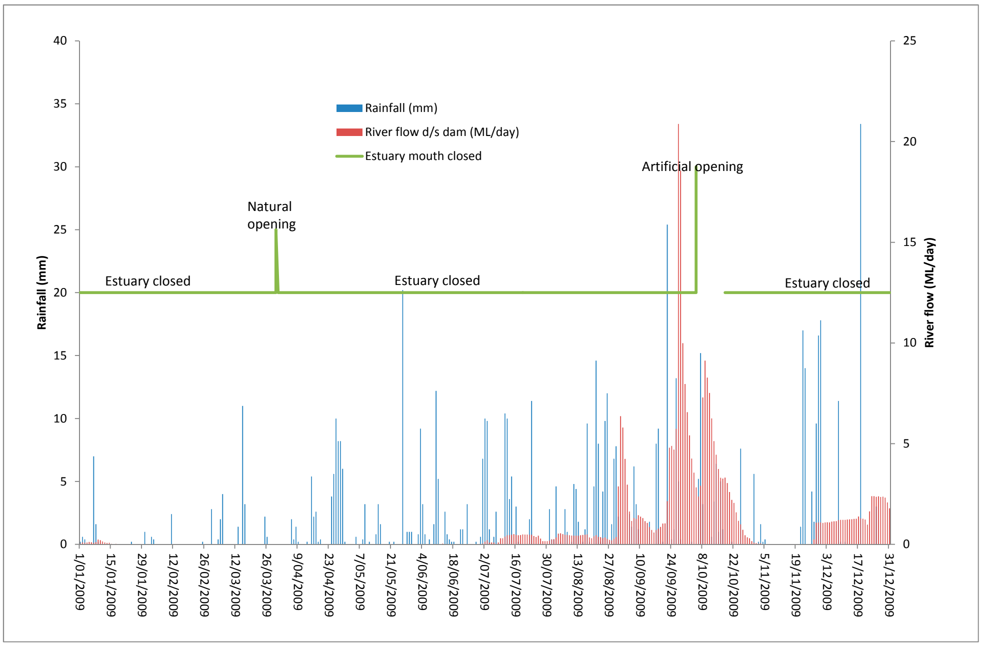


Figure 33. Rainfall, river flow and estuary closures and openings during 2009.

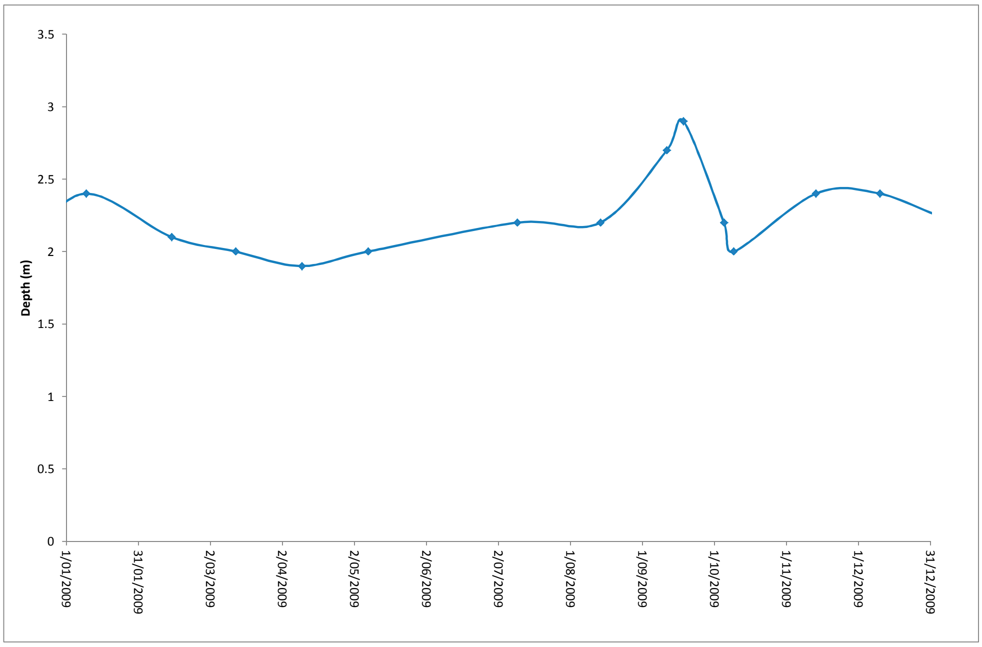


Figure 34. Water depth at site P2 during 2009.

Trends and patterns

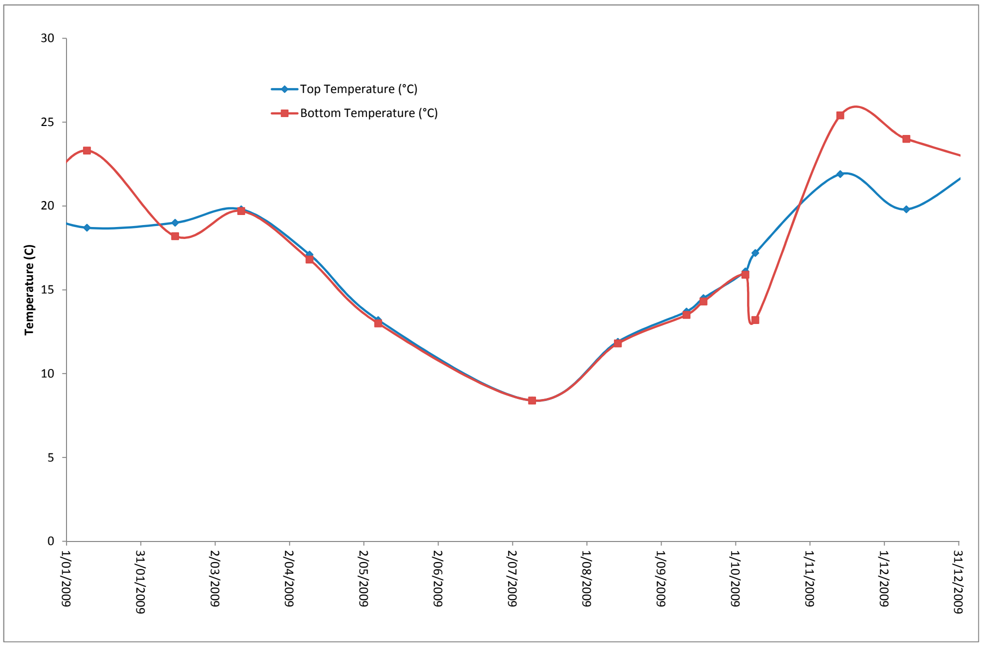


Figure 35. *Temperature (top and bottom) at site P2 during 2009.*

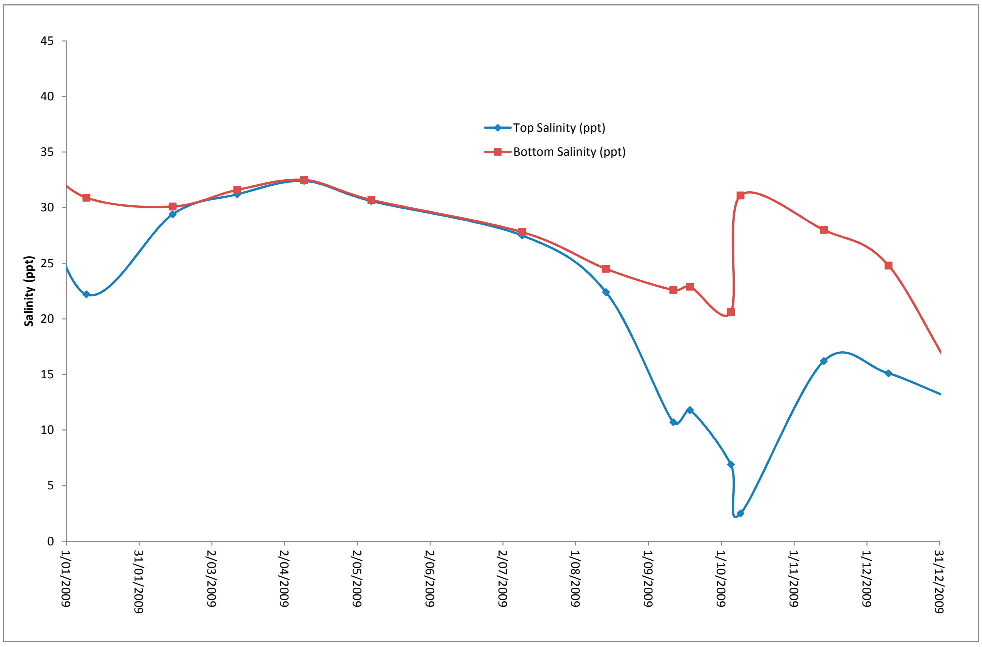


Figure 36. *Salinity (top and bottom) at site P2 during 2009.*

Trends and patterns

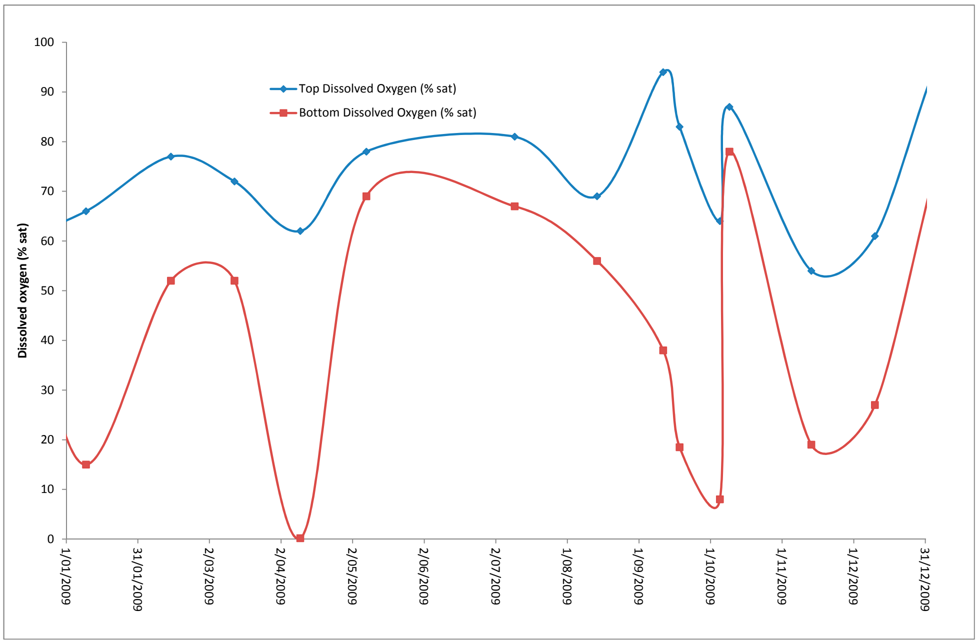


Figure 37. *Dissolved oxygen (top and bottom) at site P2 during 2009.*

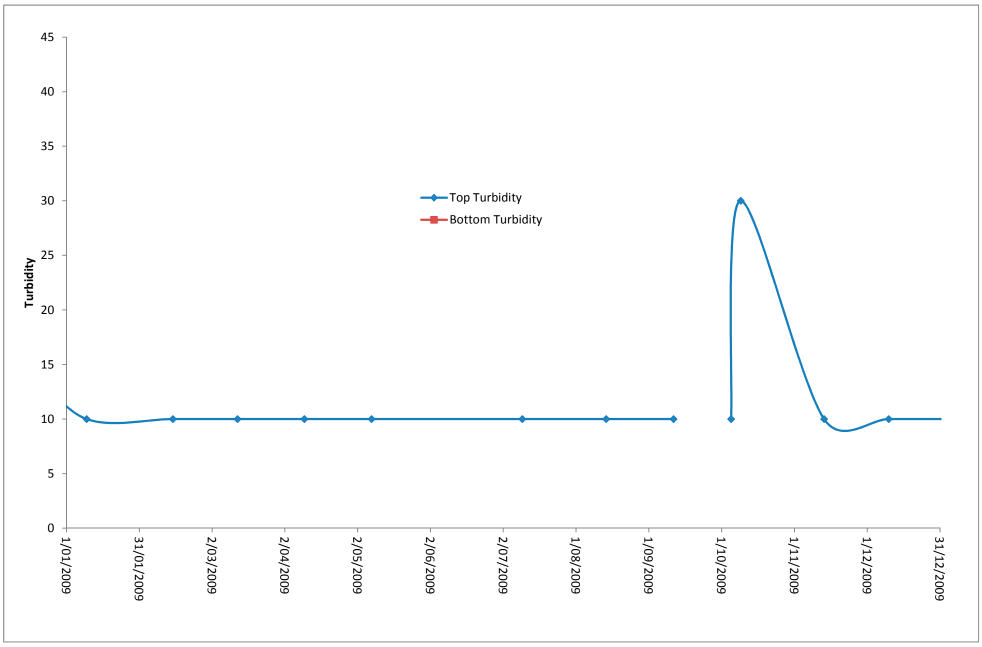


Figure 38. *Turbidity (NTU) (top only) at site P2 during 2009.*

Trends and patterns

2010

During 2010 the Painkalac Creek Estuary had two artificial estuary mouth openings on August 12 and October 9 (Figure 39). For the first half of 2010 up until August 12 the estuary mouth was closed, during this period temperature followed the same trend as previous years experiencing cooler temperatures during winter (Figure 41). Through most of autumn the bottom waters were slightly warmer than the top waters. The salinity indicated the estuary to be mostly brackish with no stratification (Figure 42). There was some fluctuations in the dissolved oxygen levels in the water during this period with the top water consistently higher than the bottom waters (Figure 43), the dissolved oxygen levels were generally in the moderate to healthy range and turbidity levels were low.

From the data collected, following the openings in August and October it is unclear how long the estuary remained open. It is assumed the estuary remained open beyond September 11, 2010 but must have closed prior to the opening in October. Following the October opening the estuary was observed to be closed on November 11 the estuary remained open for possibly a one-month period.

In 2010 the Painkalac Reservoir was at 100% capacity between August 12 and August 17, August 19 and September 16, and October 7 and December 04 (Barwon Water, 2014). During the August event the estuary received significant river flows with 106 ML/day being recorded at the gauge station (Figure 39) on the day of opening, also on the day of the opening 37mm of rainfall was recorded. The effect of the rainfall and river flow on the water level within the estuary can be seen in Figure 40. Following both openings there is a gradual drop in water level. Also evident is the gradual rise in water level within the estuary before the August opening. This is not apparent in the October opening due to no data being collected. Along with the rise in river flow is an increase in turbidity within the water column (Figure 44), additionally, there is also a decrease in top water pH (Figure 45) most likely transported into the estuary from acid sulphate soils in the catchment, possibly from the Distillery Creek sub-catchment.

Following the closure of the estuary after the October opening the estuary remained stratified with dissolved oxygen level in the bottom waters becoming critical, as river flows decreased dissolved oxygen levels in the bottom waters returned to marginal levels. Top water dissolved oxygen levels were maintained in the healthy range during this period. The pH levels also returned to normal levels.


EstuaryWatch monitoring, site P5. Photo: Corangamite CMA

Trends and patterns

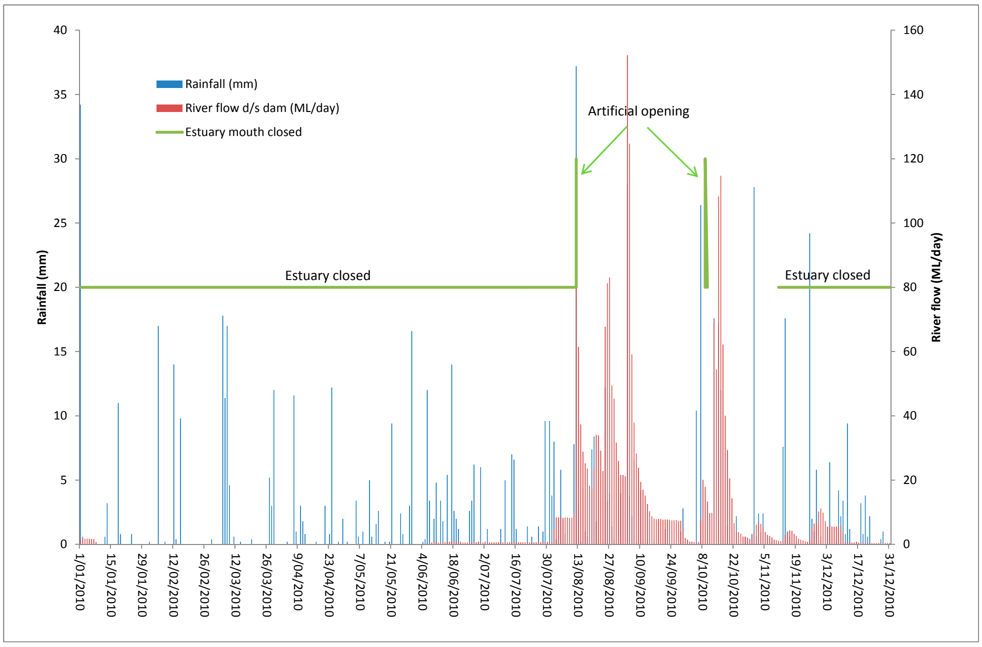


Figure 39. *Rainfall, river flow and estuary closures and openings during 2010.*

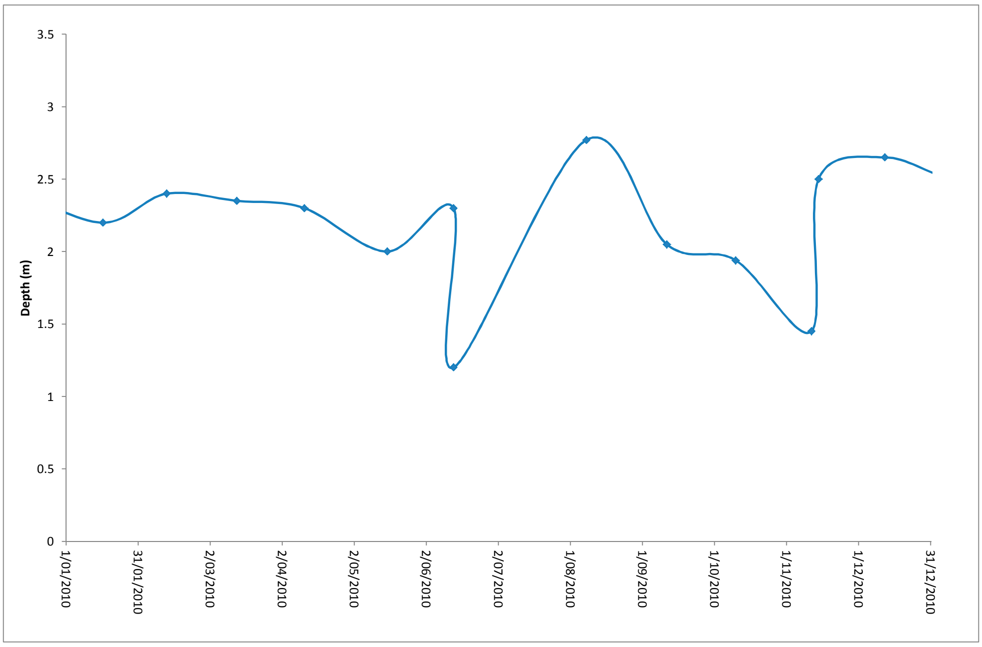


Figure 40. *Water depth at site P2 during 2010.*

Trends and patterns

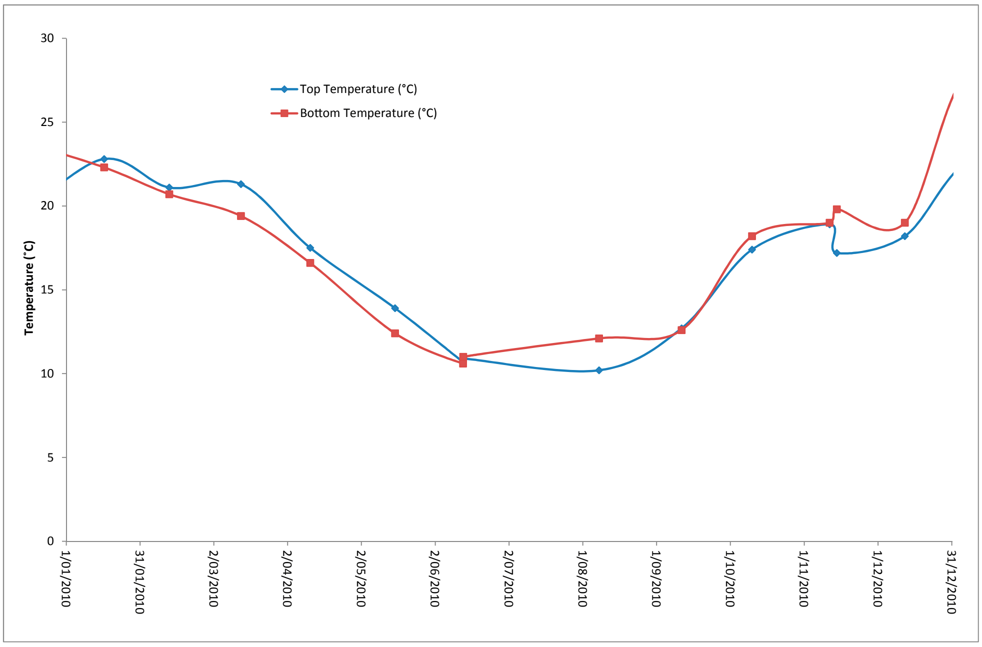


Figure 41. *Temperature (top and bottom) at site P2 during 2010.*

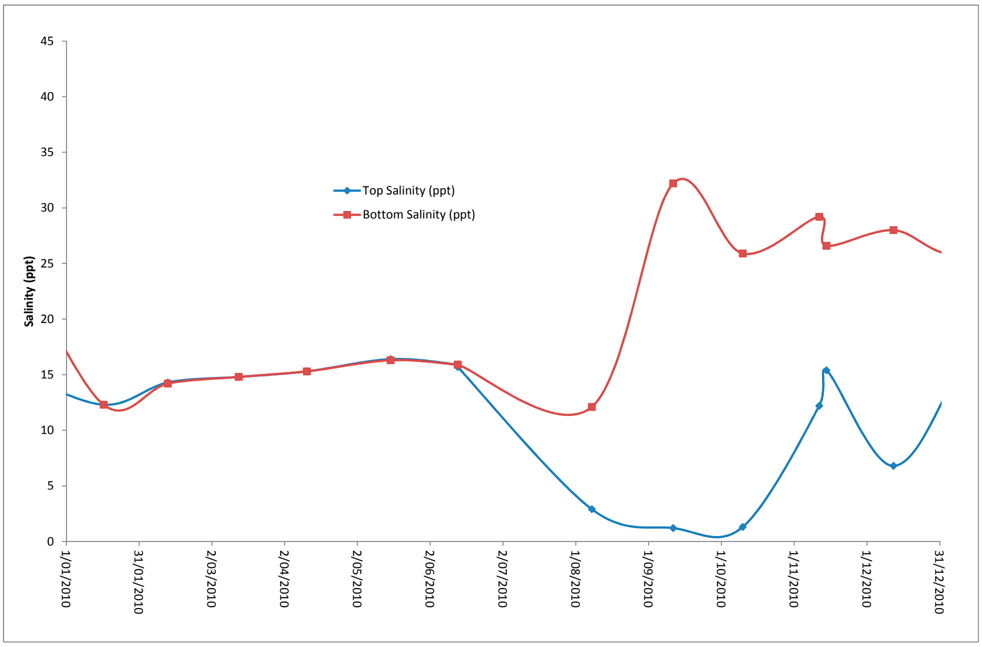


Figure 42. *Salinity (top and bottom) at site P2 during 2010.*

Trends and patterns

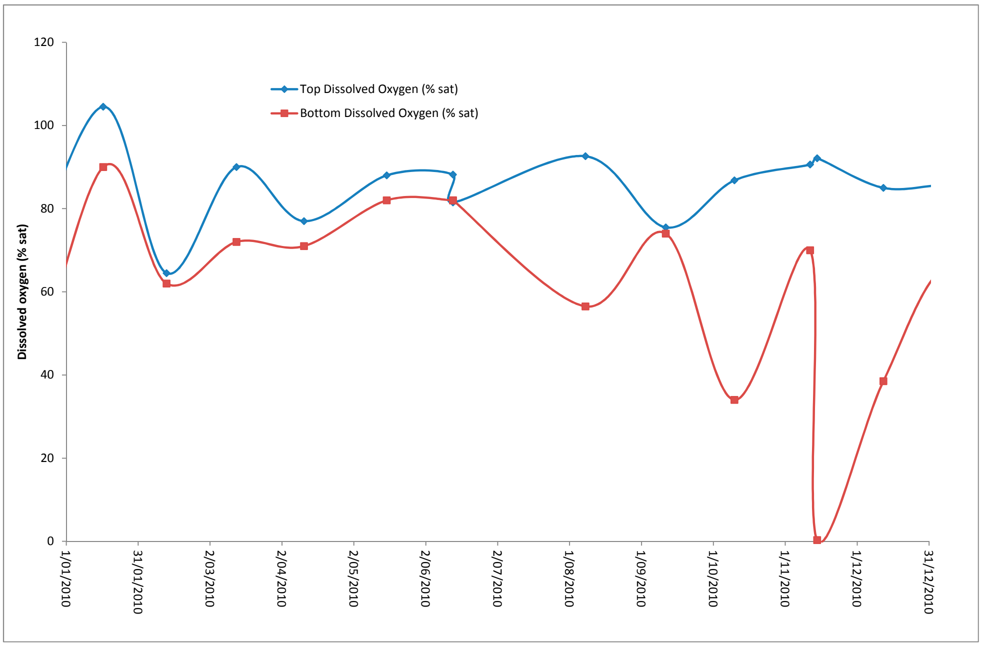


Figure 43. *Dissolved oxygen (top and bottom) at site P2 during 2010.*

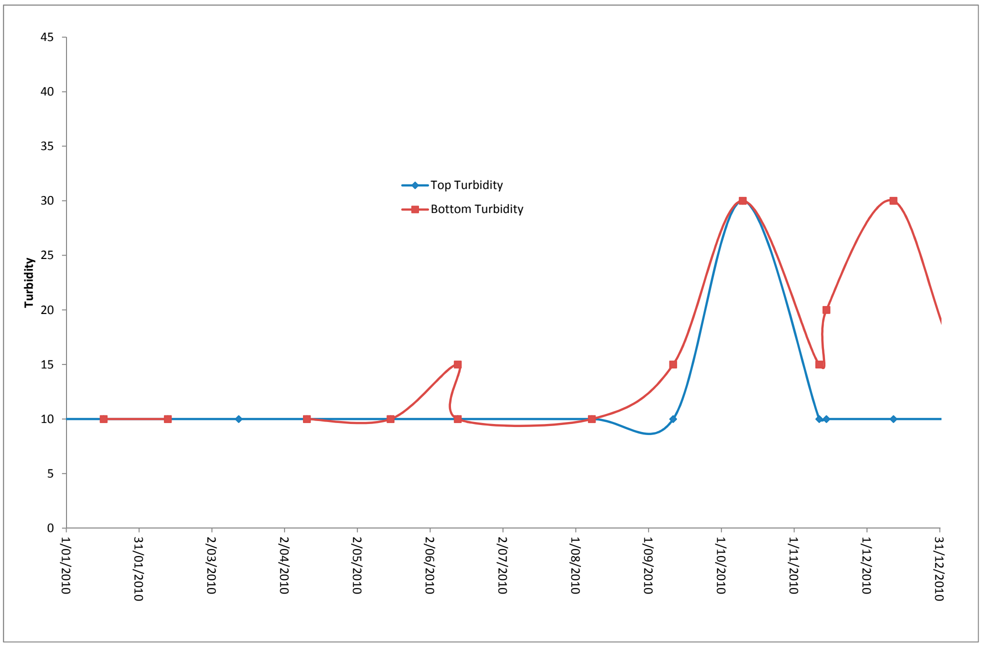


Figure 44. *Turbidity (NTU) (top and bottom) at site P2 during 2010.*

Trends and patterns

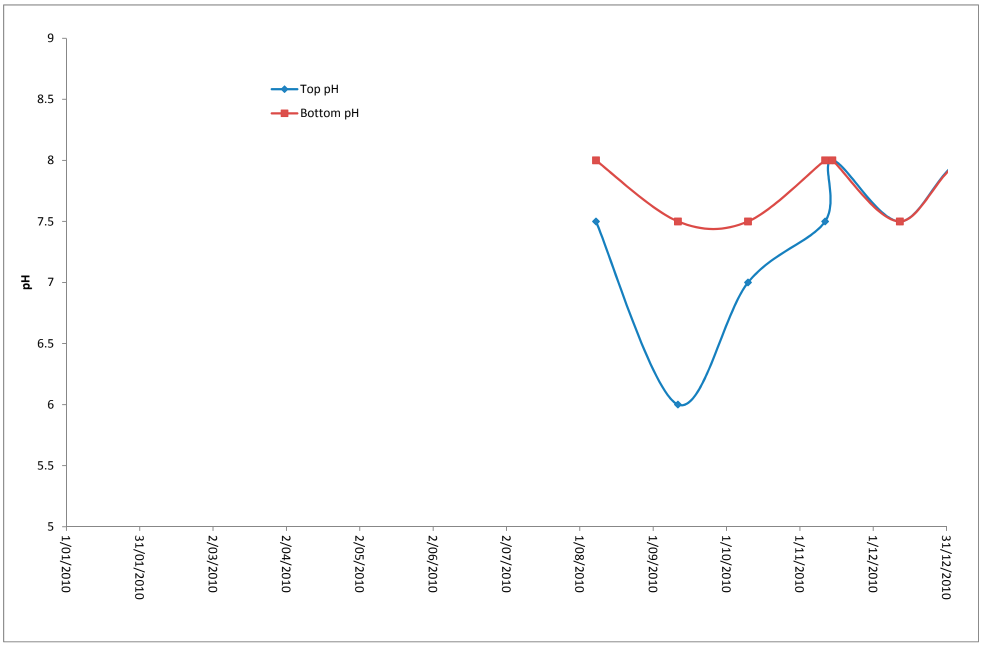


Figure 45. *pH (top and bottom) at site P2 during 2010.*

Trends and patterns

2011

During 2011 the Painkalac Creek Estuary had two artificial estuary mouth openings on the January 13 and July 14 (Figure 46). The January opening was an illegal opening. From the data collected following the opening in January the estuary remained open for only a short period, possible two weeks (as monitoring was not undertaken until February at which time the estuary was closed). Following the opening in July the estuary remained open for possibly one month.

There was a reduction in water level following both openings, water level also showed increases at times of high rainfall (Figure 47). The temperature displayed the usual seasonal pattern being cooler in winter (Figure 48). Also the bottom waters were warmer than the top during April and May.

Following the illegal opening in January by February the top and bottom waters displayed a salinity representing seawater (Figure 49). Seawater was observed to be entering the estuary at high tides on several occasions after the estuary was closed. Several high rainfall events occurred in mid-February and mid-March. The effect of this created stratification resulting in a reduction in dissolved oxygen levels in the bottom waters (Figure 50). This pattern was repeated several times over the year. The top waters dissolved oxygen levels remained in the healthy range throughout the year.

In 2011 the Painkalac Reservoir was at 100% capacity between January 12 and February 2, and July 8 and December 19 (Barwon Water, 2014). After the opening in July river flows increased and stratification occurred, there was a drop in dissolved oxygen levels in the bottom waters, it appears this stratification was reduced by influent sea water in August which also improved the dissolved oxygen levels in the bottom waters. By October stratification was once again apparent resulting in a decline in dissolved oxygen levels in the bottom waters.

In late November the estuary appeared to be mixed throughout the water column and dissolved oxygen levels in the bottom waters returned to moderate levels.

The pH levels remained within the healthy range for most of the year with only one spike in September (Figure 52). The pH was not sampled at the time of the July opening.

Turbidity levels remained reasonably low throughout the year, though sampling was not undertaken around the time of the opening in July. On several occasions the bottom water was slightly higher in turbidity than the top water (Figure 51).

Artificial estuary opening, July 2011. Photo: Corangamite CMA

Trends and patterns

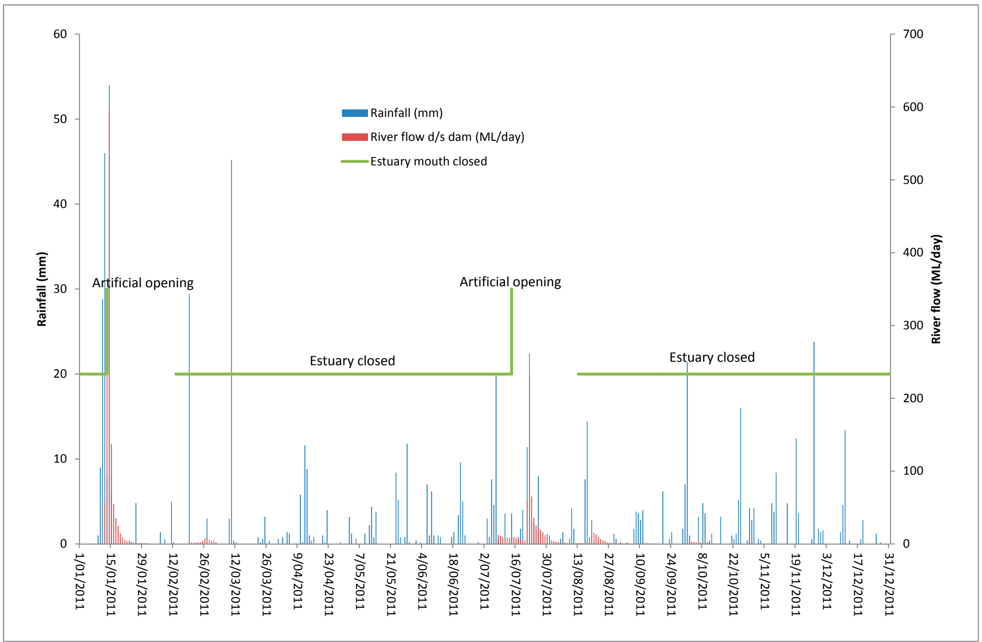


Figure 46. Rainfall, river flow and estuary closures and openings during 2011.

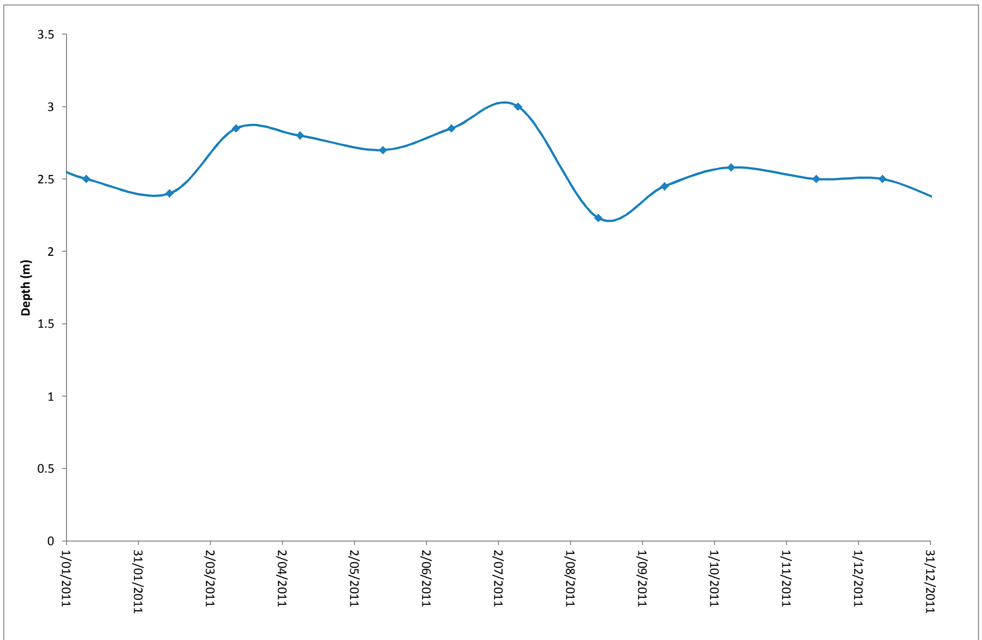


Figure 47. Water depth at site P2 during 2011.

Trends and patterns

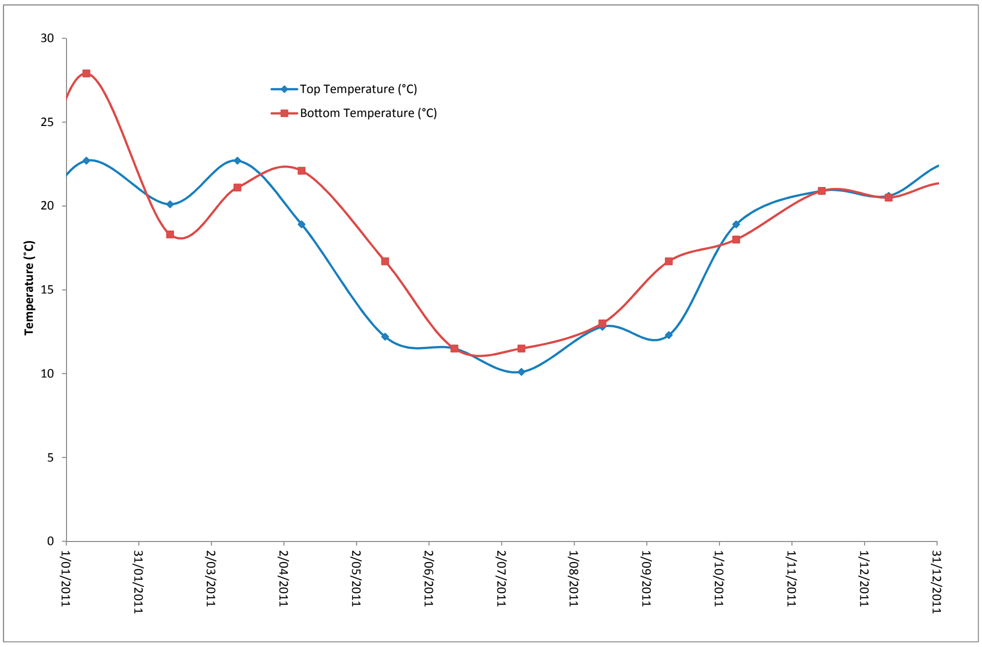


Figure 48. *Temperature (top and bottom) at site P2 during 2011.*

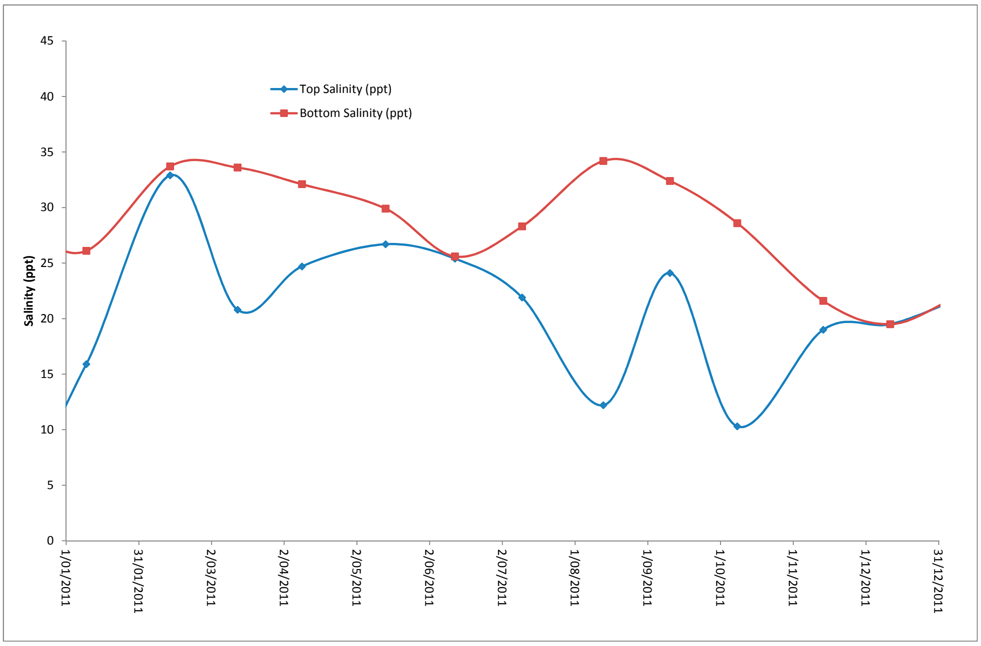


Figure 49. *Salinity (top and bottom) at site P2 during 2011.*

Trends and patterns

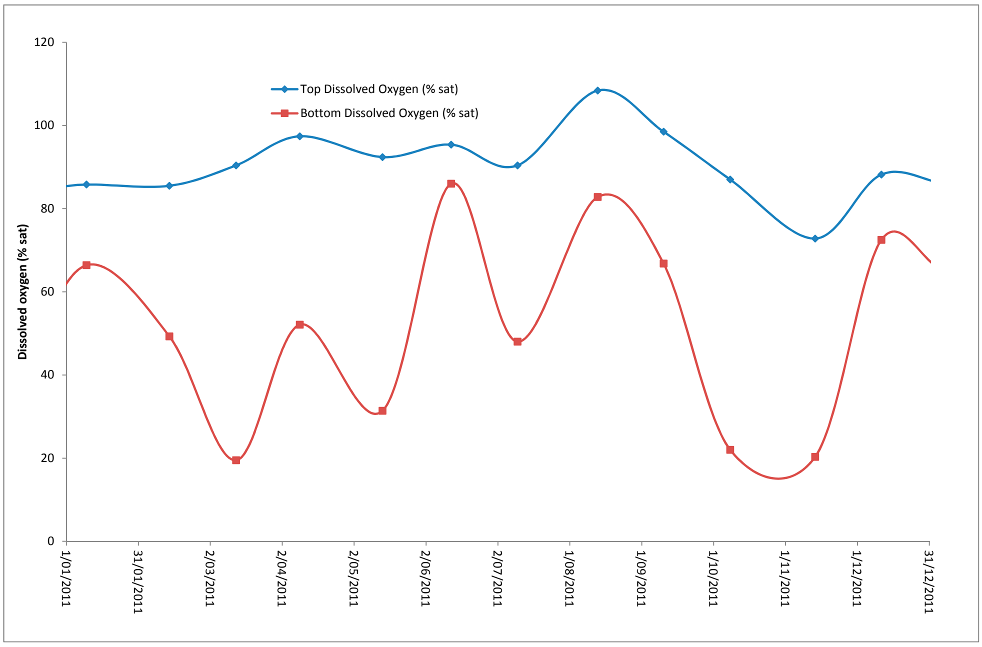


__Figure 50.__ Dissolved oxygen (top and bottom) at site P2 during 2011.

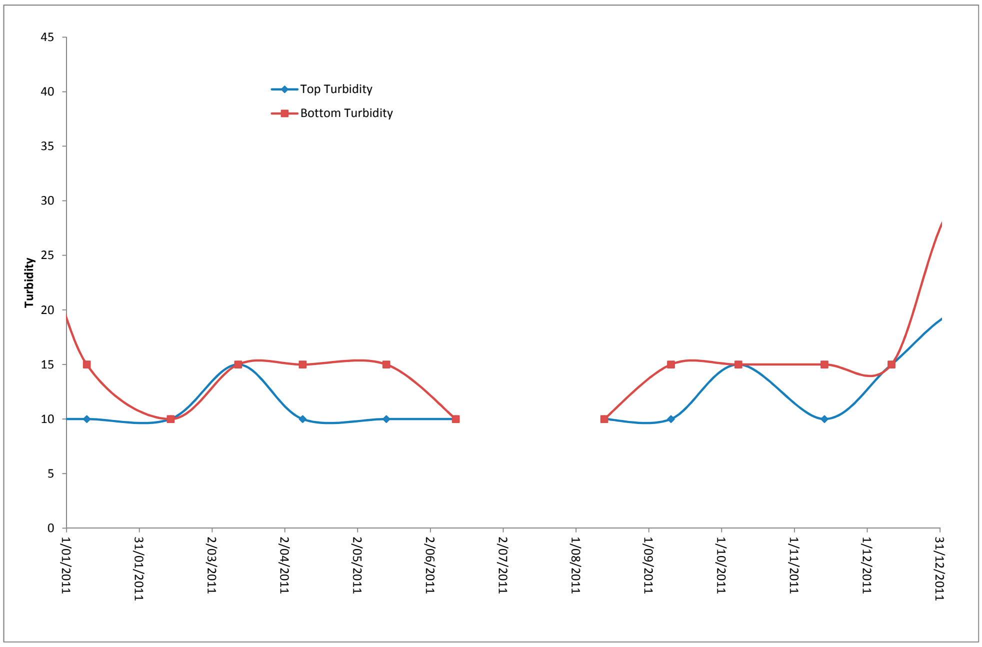


__Figure 51.__ Turbidity (NTU) (top and bottom) at site P2 during 2011.

Trends and patterns

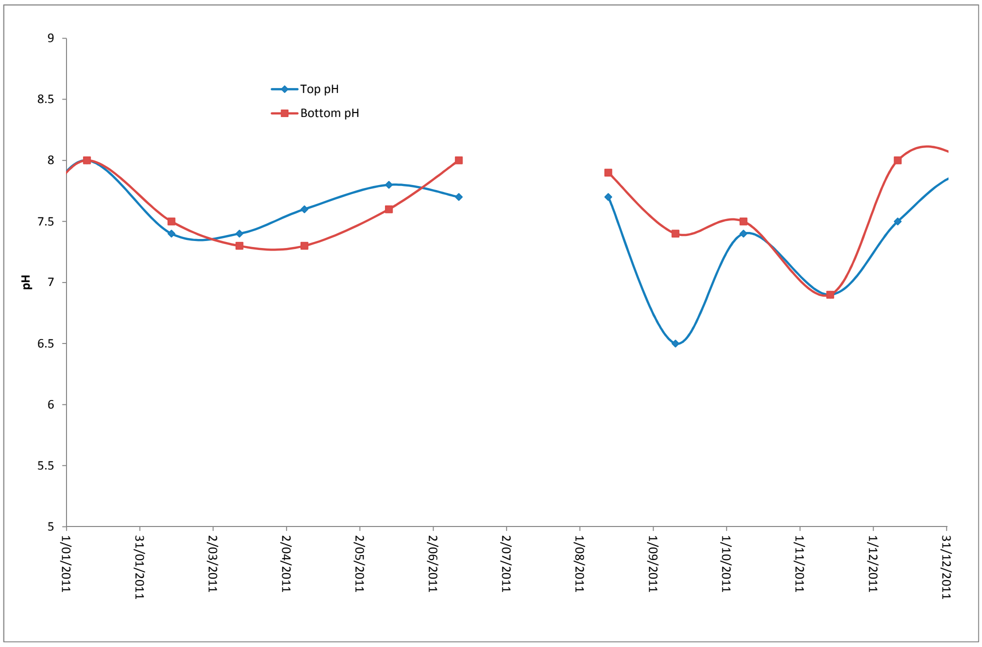


Figure 52. *pH (top and bottom) at site P2 during 2011.*

EstuaryWatch monitoring site, P2. Photo: Corangamite CMA

Trends and patterns

2012

During 2012 the Painkalac Creek Estuary had three artificial estuary mouth openings on June 5, August 11 and October 13 (Figure 53). From the data collected, following the opening in June, the estuary remained open for at least one month. Following the other two openings the estuary remained open for less than a month (as monitoring is not performed daily this is an estimate from the mouth condition data).

In 2012 the Painkalac Reservoir was at 100% capacity between June 4 and November 1 (Barwon Water, 2014). For the first part of the year until late April there was a gradual decrease in depth at the site, increased rainfall resulted in an increase in water level prior to the opening in June (Figure 54). During this summer/autumn period the salinity in the water column was stable showing no stratification (Figure 56). There was a slight increase in salinity from summer to autumn due to influent sea water overtopping the berm at high tide and evaporation.

The dissolved oxygen levels were slightly lower in the bottom waters than the top waters during summer. By early autumn the dissolved oxygen levels in the top waters became the same (moderate) as the bottom waters (Figure 57). By the June opening these returned to healthy levels. There was several higher turbidity levels observed in the bottom waters during this period. The top waters also displayed higher than usual turbidity levels compared to previous years (Figure 58). The pH remained stable during this period (Figure 59) and the temperature displayed the usual trend of cooler in winter (Figure 55).

After the June opening water levels dropped, as did the temperature in the top water. The estuary had a 0.5m layer of freshwater on the top of the near sea water bottom layer, althrough the estuary was stratified, dissolved oxygen levels were in the healthy range. Increases in turbidity were also observed as was the drop in pH in both, the top and bottom waters, the top waters had very low pH (Figure 59). The return of tidal influence was apparent after this opening before the estuary closed. Approximately one month after this opening the dissolved oxygen in the bottom waters were reduced to critical levels.

During the opening in August sampling occurred on the day of the opening and several days after. On this occasion water levels dropped after the opening as did temperature in the top water. Turbidity levels increased at the time of the opening and the pH level dropped slightly. Dissolved oxygen levels in the bottom waters recovered as tidal influence returned to the estuary.

As river flows declined the estuary closed and became stratified resulting in a drop in dissolved oxygen levels in the bottom waters. A moderate rise in water level was observed after the estuary mouth closed. The opening in October displayed a similar pattern to the opening in August.

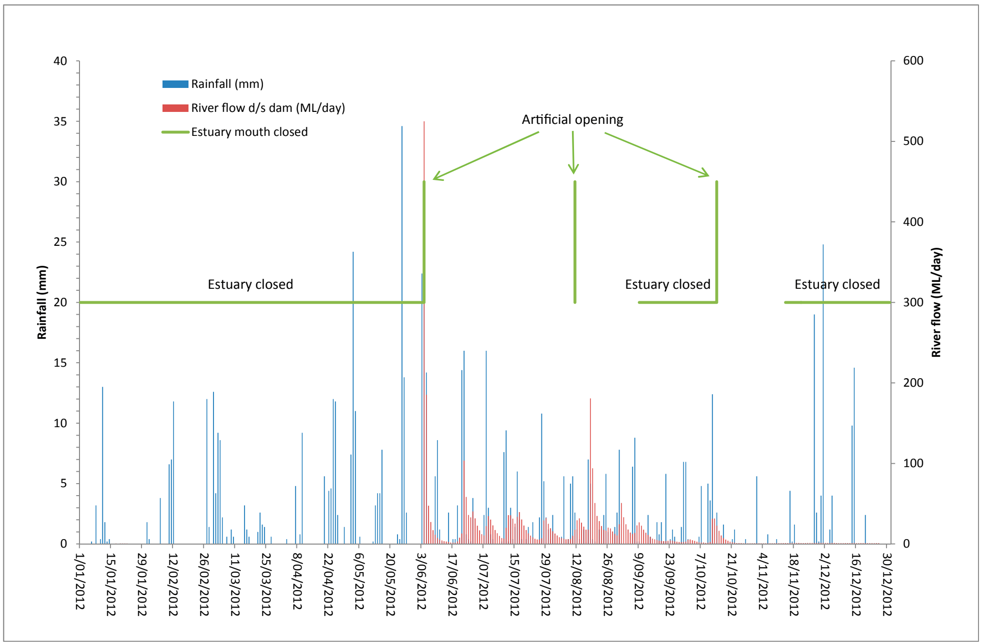


Figure 53. *Rainfall, river flow and estuary closures and openings during 2012.*

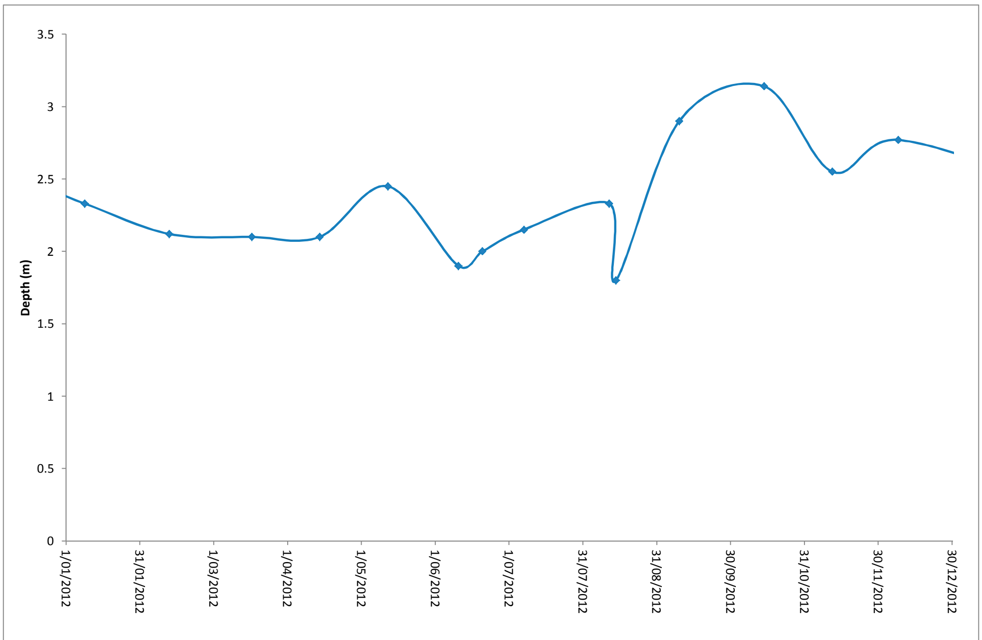


Figure 54. *Water depth at site P2 during 2012.*

Trends and patterns

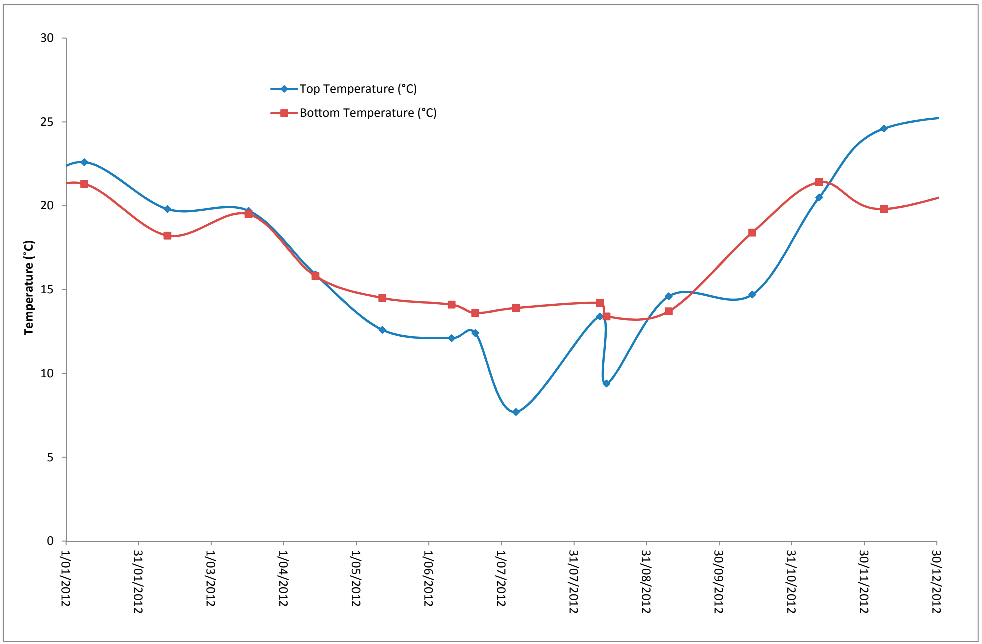


Figure 55. Temperature (top and bottom) at site P2 during 2012.

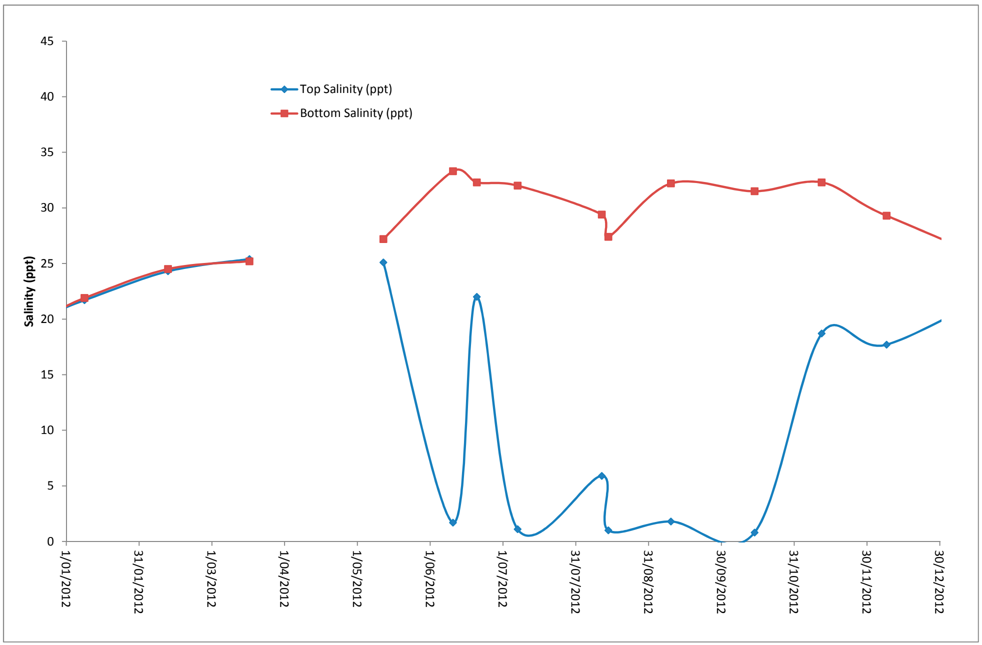


Figure 56. Salinity (top and bottom) at site P2 during 2012.

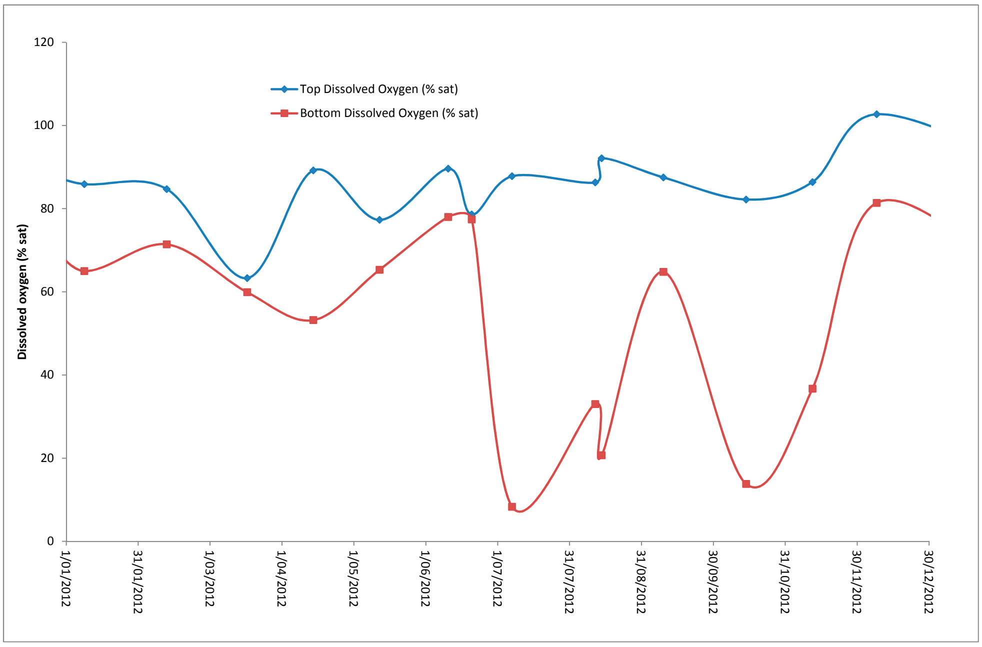


Figure 57. *Dissolved oxygen (top and bottom) at site P2 during 2012.*

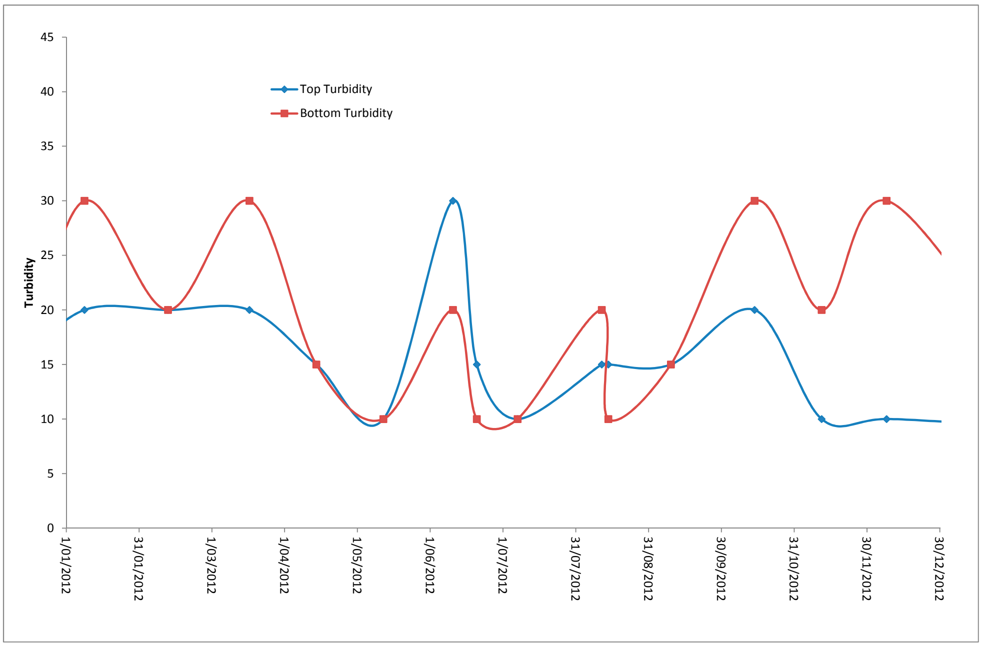


Figure 58. *Turbidity (NTU) (top and bottom) at site P2 during 2012.*

Trends and patterns

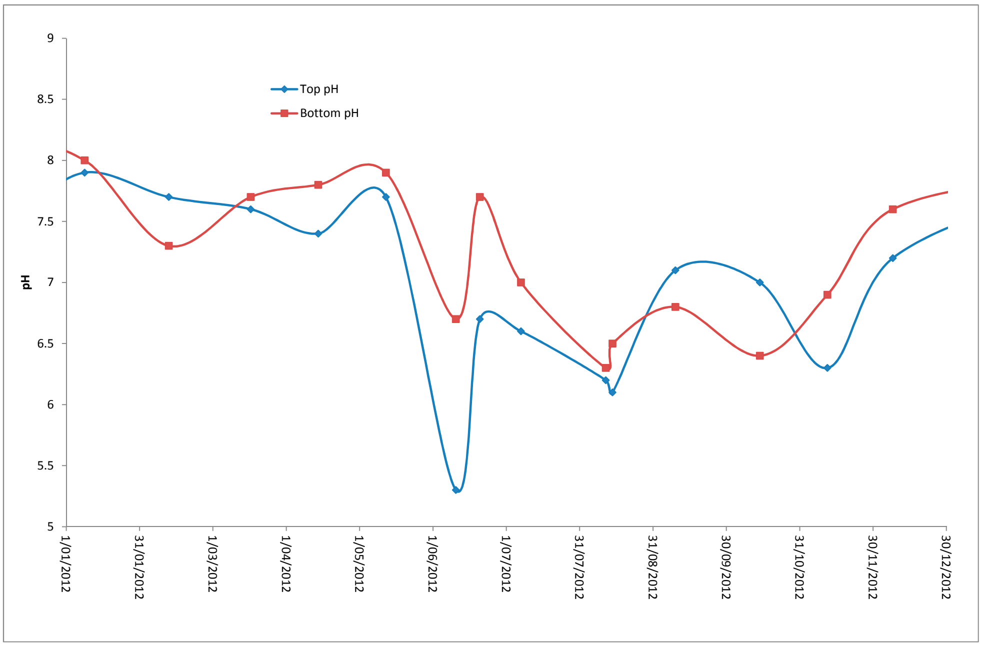


Figure 59. *pH (top and bottom) at site P2 during 2012.*

Painkalac estuary mouth, October 2012. Photo: Corangamite CMA

Trends and patterns

2013

In 2013 Painkalac Creek Reservoir was at 100% capacity between June 14 and December 17 (Barwon Water, 2014). During 2013 the Painkalac Creek Estuary had four artificial estuary mouth openings on March 13 (illegal), June 21, July 12 and August 3 (Figure 60). The data collected following the illegal opening in March, indicates the estuary remained open for only a short period, possible two days (as monitoring is not performed daily this is an estimate from the mouth condition data). After which the estuary mouth closed and the estuary became isolated from the sea. Following the artificial mouth opening in June, the time the estuary was open to the sea is not known, possibly two weeks. Following the artificial mouth opening in July the time the estuary was open to the sea is also unknown.

During the March illegal opening event there appears to be no significant change within the estuary. For the first five months of the year the estuary remained fairly stable. During this period the water level showed a gradual reduction (Figure 61), and the temperature displayed the usual trend becoming cooler during winter (Figure 63). The salinity showed a slight rise over time and represented that of brackish water. The dissolved oxygen levels showed a steady decline until late-March and recovered by mid-April. The levels in the top water remained in the healthy range and the bottom in the moderate range (Figure 64). Turbidity levels remained low and showed a slight rise to mid-April (Figure 65). The pH remained constant (Figure 66).

Prior to the opening in June the estuary became stratified due to recent rainfall and increased river flows. Dissolved oxygen in the bottom waters became marginal. The turbidity levels increased with the higher river flow and pH showed a slight decline.

No sampling occurred between the June and July opening events so interpretation prior to the July event is not possible. Following the opening in July a layer of freshwater (0.5m) was present over the brackish bottom waters, and initially the bottom water dissolved oxygen levels were critically low. There is evidence there was some mixing of top and bottom waters during the following week, and bottom water dissolved oxygen levels improved and top water salinity rose. There is also evidence tidal influence was reintroduced for a short period.

Less than a month later the estuary was opened again, once tidal influences occurred dissolved oxygen recovered to healthy levels at this site.

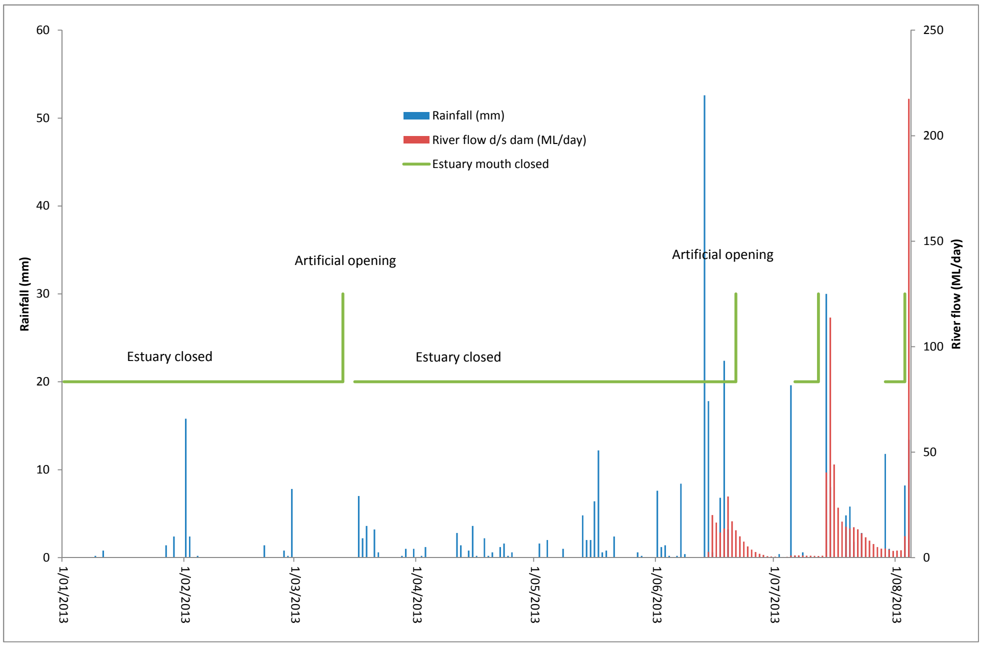


Figure 60. Rainfall, river flow and estuary closures and openings during 2013.

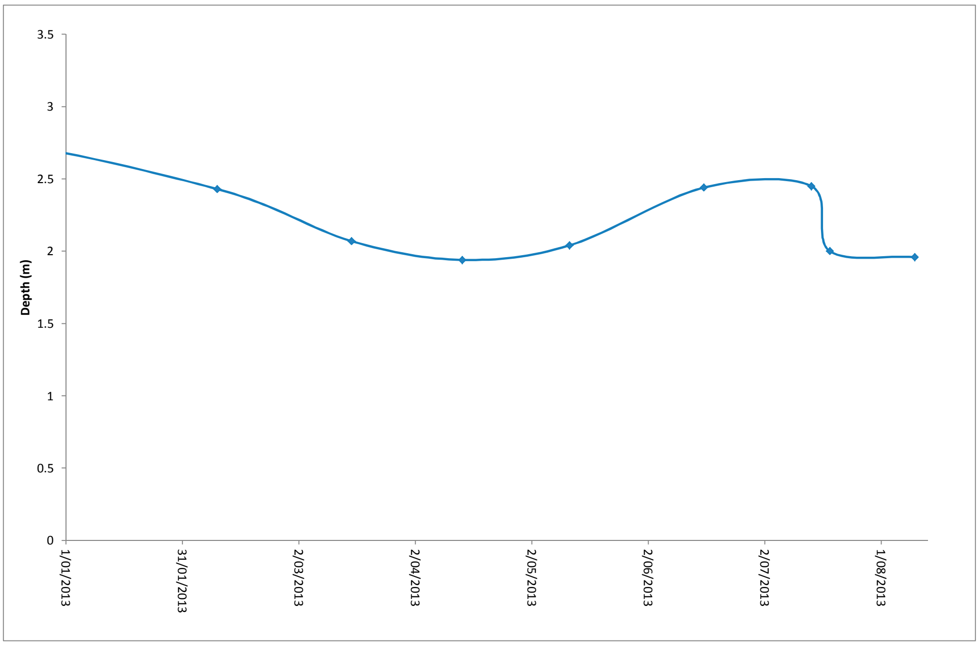


Figure 61. Water depth at site P2 during 2013.

Trends and patterns

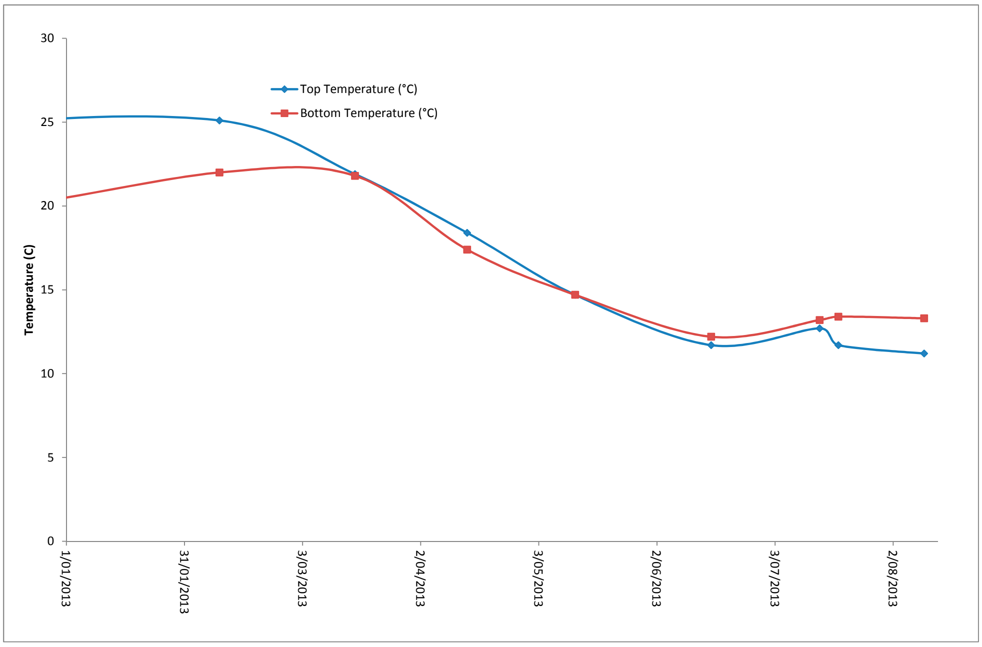


Figure 62. *Temperature (top and bottom) at site P2 during 2013.*

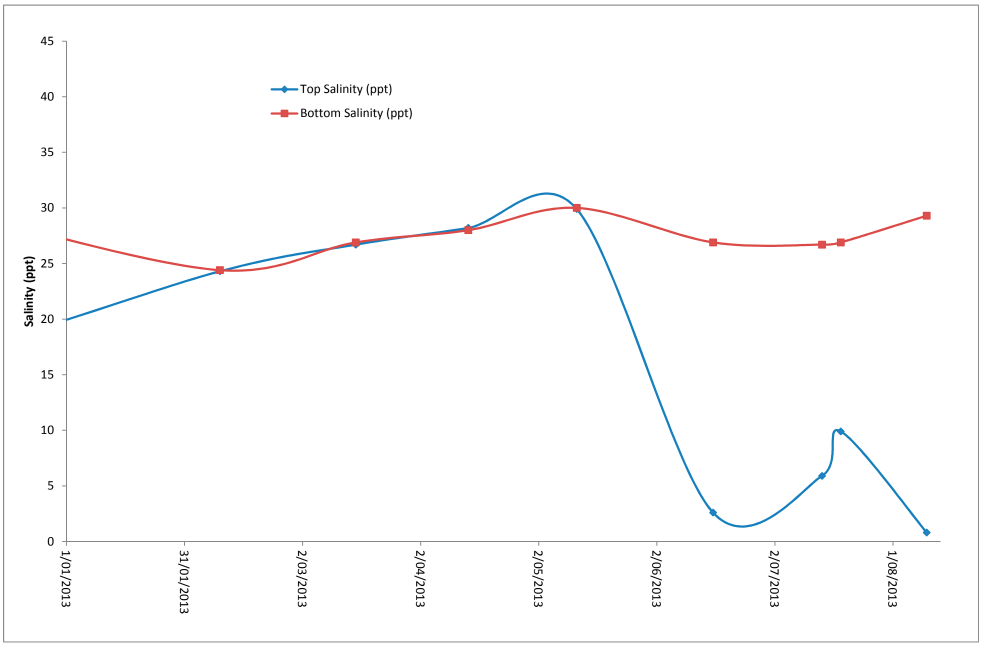


Figure 63. *Salinity (top and bottom) at site P2 during 2013.*

Trends and patterns

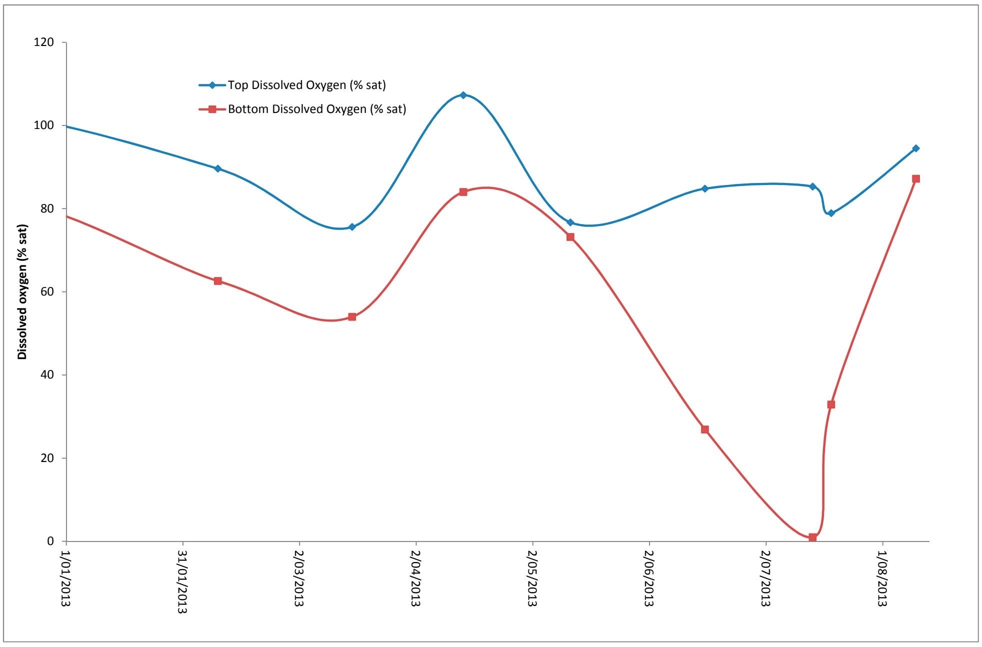


Figure 64. *Dissolved oxygen (top and bottom) at site P2 during 2013.*

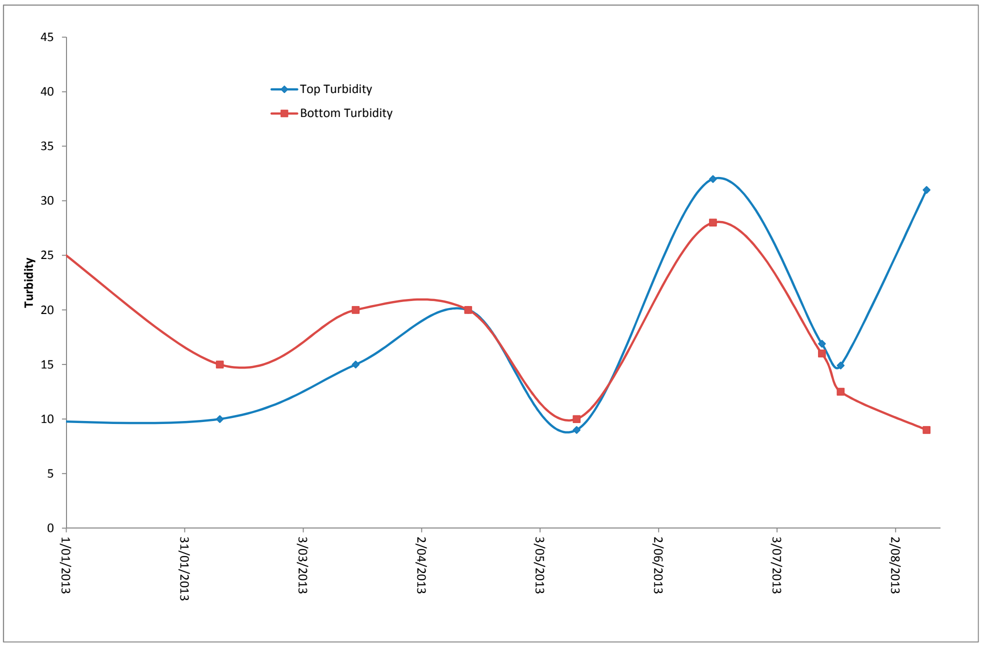


Figure 65. *Turbidity (NTU) (top and bottom) at site P2 during 2013.*

Trends and patterns

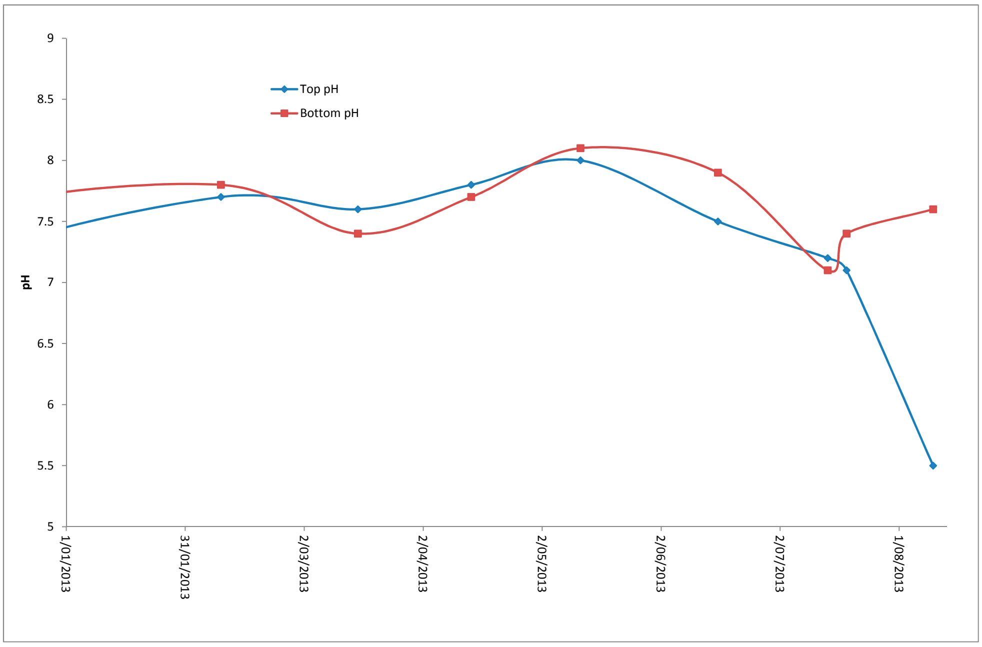


Figure 66. *pH (top and bottom) at site P2 during 2013.*

Painkalac estuary mouth, June 2013. Photo: Corangamite CMA

Trends and patterns

Water quality monitoring site P3 - Summary

Site P3 was sampled on 63 occasions from mid-2007-mid-2013. Table 2 displays the parameters measured and the range of values recorded.

The depth at this site varies dependent on the mouth condition, tidal influences and river flow. The salinity at this site ranged from mostly marine to brackish during late-2007, water levels became extremely low during November 2007 when the estuary was closed to the sea. Sampling on this occasion was not performed from the platform.

During the summer of 2007-2008 this site had higher salinity than sea water, during this period there was no stratification at this site and dissolved oxygen levels ranged from 61-88% saturation. Salinity levels remained close to sea water concentrations until spring 2008.

From spring 2008 the water remained brackish until spring 2009. Increased river flows during spring 2009 provided freshwater to the estuary, close to freshwater concentrations were recorded in the top waters, stratification was also evident with dissolved oxygen levels lower below the halocline.

The salinity levels remained brackish once again during the 2009-2010 summer until spring 2010. Dissolved oxygen levels ranged from 11.5-95% saturation during this period. The low dissolved oxygen levels were recorded in the bottom waters and the top waters were 50% saturation during February 2010. Increased spring river flows returned once again with close to freshwater being observed in the top waters.

By summer 2010-2011 the water became brackish throughout the water column. Dissolved oxygen levels ranged from 57-90% saturation during this period. There was a gap with no data collected from this site from mid-March to early-August. During the following spring (2011) and summer the waters were mostly brackish with dissolved oxygen ranging from 62-97% saturation.

During the 2012 winter, increased river flows resulted in freshwater being observed in the top waters. Stratification was evident resulting in lower dissolved oxygen concentrations being recorded in the bottom waters. By summer 2013 the waters became brackish throughout, dissolved oxygen levels ranged from 67-83% saturation. An increase in river flows in June resulted in freshwater being observed in the top waters, stratification also occurred with reduced levels of dissolved oxygen being recorded in the bottom waters.

Table 2. Displays the range of values recorded for each water quality parameter.

Parameter	Value range
Depth (m)	0.0-1.75
Temperature (°C)	7.3-28.3
Salinity (ppt)	0.8-42.9
Dissolved Oxygen (% saturation)	1.0-119.2
Turbidity (NTU)	9-41
pH (units)	5.3-8.1
Halocline depth from surface (m)	0-1.0

Trends and patterns

Water quality monitoring site P4 - Summary

Site P4 was sampled on 67 occasions from mid-2007-mid-2013. Table 3 displays the parameters measured and the range of values recorded. The depth at this site varies dependant on the mouth condition, tidal influences and river flow as with site P3.

The salinity at this site was mostly brackish during 2007. Water levels became extremely low during November 2007 and salinity levels were also low. During the summer of 2007-2008 this site had higher salinity than sea water, during this period there was no stratification at this site and dissolved oxygen levels ranged from 58-90% saturation. Salinity levels remained close to sea water concentrations until spring 2008.

From spring 2008 the water remained brackish until spring 2009, reduced salinity in the top waters in December is likely due to the high rainfall recorded the day before sampling occurred. Some stratification was observed during this period with increases in dissolved oxygen in the bottom waters. These dissolved oxygen levels were above 100% saturation and may be the result of macrophytes or benthic algae growing on the bottom substrate at this site. Increased river flows during spring 2009 provided freshwater to the estuary, close to freshwater concentrations were recorded in the top waters, no stratification was evident.

The salinity levels remained brackish during the 2009-2010 summer until spring 2010, dissolved oxygen levels ranged from 11.6-86% saturation during this period. The low dissolved oxygen levels were recorded in the bottom waters and the top waters were 50% saturation during February 2010 as with site P3. Increased spring river flows returned once again with close to freshwater observed in the top waters.

By summer 2010-2011 the water became brackish throughout the water column. Dissolved oxygen levels ranged from 50-94% saturation during this period. During winter the waters remained brackish. The following 2011-2012 spring and summer the waters were mostly brackish with dissolved oxygen ranging from 50-88% saturation.

During the 2012 winter, increased river flows resulted in freshwater being observed in the top waters. Stratification was evident resulting in low dissolved oxygen concentrations in the bottom waters as low as 14% saturation being recorded. By summer 2013 the waters became brackish throughout, dissolved oxygen levels ranged from 54-89% saturation. An increase in river flows in June resulted in freshwater being observed in the top waters, stratification also occurred with reduced levels of dissolved oxygen being recorded in the bottom waters in July as low as 1.4% saturation.

Table 3. Displays the range of values recorded for each water quality parameter.

Parameter	Value range
Depth (m)	0.5-2.4
Temperature (°C)	9.8-29.6
Salinity (ppt)	0.5-42.9
Dissolved Oxygen (% saturation)	1.4-134.6
Turbidity (NTU)	10-80
pH (units)	5.2-8.0
Halocline depth from surface (m)	0-1.0

Trends and patterns

Water quality monitoring site P5 - Summary

Site P5 was sampled on 67 occasions from mid-2007-mid-2013. Table 4 displays the parameters measured and the range of values recorded. The depth at this site varies dependant on the mouth condition and tidal movement but is influenced more by river flow than the sites downstream.

The salinity at this site was mostly brackish during 2007, with influent river flows during winter creating a freshwater top layer and significant stratification, dissolved oxygen levels as low as 1.2% saturation were recorded in the bottom waters.

Water levels became extremely low during summer 2007-2008. A depth of 0.4m was recorded at this site. This site also had higher salinity than sea water, up until late winter there was no stratification at this site and dissolved oxygen levels ranged from 27-64% saturation. Salinity levels remained close to sea water concentrations until spring 2008.

From spring 2008 the water remained brackish until spring 2009, no stratification was observed during this period. Increased river flows during spring 2009 resulted in this site be completely freshwater.

The salinity levels remained brackish over the 2009-2010 summer until spring 2010, dissolved oxygen levels ranged from 12-74% saturation during this period. The low dissolved oxygen levels were recorded in the bottom waters and the top waters were 50% saturation during February 2010 as with site P3 and P4. Increased spring river flows returned once again with the site being completely fresh water on one sampling event.

By summer 2010-2011 the water became brackish throughout the water column. Dissolved oxygen levels ranged from 37-104% saturation during this period. During winter the waters remained brackish. The following 2011-2012 spring and summer the waters were mostly brackish with dissolved oxygen ranging from 20-93% saturation.

During the 2012 winter, increased river flows resulted in freshwater being observed in the top waters. Stratification was evident resulting in low dissolved oxygen concentrations in the bottom waters as low as 24% saturation being recorded. By summer 2013 the waters became brackish throughout, dissolved oxygen levels ranged from 59-87% saturation. An increase in river flows in June resulted in freshwater being observed in the top waters, stratification also occurred with reduced levels of dissolved oxygen being recorded in the bottom waters in July as low as 3% saturation.

Table 4. Displays the range of values recorded for each water quality parameter.

Parameter	Value range
Depth (m)	0.2-1.8
Temperature (°C)	8.3-27.6
Salinity (ppt)	0.2-42.6
Dissolved Oxygen (% saturation)	1.2-125.5
Turbidity (NTU)	10-69
pH (units)	5-8.1

Processes

Processes

Estuary closures and openings

The Painkalac Creek Estuary is closed to the sea most of the time. This is mostly due to very low river flows. When the estuary is closed, on many occasions seawater is observed over topping the berm and entering the estuary.

Figure 67 displays the conditions observed in the estuary on April 14, 2013 after a period of six months of estuary closure, there was an illegal opening on March 13, 2013. However, on this occasion there was insufficient river flow to create a significant channel at the estuary mouth resulting in the estuary closing soon after this event.

The waters of the estuary were fully mixed and had a salinity of brackish water throughout, the dissolved oxygen levels were also maintained in the healthy range in the lower estuary, at the most upstream site (P5) dissolved oxygen levels were in the moderate range. This pattern is common throughout the seven years that the EstuaryWatch program has been collecting data after prolonged periods of closure.

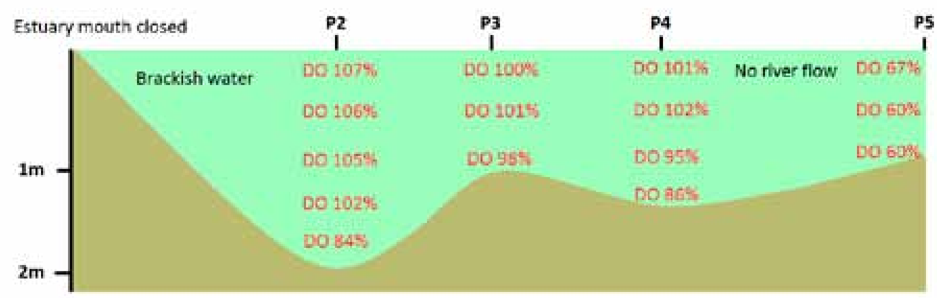


Figure 67. *The Painkalac Creek Estuary closed and fully mixed on 14/04/2013.*

Processes

On occasions when there is significant rainfall events in the catchment and river flows increase, stratification along a salinity gradient occurs within the estuary, the halocline depth is usually 0.5-1.0m. The top layer has near freshwater salinities and the lower layer below the halocline has brackish water salinities.

The results of this stratification is the reduction of dissolved oxygen levels in the bottom waters, the dissolved oxygen levels were often observed to be in the marginal to critical range, on several occasions the dissolved oxygen levels were at levels that would have caused significant stress and be potentially lethal to oxygen dependent biota.

Figure 68 displays the critically low dissolved oxygen levels observed on July 14, 2013, two days after an artificial opening. On this occasion it appears that the river flows were strong enough to reduce the flow of sea water into the estuary at high tide. During the two days following the opening, salinity concentrations in the bottom waters were similar at all the lower estuary sites. As the river flows reduced, the sea water would have been able flow back into the estuary on the high tides bringing with it oxygenated water.

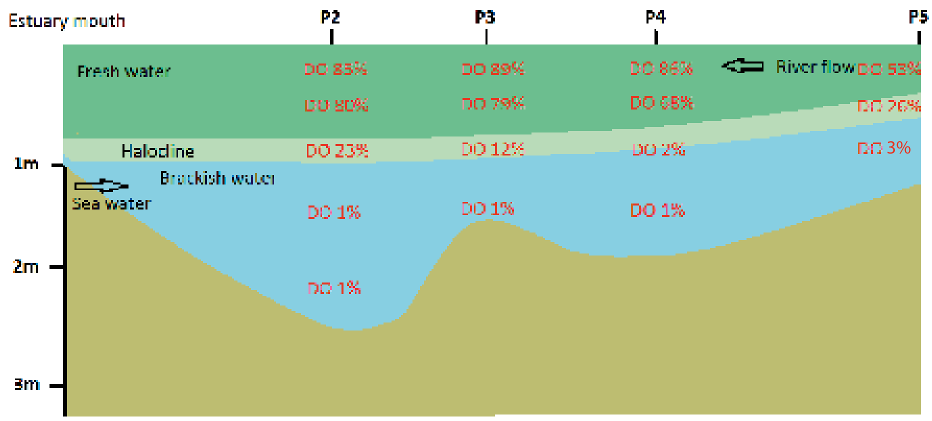


Figure 68. *Stratification and low dissolved oxygen levels in the bottom waters of the Painkalac Creek Estuary on 14/07/2013.*

Processes

Artificial openings of the estuary mouth occur due to the threat of floodwaters inundating houses located on the Painkalac Creek Estuary's natural floodplain and the Great Ocean Road. These openings occur due to rising water levels and are closely monitored along with weather patterns and river flow to reduce the risk of flooding. They are often classified as an 'emergency opening'. The result of this is that the water levels within the estuary rarely reach a level suitable for a natural opening. Of the two recorded potential natural openings sea water was recorded to be entering the estuary. Therefore the rising water level may have been due to high tide events with waves over topping the berm and entering the estuary. While the estuary was closed there may have been no flow leaving the estuary, indicating the estuary to be isolated from the sea except at high tide when sea water enters.

The water quality within the estuary is also regulated by these artificial openings, and not necessarily in a bad way. As the water level in the estuary rises due to inputs from rainfall and river flow, the estuary starts to stratify at a depth of up to 1m below the surface, more often only 0.5m below the surface. The top layer of influent freshwater does not mix with the denser salt water creating a stratified layer. As these waters become isolated from the surface, oxygen demanding organisms consume the dissolved oxygen from the salt water, reducing oxygen levels in the lower salt water layer. Additionally, following heavy rainfall and increased river flow is an increase in turbidity levels, as the influent water slows through the closed estuary these particles that create the increased turbidity settle and drop through the water column, the breakdown of these particles, often organic, results in further consumption of dissolved oxygen by microbial organisms. On several occasions the dissolved oxygen levels in the bottom waters were extremely low and would have been potentially lethal to fish dependant on salt water. The scale of reduction in dissolved oxygen levels in the bottom waters of the estuary is dependent on the duration of the stratified layer. After approximately two weeks, dissolved oxygen levels in the bottom waters become greatly reduced, this is usually at a time with significant rainfall and increased river flow. Increase in the estuary water level results in the need to artificially open the estuary mouth.

Upon opening the estuary mouth the freshwater layer is the first layer to be drained off as it flows out to sea. The reintroduction of sea water into the estuary on the returning high tides, results in the breakdown of the stratification within the estuary and re-oxygenation throughout the water column. On no occasion was the river flow great enough to fully flush the estuary of salt water.

Additionally, the artificial estuary opening also alters the degree and duration of inundation of the floodplain and associated salt marsh communities, therefore impacting on the habitat created by these communities once flooded. This is not assessed in this study however the consequences of altering the natural seasonal flooding and duration of inundation is likely to impact on the spawning and recruitment of native fish species and the development and recruitment of salt marsh communities.

Processes

Low pH

The pH levels throughout the Painkalac Creek Estuary are generally within the healthy range (7-8.5), however, on several occasions very low pH values were recorded, the lowest being five at site P5 (Figure 69). Values lower than seven in estuarine environments and 6.5 in riverine environments are considered to pose a risk to the environment and its biota.

The low pH values are generally only recorded within the freshwater layer as brackish and sea water have a buffering capacity due to concentrations of calcium carbonate dissolved in the water, this in effect neutralises the acid water maintaining the pH in the healthy range.

The times at which these low pH values were recorded correspond with times of increased rainfall and river flow and are potentially related to issues within the catchment. The source of the low pH inflows needs to be considered for further investigation. Several studies have been undertaken in the neighbouring catchment of the Anglesea River after severely low pH levels were recorded in the Anglesea River estuary which resulted in significant fish deaths.

Like the Anglesea River, the Painkalac Creek and the Distillery Creek sub-catchment are likely to contain acid sulphate soils and are naturally occurring in the catchment. These acid waters are generated following significant rainfall events in the catchment. A simple test of the waters from both the Painkalac Creek and the Distillery Creek at the time when low pH values are recorded at site P5 would give an indication of the source. This would then enable further management of the issue to be undertaken. If the source of the acid water is from the Distillery Creek sub-catchment then additional river flow releases from the Painkalac reservoir may enable dilution of this water upon reaching the estuary.

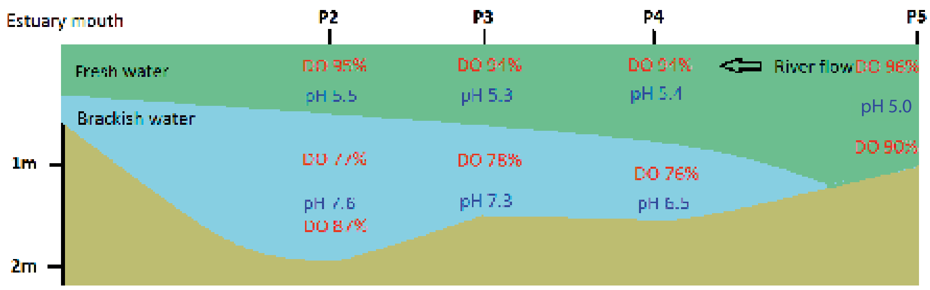


Figure 69. *Very low pH levels recorded in the Painkalac River Estuary on 10/08/2013.*

Processes

Reduction of water level during closures

On many occasions the Painkalac Creek Estuary experiences dramatic reductions in water level over the summer period. This occurs at times when the estuary is closed to the sea with little or no river flows entering the estuary for an extended period of time.

During March to November the required passing flow is just 0.5ML/day. At times this water does not reach the estuary and is absorbed by the river channel prior to reaching the flow station just 150m downstream of the release pipe *(Pers. Comm. Barwon Water)*.

During the summer period (December to February) the volumes of river flow entering the estuary is dependent on rainfall, the release from the reservoir is determined by reservoir in flows as during this period, outflows are to match inflows.

The reductions in water level in the estuary during the summer to autumn period are due to evaporation from the water body. The rates of evaporation are dependent on several variables such as temperature, solar radiation, cloud cover and wind. Figure 70 displays the reductions in water level observed within the Painkalac Creek Estuary during the summer/autumn period. Also displayed is the increase in water level following increased rainfall and river flow during May and June. From December to April the water level dropped from 1.68m to 0.6m resulting in a water level drop of 1.08m.

The rates of evaporation would vary depending on the weather related variables mentioned previously. The Bureau of Meteorology (BOM) estimate the average evaporation from a Class A evaporation pan for this area within Victoria to be, December (175mm), January (175mm), February (175mm), March (150mm) and April (100mm). For the period from December to April this results in a total average evaporation of 775mm (0.78m).

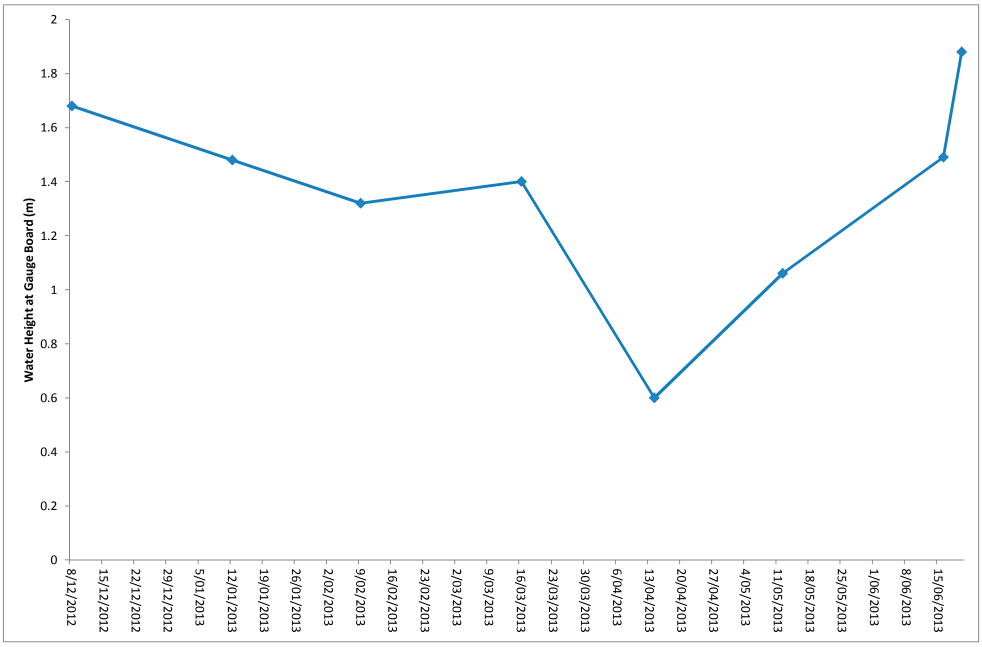


Figure 70. *Water height at the Gauge Board from the 8/12/2012-20/06/2013.*

With consideration of the shallowness, substrate colour, slight turbidity and capillary effect on the edges of the estuary all of which are likely to increase the rate of evaporation, it is conceivable that the water level reductions are due to evaporation. The increase in salinity sometimes observed during this period also indicates evaporation is the main driver in these reductions in water level.

Processes

Impacts of the reservoir

The Painkalac Reservoir is a valued asset that provides potable drinking water to the townships of Aireys Inlet and Fairhaven, it also provides a degree of flood mitigation for the township of Aireys Inlet. The consequence of having a reservoir within the Painkalac Creek catchment has created a variety of potential changes for the Painkalac Creek Estuary.

Prior to the construction of the reservoir there is limited data to assess the changes to the river flow in the Painkalac Creek and is not part of this study. There is however evidence that changes to the flow regime has occurred since the adoption of the Bulk entitlement in 1997 (Figures 11 & 13). There are problems with the flow data from 1992-1999 so this period was not assessed.

Figure 71 displays the differences between the river inflow to the reservoir and the river flow downstream of the reservoir during high river flow events from 2007-2013. It can be seen the reduction of river flow downstream of the reservoir in comparison to the river flow entering the reservoir. During the summer months this is due to the limitation of size of the bypass pipe which is installed to enable the flows to a maximum of 3-5 ML/day to bypass the reservoir, when the reservoir is not spilling over the spillway. For greater volumes to flow into the Painkalac Creek the reservoir needs to be full and flows pass over the spillway. The impact of this is a reduction in the number of high flow events or 'freshes' during this period and a limit to the flow volume during moderate flow events.

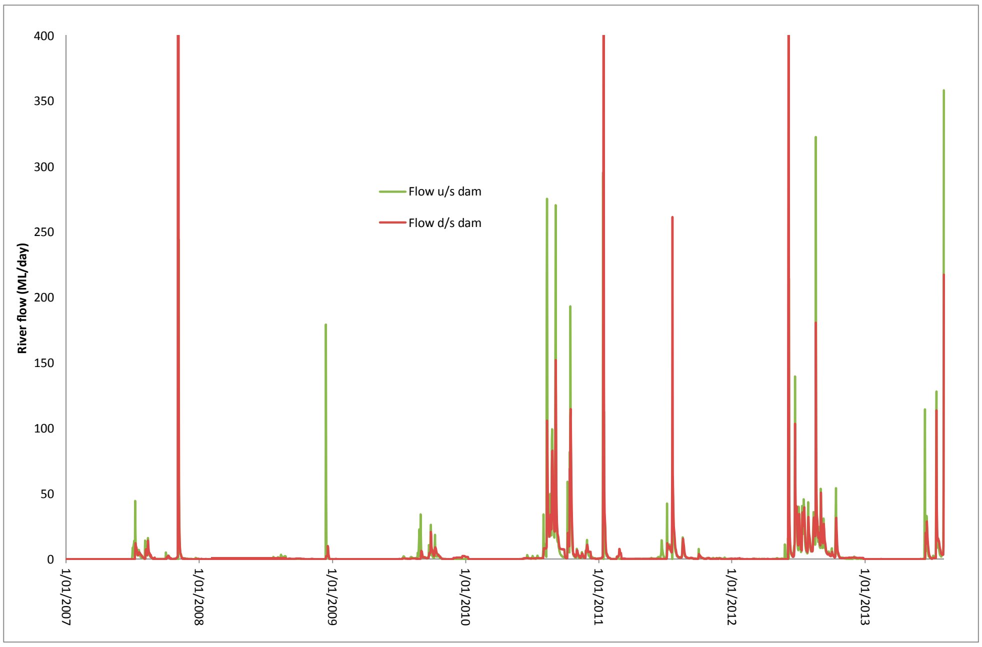


Figure 71. *River flow upstream and downstream of the Painkalac Creek Reservoir from 2007-2013.*

Processes

At times during summer there is a potential reduction and alteration of bypassing flows (Figure 72) (some data was missing from the downstream site during January). Also evident is the reduction of flow during the late May to mid-June period.

This is a common occurrence during the March to November period where downstream flows are reduced to 0.5 ML/day until the reservoir fills to its capacity and additional inflows then spill over the spillway (Figure 13).

During 2008 the reservoir was at capacity for a short period of time so the river flow downstream of the reservoir did not exceed 0.5 ML/day for the whole year until mid-December (Figure 73). The impact of this is the reduced potential for variability in river flow, almost completely controlled by the reservoir. The consequences of these alterations to the flow regime and volumes can potentially impact on fish spawning and behaviour.

Painkalac Reservoir, 2013. Photo: Corangamite CMA

Painkalac Reservoir spillway, 2013. Photo: Corangamite CMA

Processes

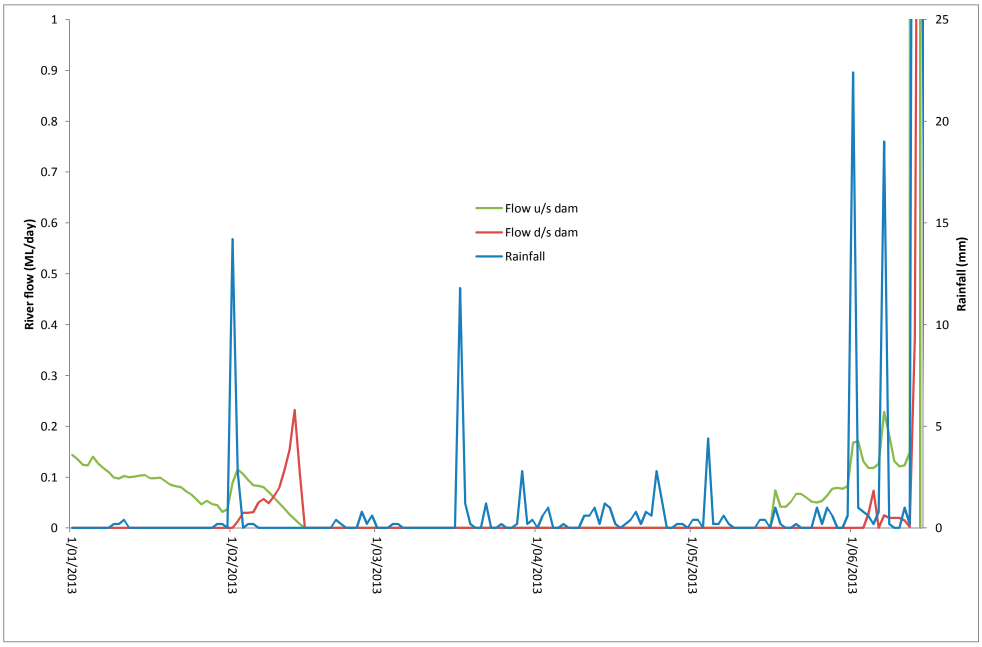


Figure 72. Rainfall and river flow upstream and downstream of the Painkalac Creek Reservoir from January to June 2013.

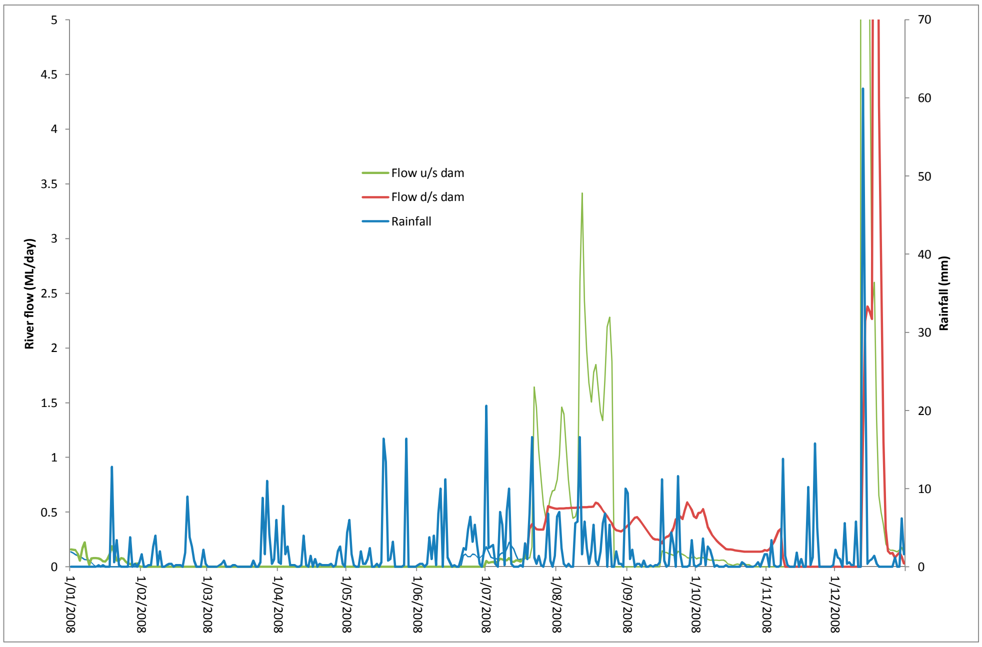


Figure 73. Rainfall and river flow upstream and downstream of the Painkalac Creek Reservoir for 2008.

General estuary condition

General estuary condition

Since 2007 the Painkalac Creek Estuary has experienced significant variability in the dynamics that influence the processes common to estuarine environments, from severely reduced inflows leading to great reductions in water levels, and closure from the sea for an extended period, to extreme summer rainfall events leading to flooding.

The flow regime to and from the estuary is almost completely controlled by human intervention, with the Painkalac Creek Reservoir moderating inflows, and the need to open the estuary mouth as water levels rise and threaten infrastructure, determining the extent and duration of flooding. The water quality within the estuary is generally maintained at good levels. The early opening of the estuary as river flows increase reduces the duration of stratification, therefore, reduces the reduction in dissolved oxygen within the bottom waters of the estuary on many occasions.

A comparison with the EPA Environmental Water Quality Guidelines for Victorian Riverine Estuaries (2011) indicates that the water quality within the estuary during 2008 and 2009 was not as good as expected, what is displayed is the better scores during the years with higher rainfall and river flows. During 2008-2009 the estuary displayed an extended period of closure. During 2010-2012 the values were very close to the guideline values indicating the estuary to be in a reasonably healthy condition during these years.

Indicator	Annual median		Guideline values	
	Top	Bottom	Top	Bottom
2008				
Dissolved oxygen (% sat)	72	43.5	90	65
Turbidity (NTU)	15	na	5	7
pH (pH units)	na	na	7.0-8.0	7.0-8.0
2009				
Dissolved oxygen (% sat)	72	38	90	65
Turbidity (NTU)	10	na	5	7
pH (pH units)	na	na	7.0-8.0	7.0-8.0
2010				
Dissolved oxygen (% sat)	88	71	90	65
Turbidity (NTU)	10	12.5	5	7
pH (pH units)	na	na	7.0-8.0	7.0-8.0
2011				
Dissolved oxygen (% sat)	90.4	50.7	90	65
Turbidity (NTU)	10	15	5	7
pH (pH units)	7.5	7.5	7.0-8.0	7.0-8.0
2012				
Dissolved oxygen (% sat)	86.4	62.4	90	65
Turbidity (NTU)	15	20	5	7
pH (pH units)	7.1	7.2	7.0-8.0	7.0-8.0

General estuary condition

The issue of low pH levels on several occasions needs further investigation as this is likely to impact on the estuary biota. Finding the source of the acid water should be a priority.

This study has been on the water quality results collected by EstuaryWatch volunteers and has not assessed the ecology within the Painkalac Creek Estuary. However from the river flow data and artificial estuary opening information, the alteration to seasonal river flows, both high and low flows, and the timing and duration of flooding is likely to impact on several native fish species recruitment and development and is likely to impact on recruitment of salt marsh communities.

Low water level, February 2007. Photo: Corangamite CMA

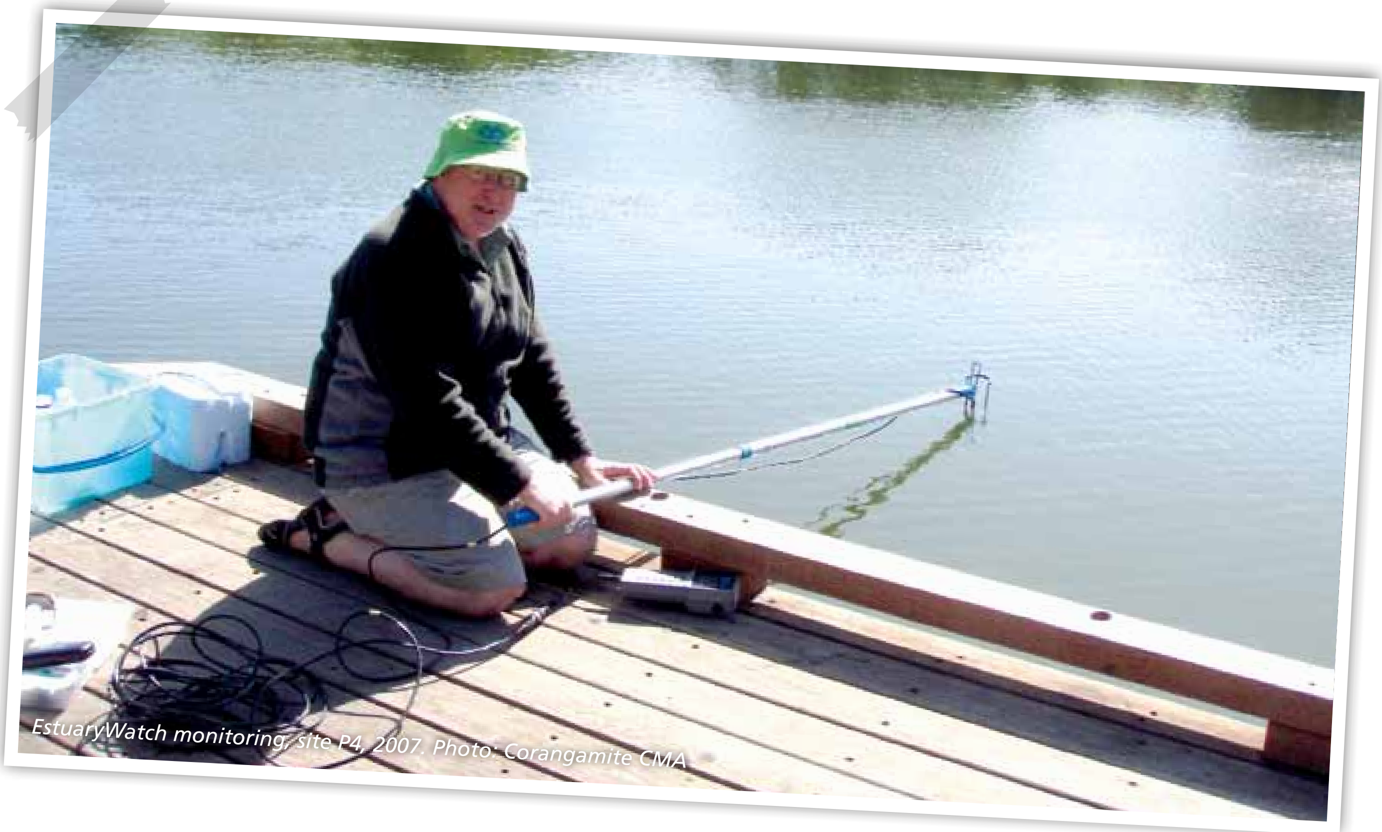
Recommendations

Recommendations

Overall, the data collected by the EstuaryWatch volunteers is very good, making the data set reliable with many comments attached to document any irregularities.

Some improvement in the depth monitoring could be done by ensuring sampling is undertaken at the exact location each time, if the monitoring is undertaken at another location due to low water levels this needs to be given an additional site code (ie. P3-dry, then P3a is used). This may be a data interpretation error however some site water level data did not match changes in gauge board level.

The installation of an automated depth sensor with telemetry at the Great Ocean Road Bridge would provide significant information regarding changes in depth within the estuary. This would also aid Surf Coast Shire in monitoring the estuary and managing the artificial openings and mitigating flooding.



EstuaryWatch monitoring, site P4, 2007. Photo: Corangamite CMA

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