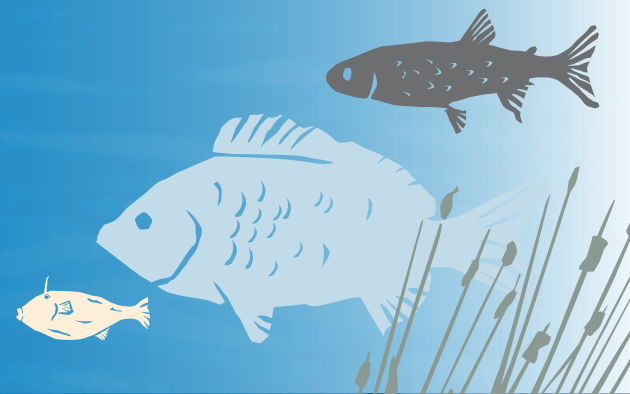




Interpreting Estuary Health Data

EstuaryWatch Victoria



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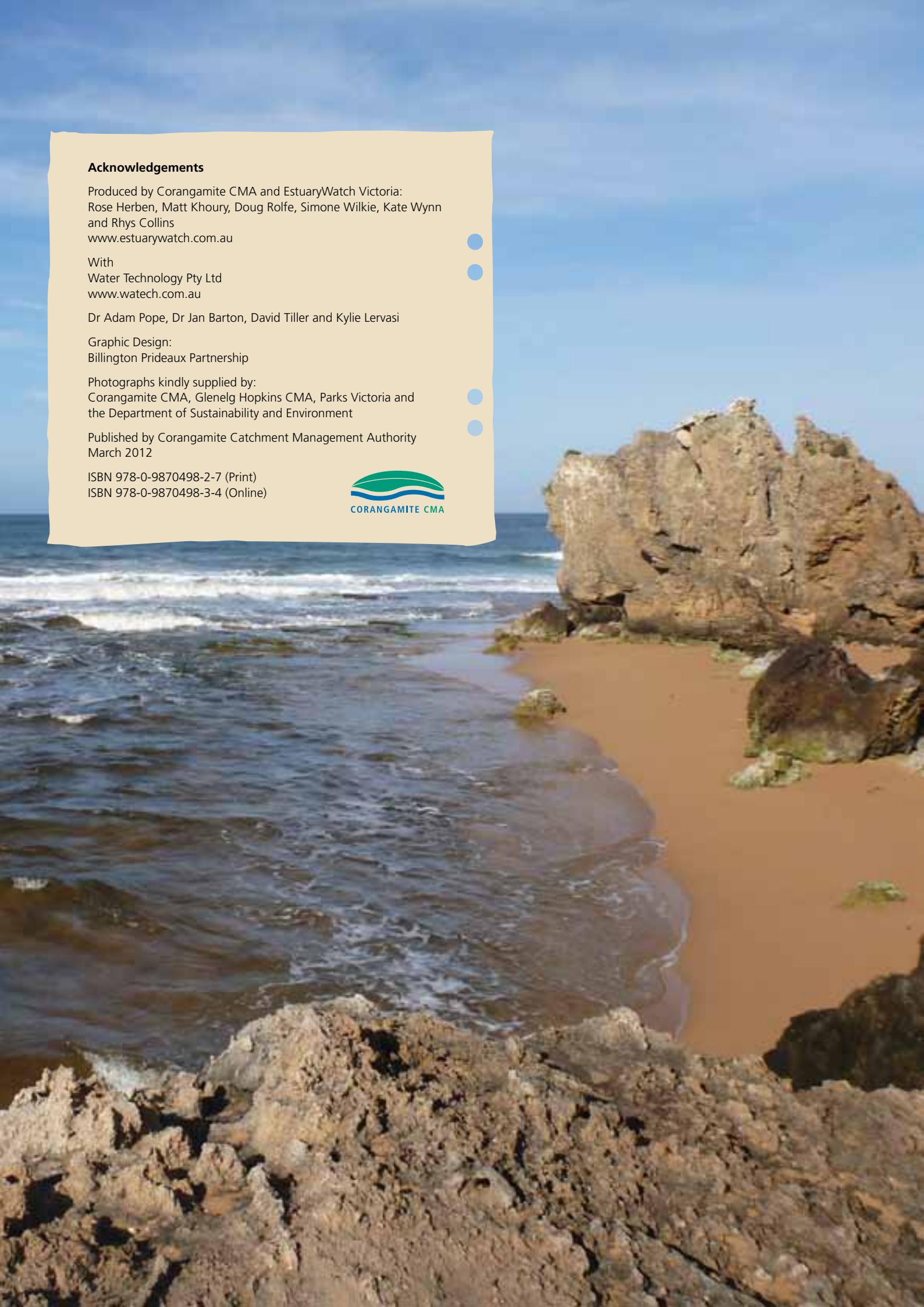
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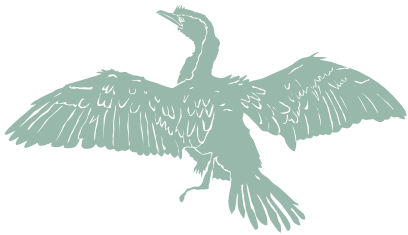
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EstuaryWatch Victoria

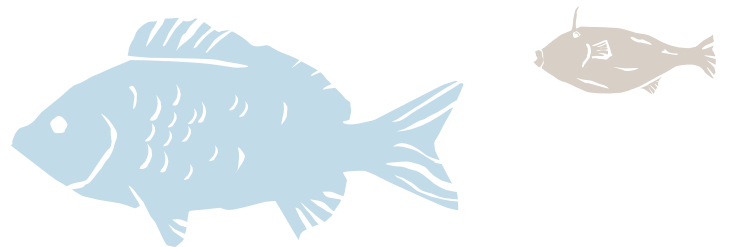
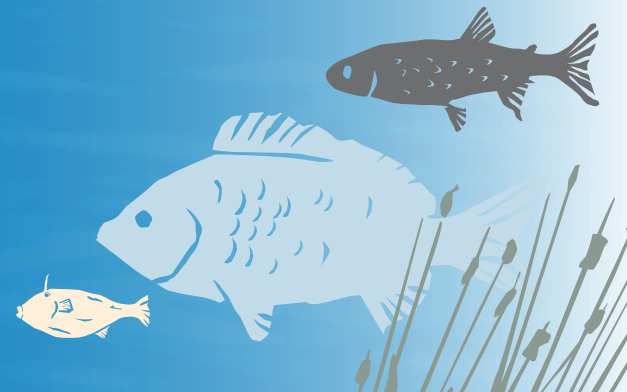
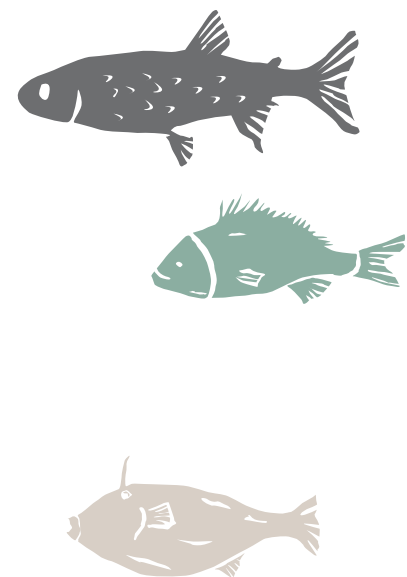


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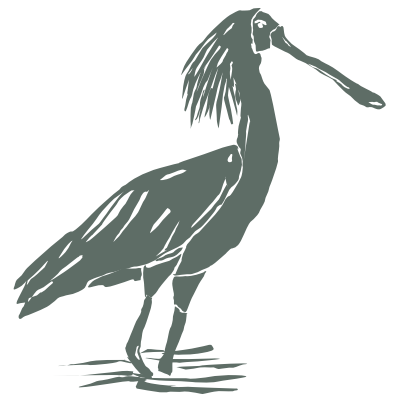


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1.1 Background

Estuaries are an important link between the ocean and the land, where salty marine waters mix with freshwater from rivers and streams. Estuaries are dependent on both sources of water to provide a healthy environment. Estuaries are as diverse in their physical form as they are in their state of health. However, they all share the distinction of being highly valued by the small communities living alongside them.



Figure 1 Thompson Creek Estuary



Figure 3 Johanna River Estuary

In 2006, in response to a groundswell of public interest in estuary health and in an effort to meet the estuary manager's information needs, EstuaryWatch was initiated as part of the Large Scale River Restoration Initiative – Managing our Great Ocean Road Estuaries (a program coordinated through the Corangamite Catchment Management Authority). Following the successful implementation of the EstuaryWatch Program in the Corangamite Region the program was expanded in 2010 to enable other interested communities throughout Victoria to participate in EstuaryWatch.



EstuaryWatch is a community based estuarine monitoring program. The guiding vision for the program is to:

Raise awareness and provide educational opportunities to the community in estuarine environments; and to

Enable communities and stakeholders to better inform decision making on estuarine health.

Working towards this vision, EstuaryWatch utilises groups of community volunteers to monitor the estuary mouth condition and water quality at designated sites across Victoria. Monitoring is completed at least once a month as outlined in *Monitoring Your Estuary – A Methods Manual For Communities* (Pope and Wynn, 2007).



Figure 2 Aire River Estuary



Figure 4 EstuaryWatch training for the Gellibrand River EstuaryWatchers

An EstuaryWatch Coordinator recruits and trains volunteers and oversees the collection and storage of monitoring data on the EstuaryWatch Online Database (www.estuarywatch.com.au) in accordance with strict quality assurance and quality control (QA/QC) procedures. Independent advice and critical review is regularly sought on the program from experts within the estuary management and research fields. These measures ensure relevant data is collected across a representative group of estuaries and is collected in a manner useful for interpretation.

1.2 What can EstuaryWatch data be used for?

Data collected by EstuaryWatch can be utilised in three ways:

- information and education purposes
- short-term management
- long-term management



Figure 5 EstuaryWatch monitoring training day on the Barham River Estuary, Apollo Bay

1.2.1 Information and education

EstuaryWatch volunteers can use data they collect for information and education purposes. It's also valuable to anyone with an interest in an estuary's health, estuary managers or for environmental educators. Gathering and understanding data over a long time frame builds a communities' knowledge of their local estuary.

1.2.2 Short-term management

Short term management is where data is collected by EstuaryWatchers and after interpreting their data they notice an anomaly compared to long term trends. The EstuaryWatchers then report it to the EstuaryWatch Coordinator for further investigation or action.

For short term data reporting to work, EstuaryWatchers must have an understanding of the typical limits for a particular parameter and the thresholds above or below which problems may occur. This manual, training and support from the EstuaryWatch Coordinator and the increasing experience of EstuaryWatchers will assist in the successful utilisation of EstuaryWatch data in short term management.



Figure 6 Black water event at Campbell's Creek, Port Campbell

1.2.3 Long-term management

The information EstuaryWatch gathers can be valuable in understanding the variability of an estuary over time or in making comparisons to other estuaries. There are numerous applications for EstuaryWatch data within current estuary management systems. These are monitoring programs, decision support systems and assessment methods that rely on background or current data such as the Estuary Entrance Management Support System (EEMSS), Index of Estuary Condition (IEC), Estuary Management Plans and Future Coasts.



1.3 How to use this manual

The numbers and descriptors recorded by EstuaryWatchers hold the key to a myriad of information about an estuary and its health. The trick is to know how to interpret EstuaryWatch data.

This manual has been prepared to assist EstuaryWatchers and estuary managers to understand and interpret the data collected through the EstuaryWatch program. The manual includes an overview of the important components of estuarine systems, describes key processes that structure and define estuaries, and details how and why EstuaryWatch observations are likely to change.

Data needs to be interpreted to create the information required to understand the health or condition of an estuary. This manual aims to provide methods and approaches to enable the use of EstuaryWatch data. It is ideal to read:

- **Section 2** to understand estuaries and how they function
- **Section 3** to get an understanding of the water quality indicators that EstuaryWatchers gather
- **Section 4** to gain details on the basics of analysing raw data to glean information
- **Section 5** to understand the estuary being monitored and determine whether the observed water quality data is within expectations for that estuary
- **Section 6** to get an understanding of the major estuary scenarios or conditions encountered and the likely water quality expected there is a flowchart to guide interpretation of data collected
- **Section 7** to obtain guidance on using the information through interpreting the data



Figure 7 Spring Creek EstuaryWatchers recording salinity readings

1.4 Who to contact for further information

Interpreting EstuaryWatch data can lead to conclusions that are interesting, exhilarating and sometimes even alarming. If you have any questions or concerns about data you have collected and interpreted that cannot be answered by this manual, please contact the EstuaryWatch Coordinator at your relevant Catchment Management Authority (CMA).

Glenelg Hopkins CMA	Phone (03) 5571 2526
Corangamite CMA	Phone (03) 5232 9100
Melbourne Water	Phone (03) 9235 7100
West Gippsland CMA	Phone 1300 094 262
East Gippsland CMA	Phone (03) 5152 0600



2.1 What is an estuary – overview of Victorian estuaries

Estuaries are semi-enclosed bodies of water where saltwater from the sea mixes with freshwater flowing from the land. Estuarine boundaries extend laterally onto the coastal floodplain, upstream to the furthest extent of marine water intrusion, and downstream to the coastline. Within these boundaries they include a particularly diverse range of habitats that are influenced and defined by their degree of inundation, salinity regimes, light availability and sediment particle size.



Figure 8 Mangroves on the Barwon River Estuary

Over 120 rivers, streams and creeks enter the sea along Victoria's coastline including those that run into major embayments like Port Phillip, Western Port bays and Corner Inlet, as well as riverine sub-estuaries of the Gippsland Lakes, Victoria's largest estuary. Ninety-five of these systems have been identified as having distinct estuaries.

Victorian estuaries include systems that are permanently and intermittently open to the sea with salinities that vary from almost fresh to saltier than the ocean (this is called hypersaline). In general, environmental conditions may be stable over long periods of time or change frequently or rapidly. As a result, estuaries, particularly those that are intermittently open can be highly variable environments that often appear to be unpredictable in their characteristics. This can make interpreting EstuaryWatch data challenging, but it also highlights the usefulness of long-term data such as EstuaryWatch.

Victoria's estuaries are small to medium sized compared to most Australian estuaries and are most comparable to those of southern West Australia and the south coast of New South Wales. The majority of Victoria's estuaries have a water area of less than one km², and most are less than 20 kilometres long. Only five estuaries, Anderson Inlet, Yarra River, Lake Tyers, Mallacoota Inlet, Glenelg River and the Gippsland Lakes are longer than 20 kilometres.

Victorian estuaries are a product of their landscape and climate, the freshwater flow they receive and the energy and input from

the coastal waters and prevailing winds. The habitats and range of physical conditions in our estuaries are largely determined by the timing and amount of fresh and salt water flowing to them and the physical size and shape of the estuary and its floodplain. Seasonal changes in freshwater flow are important drivers of estuary dynamics. Longer term and less predictable events such as droughts and floods can be major influences, especially in intermittent estuaries. The orientation to prevailing winds, creating wind mixing of waters, can also be a very important influence on Victorian estuaries.

Estuaries are important and productive parts of the coastal region. Being at the receiving end of catchments and popular places for settlement they are systems that are often at risk of major impacts from human activities. They are also very dynamic systems with variability over time. To understand how these systems work and to detect problems requires regular monitoring of indicators that can be clearly interpreted.



Figure 9 Saltmarsh at the Karaaf Wetlands on the Thompson River Estuary



Figure 10 Seagrass, a habitat found in many of Victoria's estuaries



2.2 Types of Estuaries

Grouping estuaries into functional types with similar major driving processes, assists EstuaryWatchers to make comparisons between estuaries and understand changes within the estuary. Factors influencing estuary function include coastal energy, tidal range, freshwater hydrology and physical characteristics of the catchment.

Victoria's estuaries can be broadly split into two categories, those that flow out onto high energy open coasts and those that flow out into low energy coasts such as large embayments like Port Phillip and Western Port bays, and Corner Inlet as well as into the large Gippsland Lakes estuary.



Figure 11 The Snowy River Estuary flowing into a high energy open coast



Figure 12 Nicholson River Estuary flowing into the low energy coast of the Gippsland Lakes

The majority of Victorian estuaries that flow into low energy coasts are permanently open with no lagoon. Estuaries that flow into Port Phillip Bay and the Gippsland Lakes have a limited tidal range compared to those flowing into Western Port Bay and Corner Inlet/Nooramunga.

Estuaries that flow onto open, high energy coasts usually have intermittently open entrances and often have lagoons. Just over half of Victorian estuaries have entrances that are naturally closed by sand bars from time to time. The amount and timing of freshwater inflow influences the frequency and duration of entrance closure. Factors influencing sand supply to the entrance include orientation of the coast to the dominant weather patterns, major currents, waves and presence of rocky reefs or cliffs. Chapter 5 examines physical processes in more detail.

Rainfall, size, slope and geology of a catchment influences sediment and freshwater supply to estuaries across the state. Estuaries on open coasts can be divided into subgroups based on their coastal alignment (see table 1).



Table 1 Estuary classification characteristics

Estuary Type	Examples	Characteristics
Open coast east facing	Great Ocean Road east of Cape Otway	Tend to be small estuaries with small steep catchments providing short pulses of fresh water flows.
Open coast west facing	Coast west of Cape Otway and between Western Port Bay and Wilsons Promontory	Tend to have larger, flatter catchments
Open coast South Facing	Open coast of east Gippsland	Have large but steep catchments and are influenced by a less seasonal rainfall pattern than other estuaries in the state



Figure 13 St George River Estuary. An example of an open coast east facing estuary



Figure 15 Thurra River Estuary. An example of an open coast south facing estuary



Figure 14 The Aire River Estuary. An example of an open coast west facing estuary



2.3 Estuarine Hydrological Regime

The hydrological regime of an estuary can impact upon different aspects of an estuary and therefore significantly influence the data gathered through EstuaryWatch. The hydrological regime is described as the volume, depth, frequency and salinity of water within the estuary.

The presence or absence of particular types of estuarine vegetation is largely influenced by the hydrological regime. Natural connectivity of the floodplain with the channel is important to many estuarine species and processes. Many estuarine plants rely on particular inundation regimes for survival. The inundated vegetation provides habitat for birds and a breeding area for native fish.



Figure 16 Estuarine Vegetation (Arundel, 2007)

Connectivity to the floodplain also increases the area of the estuary and slows water movement; this improves the effectiveness of the estuary as a nutrient filter and sediment sink. Seagrass beds can stabilise sediments and increase sediment deposition. Submerged plants such as seagrass also provide nursery areas for juvenile fish and habitat for invertebrates.

Fish species in an estuary vary with depth of the estuary, time of the year, salinity and whether the estuary is permanently or intermittently open. Species considered freshwater may move into the estuary during periods of high fresh water inflow and marine species often move into estuaries on incoming tides. Other species, such as eels and galaxiids, migrate between the freshwater, estuarine and marine environments at different times of the year. Different species and life stages of fish may also occupy different habitats within the estuary; such as seagrass beds, sandy substrate or inundated vegetation.

Understanding whether an estuary is healthy from water quality data also requires an understanding of the estuary hydrodynamics and the dynamics of the sand bar at the entrance. Hydrodynamics describes the timing and volume of fresh and sea water and how this mixes through the water profile. Different processes and ecological responses occur in permanently and intermittently open estuaries. Variation also occurs within estuaries as the deep, narrow middle and upper riverine sections have very different conditions to the shallow, wide lagoon near the entrance.

In summary, understanding how water quality changes in response to estuary mouth condition helps to define whether conditions are natural or outside those expected.

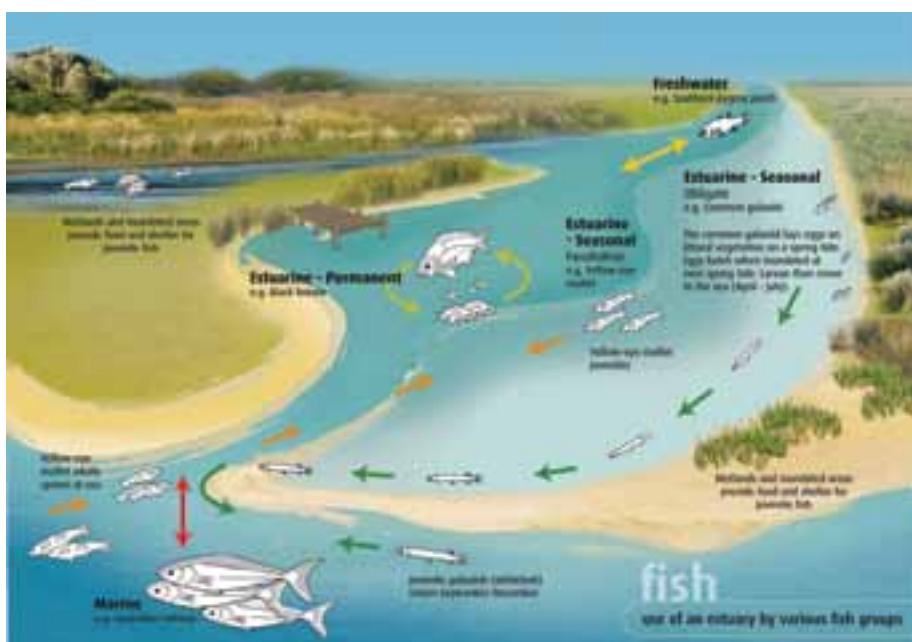


Figure 17 Use of an estuary by fish groups (Arundel, 2007)

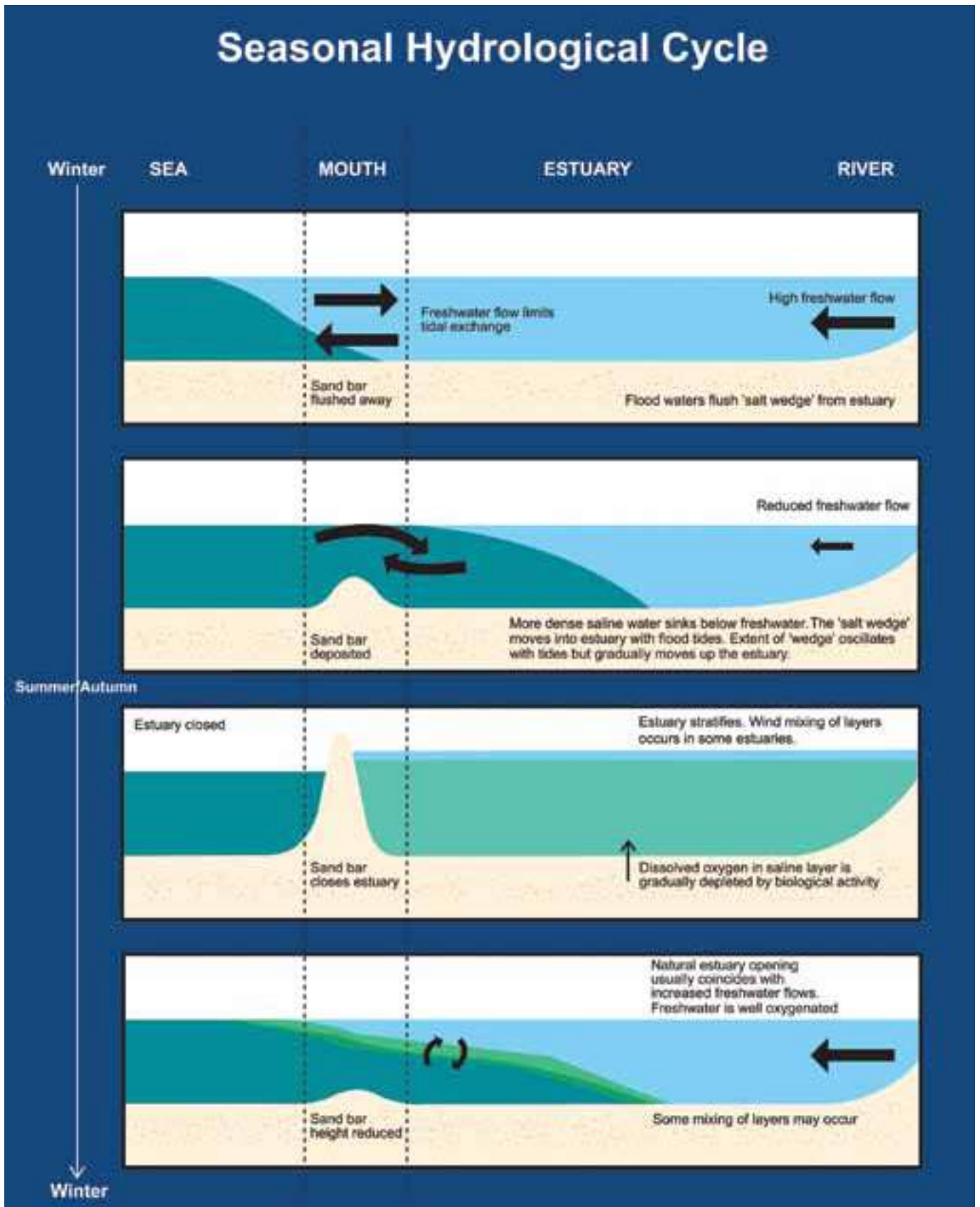


Figure 18 Seasonal hydrological cycle for an intermittently open estuary (Arundel, 2007)



2.4 Estuary assets, values and threats

2.4.1 Estuary values

The estuary environment can be described using six components. The six components are physical form, hydrology, water quality, sediment, flora and fauna:

- Physical form** – The physical form of an estuary includes its bed, banks, water depth and its connectivity to other environments such as the sea or adjacent wetlands. The physical form of an estuary influences the available habitats, the hydrology, water quality, sediment type and extent and suitability for particular biota.
- Hydrology** – Estuarine hydrology is driven by the volume and timing of marine, freshwater and groundwater inflows.
- Water quality** – Hydrology directly influences water quality through its influence on the salinity regime and stratification in the estuary. Water quality influences the habitat available for flora and fauna within the estuary. Salinity plays a major role in the functioning of estuary ecology. The salinity dynamics within the estuary often influence the observed water quality such as dissolved oxygen, turbidity, pH and colour.
- Sediment** – The sediment or benthos is an important component of estuaries because of the important role it plays as habitat and in the storage and cycling of nutrients.
- Flora** – Flora in estuaries ranges from microphytes in the water (phytoplankton) and microphytobenthos on the sediment to macrophytes in the water column and terrestrial flora around the estuary.
- Fauna** – Fauna in estuaries includes aquatic micro and macro-invertebrates and vertebrates such as fish and birds.

Estuaries are highly valued for their social, environmental and economic characteristics.

Environmental values associated with estuaries include:

- supporting rare and threatened flora and fauna such as internationally significant bird species
- providing spawning and nursery areas for fish
- acting as natural sediment and nutrient filters

Social and economic values associated with estuaries include:

- tourism
- boating
- swimming
- bird watching

The values within an estuary are interdependent and often targeting improvements in one area can benefit other values. In some cases, taking an action to protect or improve conditions for one value may adversely affect another value.

Estuary managers must carefully balance their management activities to ensure the most beneficial outcomes are achieved for the environmental, social and economic values. An example of this is the decision of whether to open or not open an estuary mouth artificially. Protecting agricultural land or roads from flooding by artificially opening an estuary may adversely impact fish spawning if undertaken at a critical time in the year. The relationships between many of the physical, chemical and biological components of estuaries are represented in Figure 19.

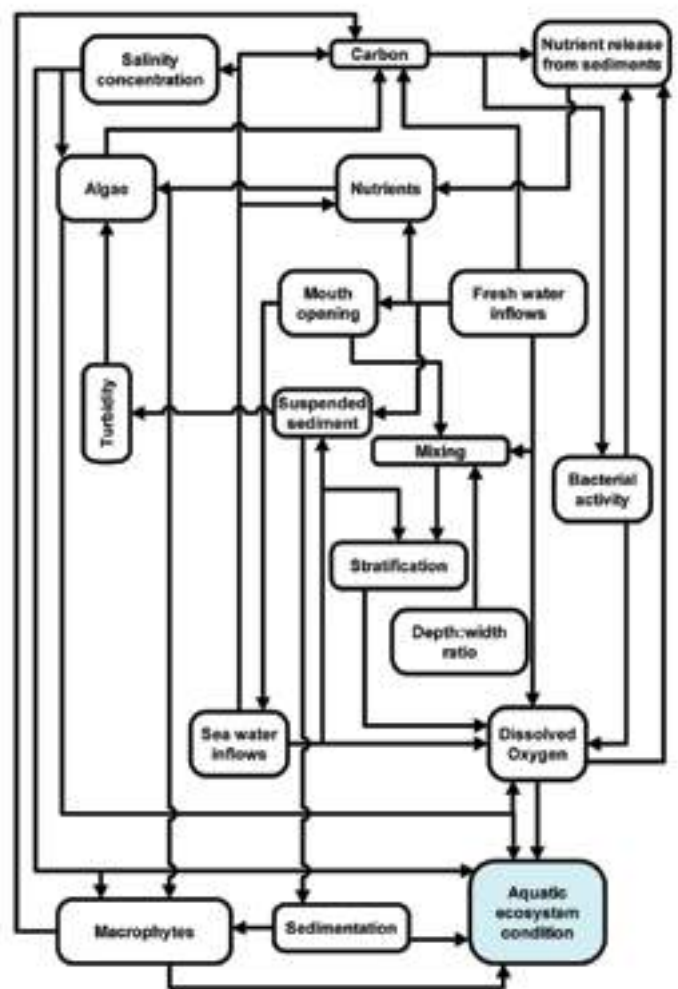


Figure 19 Example of a conceptual model of the factors affecting water quality and ecosystem health in estuaries (EPA 2011)



2.4.2 Threats to estuaries

The condition of our estuaries is threatened by:

> Intensifying land uses of catchments



Figure 20 A fence line adjacent to Swan Bay, Queenscliff, showing the difference in vegetation cover between farming land and an area protected from cattle

> Changes in the flows of fresh water



Figure 21 Barwon River tidal barrage

> Modifications to entrances, beds and banks of estuaries



Figure 22 Rock wall at Anglesea

> Built structures altering connectivity



Figure 23 Fish way on Cumberland River Estuary

> Climate change



Figure 24 Increased wave surge and sea level rise will impact on coastlines and subsequently estuary shape and form. Pictured here is coastal erosion on East Beach at Port Fairy



Physical factors such as fresh water inflow, residence time and flushing rates can affect how sensitive an estuary is to different threats. (Residence time refers to the period of time that water may be enclosed in the lagoon of a closed estuary, without interaction with the sea). Intermittent estuaries can have periods where residence times are very long, so they may be more vulnerable to some human threats.

The interaction of threats and their impacts on estuary health is often complex. For example, flows to estuaries can be affected by:

- a change from natural forested vegetation to cropping in the catchment of an estuary. This increases sediment and nutrients and changes the amount and timing of fresh water flows into the estuary
- dams and water extraction (this also impacts on the hydrology)
- entrance modification by permanent openings using training walls or dredging
- artificial openings of intermittent estuaries
- constraining and separation from floodplains by sea walls and levee banks

The size and shape of estuaries and the quality and quantity of water in many estuaries has been changed because of these threats.

Another example of the complex nature of threats is determining the agent causing estuary mouth closures and the subsequent threats created. The frequency and duration of estuary entrance closures are likely to have changed with altered land use and hydrology, as reduced flows tend to reduce the frequency of entrance opening. On the other hand increased frequencies of opening due to artificial opening of estuary entrances can also alter the timing and depth of the inundation regime of riparian areas. This can cause the loss of fish eggs and larvae and a reduction in available breeding and foraging habitat for fish and birds. The full consequences of artificial entrance opening and increased periods of closure are poorly understood.



Figure 25 Artificial estuary opening

For further information on threats to estuaries, refer to the OzCoasts website (Australian Government), www.ozcoasts.gov.au. This site has comprehensive fact sheets on a number of threats such as altered pH, aquatic sediments, excess nutrients, habitat removal, organic matter, pest species, toxicants, and water temperature.

2.4.3 Interaction of values and threats

The information collected by EstuaryWatch provides valuable data to assist with the analysis of potential threats to estuary values. Data collected over a long period of time, encompassing a range of climatic conditions paints a picture of variability within an estuary and how this may affect the viability of values critical to estuary health.



2.5 Indicators of estuarine health

Indicators of estuary condition or health i.e. dissolved oxygen, pH, salinity, temperature, turbidity and colour are parameters used to represent the result of a threat to ecosystem health. For example, turbidity is used as a measure (indicator) of potential excessive sediment in the water column that will either result in sedimentation or reduce light penetration (the specific threat). Turbidity measures the potential for an impact, a more direct measure of impact would be sedimentation and light penetration but these are time consuming and difficult so are not generally undertaken.

Water quality affects most estuary values. As discussed in Section 1.2, there are a number of methods of using Estuarywatch data including information and education purposes, short-term management and long-term management. Water quality indicators, such as those collected by EstuaryWatch, are variable in most estuaries. Long-term sampling is needed to gain an appreciation of whether the observations are natural variation or significant on-going changes. Data collected on a particular date, a snapshot of condition is also useful. It can be used to help interpret ecological status and compare to alert or trigger levels.

A good understanding of causes and patterns through time is important when using water quality indicators to assess condition of estuaries. For example, the relationship between low oxygen levels and water condition in estuaries can be complex. The natural cycle of decomposing seaweed or long residence times have been known to cause hypoxic conditions in estuaries otherwise considered pristine. Understanding what is 'normal' in an estuary enables the groups that are monitoring to raise the alarm when measurements are outside these bounds.

Water quality parameters will vary significantly over time, particularly with the seasons, day to day and over the tidal cycle. As estuaries vary in size and shape, recognising differences is important in understanding, then assessing, estuarine health. The principal way of establishing these natural variations is to undertake regular monitoring and document the data over a long time. It is also important to document the conditions around the estuary which may impact on water quality at the same time as the monitoring is undertaken. This enables a meaningful picture of estuary variability to be gauged. EstuaryWatch data collection is structured to meet these requirements.



Figure 26 Turbidity monitoring at Anglesea River Estuary

2.6 Key questions for estuary health

Some key questions to ask when interpreting EstuaryWatch data are:

- Does the estuary drain to the open coast or an embayment?
- Does the estuary entrance close?
- Has the frequency or duration of closures changed?
- Are there any particular high value assets in the estuary that are being assessed?
- How does water quality or hydrology threaten these assets?
- What alterations to the estuary have occurred that may change the water quality, or hydrology?



EstuaryWatchers gather a range of data on their estuary every time they monitor. Central to the monitoring is the collection of water quality indicators. These are discussed below.

3.1 Dissolved Oxygen

Definition: Dissolved oxygen (DO) is a measure of the concentration of oxygen gas dissolved in water. Oxygen can be generated from photosynthesis within an estuary, mixed into surface waters from the atmosphere or imported to the estuary in fresh or marine waters.

Dissolved oxygen can be recorded in two ways. The first, mg/L, represents the number of milligrams of oxygen per litre of water. The second way of recording dissolved oxygen is as per cent saturation. Per cent saturation is based on the highest dissolved oxygen concentration possible in a water sample under the limits of temperature, salinity and atmospheric pressure. As salinity and/or temperature increase, the amount of oxygen that water can hold decreases substantially. For example at 20°C, 100 per cent saturation for freshwater is 9.09 mg/L. At the same temperature, 100 per cent saturation for sea water is 7.43mg/L (Pope and Wynn, 2007).

The major sources of oxygen demanding substances include:

- sewage effluent discharges (organic matter breaking down)
- industrial discharges (organic and inorganic chemicals breaking down)
- septic tank discharges (organic matter breaking down)
- leaf litter from the floodplain, river banks and dry waterways (organic matter breaking down)
- aquatic plant material- Macrophytes and phytoplankton (organic matter breaking down)
- blackwater events – low oxygen organically rich waters entering from floodplain wetlands, backwaters and tributaries (a result of organic matter breaking down)
- organic matter accumulation in sediments (organic matter breaking down).

Decomposition of this organic matter consumes oxygen and may result in lower oxygen concentrations, particularly as flows reduce. DO concentrations below 80 per cent saturation may be a sign of unusual oxygen demand in these conditions and concentrations below 50 per cent are likely to present a challenge to estuarine animals. DO variability can also occur between daylight hours and night-time when photosynthesising organisms produce (daytime) or consume (night-time) oxygen.



Figure 27 Monitoring for dissolved oxygen at the Gellibrand River Estuary

3.2 Turbidity

Definition: Turbidity is a measure of the clarity of water. As suspended particulate matter including clay, silt, detritus and plankton in the water increases, the clarity decreases and the water takes on a muddy appearance. Turbidity does not measure the quantity of suspended matter in the water, just its effects on clarity.

Sources of turbidity:

- most of the sediment in estuaries comes from catchment, river, streambed and bank erosion. Sediment entering upstream waterways is a natural process, but land use can result in excessive quantities entering these waterways. Agricultural, forestry activities and urban developments can all lead to extensive soil disturbance, erosion and sediment runoff to estuaries. Unsealed roads can also contribute substantial quantities of sediment. Carp, an introduced pest fish species, can increase the mobilisation of sediment in the catchment due to its habit of digging around in stream sediments and dislodging macrophytes, resulting in unstable stream beds
- sewage effluent discharges
- industrial discharges
- septic tank discharges.



3.3 pH

Definition: The pH of water is a measure of its acidity or alkalinity. The actual component of the water being measured is its concentration of hydrogen ions (H^+). In water, some of the H_2O molecules will dissociate into H^+ ions (also called protons) and OH^- ions (hydroxide). When there are more H^+ ions than OH^- ions the water will have a pH below 7 and is acidic. Conversely, when there are more OH^- ions than H^+ ions the water has a pH greater than 7 and is alkaline. When the pH of a water body is 7, the H^+ concentration is the same as the concentration of hydroxide (OH^-) ions and is neutral. When the water is approximately neutral, it is called circum-neutral.



Figure 28 EstuaryWatch monitor using the PCS Testr 35 Meter to test for pH

Sources of acid and alkaline substances:

Natural sources

- geology and soils of the catchment can influence pH through the bedrock. For example, granitic rocks typically contribute to a lowering of groundwater pH, whereas basaltic rocks and rocks with carbonates tend to increase pH. Soil characteristics also influence pH, with soils high in organic acids typically reducing the pH of groundwater whereas soils high in salts typically increasing groundwater pH
- the presence of acid sulphate soils may lead to acidification of estuaries. Sulphides will naturally form in anaerobic (oxygen free) sediments where sulphates from groundwater or seawater accumulate and where iron oxides and organic matter levels are high. Bacteria are responsible for the conversion of sulphate to sulphide in anaerobic conditions. Left covered with water these sediments are stable and the sulphides remain bound in the sediments. If, however, the water levels drop due to drought, drainage or water extraction the sediments are exposed to oxygen and sulphuric acid is formed. When the sediment is re-wetted, acid can be mobilised from the sediments
- the photosynthesis and respiration of algae and other plants in an estuary can have an effect on pH, through altering the concentration of dissolved carbon dioxide (CO_2) in the water. Dissolved CO_2 forms a weak acid (carbonic acid). During daylight, photosynthesis results in the uptake of CO_2 , thereby reducing the concentration of CO_2 and therefore reducing the acidity (that is, increasing pH). In contrast, during the night, when respiration is the dominant process, dissolved CO_2 concentrations can increase markedly thereby creating more acidic (low pH) conditions. Where there is high algal biomass, these diurnal (day-night) fluctuations can be clearly identifiable and are usually accompanied by significant diurnal fluctuations in dissolved oxygen
- rain typically dissolves some atmospheric CO_2 as it falls, and consequently rainfall often contributes to a minor reduction in the pH. However, this reduction may be overridden by inputs of dissolved salts washed in from the catchment, which raise pH.

Human-induced changes to pH

- agricultural land practices (leading to soil acidification), waste discharges, and air pollution. Soil acidification typically occurs through a leaching of base cations from the upper soil horizons, leaving an excess of H^+ ions. Water flowing through the acidic soils enters the receiving water body with low pH. Agricultural practices can also lead to increased nutrients, which increase algal growth and consequently lead to the greater diurnal fluctuation of pH as described above
- changes to the hydrology of rivers, wetlands and estuaries can also lead to acidification. A drop in water levels allows exposure of acid sulphate soils. When these sediments are exposed to oxygen, sulphuric acid forms. If water levels rise as a result of increased flows, acid can mobilise from sediments
- discharges from factories, mine sites and other industrial locations can often contain liquids with high or low pH. Spills or uncontrolled discharges will generally result in rapid and large changes to pH over a short period of time compared to natural or catchment induced changes
- emissions from car exhausts and coal-burning power plants increase the concentrations of nitrogen oxides (NO_2 , NO_3) and sulphur dioxide (SO_2) in the air. These pollutants can react in the atmosphere to form nitric acid (HNO_3) and sulphuric acid (H_2SO_4). These acids can affect the pH in catchments by combining with moisture in the air and falling to the earth as acid rain.



3.4 Colour

Definition: The colour of water results from the combination of dissolved and suspended substances. These include metals e.g. iron and manganese, dissolved organic matter e.g. humus and peat materials, plankton e.g. diatoms and Cyanobacteria, colloidal substances e.g. carbonates and clays and industrial wastes. Turbidity, even at low levels, will make the apparent colour higher than the true colour. The true colour of a water sample can be measured after removing all suspended material. Colour is also pH dependent, with the colour increasing as pH increases.

The most common method for assessing colour is to compare samples to colour samples. The Forel-Ule Scale is a method commonly used to determine the color of bodies of water. The colour palette is made by mixing solutions of ammonia, copper sulphate, potassium-chromate and cobalt-sulphate with distilled water. The method is useful for measuring colour in natural waters but may not be as useful for assessing highly coloured industrial wastes.

Sources of colour:

Natural sources

- the geology can contribute iron and manganese ions, and soils contribute sediment. Most importantly it's the colloidal material that is the major contributor to the colour
- water draining wetland plant communities and riparian vegetation can be high in tannins and lignins. The decay of plant material, including macrophytes, phytoplankton and terrestrial leaves and branches, in water bodies and adjacent floodplains will contribute tannin coloured waters (blackwater events)
- bottom sediments can be a source of colour. Organic and inorganic particles released from the sediment will change the apparent colour and anoxic sediments release organic material and dissolved iron
- the water itself changes the apparent colour due to light absorption, scattering and reflection and as the water gets deeper the apparent colour can change. Reflection off the bottom can also change the colour.
- changes in water colour can be related to planktonic algae concentrations. When there is a rapid increase in the population of algae in an aquatic system (algal bloom) these colour changes are more noticeable.

3.5 Salinity (Electrical Conductivity – EC)

Definition: Salinity is the amount of salt dissolved in the water. There are many salts dissolved in water, most notable sodium chloride. The amount of salt in the water can be measured directly by evaporating the water from a known volume of water and weighing the residual. However this is time consuming. A solution of salt will conduct electricity, and the amount it conducts depends on the concentration of the dissolved salts, the conductivity in a solution increases as the amount of salts dissolved in the water increases. Electrical Conductivity (EC) uses this characteristic to estimate the levels of salinity. The units of EC in water are usually expressed as micro Siemens per centimetre ($\mu\text{S}/\text{cm}$). Most meters will calculate salinity (ppt) from EC using an in-built conversion factor.



Figure 29 Monitoring for salinity on Lake Connewarre, part of the Barwon River Estuary

Sources of salt:

- the overriding influence on salinity in estuaries is from marine inflows
- the salinity of the freshwater surface layer will be influenced by the catchment. Salinity levels in inflowing rivers and streams will vary due to the influences of geology, urban and agricultural runoff, sewage and industrial effluent, and most importantly, groundwater. Groundwater can have very high salt concentrations, and rising groundwater tables have elevated salinity levels in many rivers in Victoria.



This chapter explores how to interpret collected EstuaryWatch data to assist in developing information useful in estuary management.

Interpreted data creates the information needed to understand estuary health or condition. Data by itself therefore is limited. Data summaries, graphs and statistical analysis turn data into information. This section provides information on approaches for manipulating data to provide information to enhance understanding.

4.1 What are data and what is information?

Data are the measurements you take that represent the condition or health of the environment at that time. The environmental conditions in an estuary will change over time, at least seasonally but often daily.

A suite of data covering a range of indicators of condition taken only on one occasion can tell you about condition at that time only. This is often called a snapshot of the condition. Data collected from several occasions begins to tell you about variability and change over time. As data accumulate, seasonal and longer term changes will be discovered and confidence will increase.

Data needs to be analysed and interpreted to provide information. A good quality long term data set will assist in providing good information, but understanding and achieving good estuary management only occurs when the data is correctly interpreted.

One approach is to compare data and data summaries to estuarine water quality guidelines (objectives or targets). Estuary guidelines are available in the National Water Quality Guidelines (ANZECC & ARMCANZ, 2000), State Environment Protection Policy (Waters of Victoria) (EPA Victoria, 2003) and Environmental Water Quality Guidelines For Victorian Riverine Estuaries (EPA Victoria, 2011) and will be of assistance in interpreting water quality data.

Another approach is to use control charting. Control charts allow the user to compare environmental measurements taken in an estuary of interest with what would be expected for an estuary in good condition, given the conditions in the estuary at the time (EPA, 2011). For more information on control charts see Appendix A.



EstuaryWatch Physico-chemical Data Sheet - YSI								
Sampled by:								
Estuary: Hopkins		Site: 2		Max Depth: 3.25		Date: 10-12-11	Time: 10:00	
Last membrane replacement: (please indicate the meter, date and time recorded on your membrane replacement record sheet in the space below)								
Meter: YSI 10		Date: 10-12-11		Time: 8:40				
Calibrations required: (i.e. for DO or Salinity)				Yes (No)				
<ul style="list-style-type: none"> If you selected yes in the above section please indicate Which calibrations you performed (please circle): DO / Salinity 								
Calibrations recorded on calibration record sheet:				Yes / No / N/A				
Depth Profiling								
Depth (m)	Temp (°C)	Salinity (ppt)	D.O. (mg/L)	D.O. (% sat)	EC (mS/cm)	Notes		
0.10	23.6	17.7	11.4	135.4	10.65			
0.50	22.9	18.7	10.05	129.3	30.37			
1.00	20.6	28.2	7.45	98.5	49.38			
1.50	19.4	32.0	6.29	88.1	48.59			
2.00	19.1	32.6	5.92	77.6	49.69			
2.50	18.9	33.2	5.29	66.3	50.5			
3.00	18.7	33.5	4.48	60.2	50.9			
3.50	18.6	31.4	4.02	52.5	48.58			
4.00								
* - sample at 10cm above bottom								
Freshwater inflow (circle most appropriate)				Dry	Pool	Slow	Med	Fast
Top and Bottom Sample (indicate bottom depth if different to max depth)								
Top Turbidity (10cm): 15-20				Bottom Turbidity: <10				
Top pH (10cm): 8.5				Bottom pH: 8.0				
www.estuarywatch.com.au								

Figure 30 One EstuaryWatch sampling event at Hopkins River Estuary (GHCMA). A snapshot of data

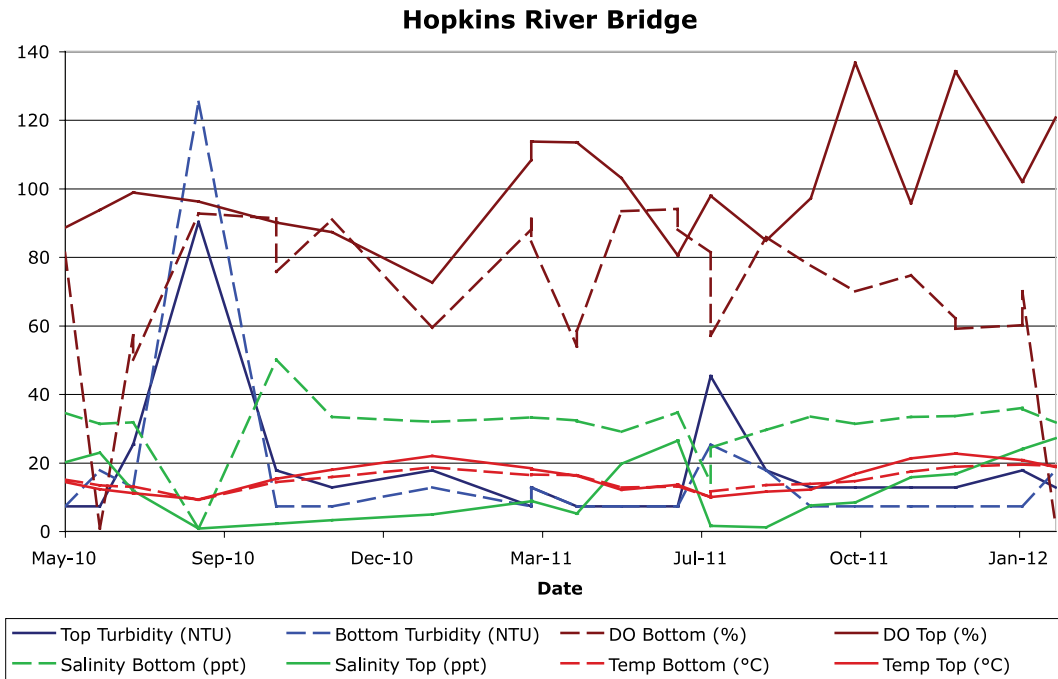


Figure 31 Long term multi-variate data taken from EstuaryWatch monitoring at the Hopkins River Estuary (GHCMA). Shows variability over time

4.2 Analysing and interpreting data

There are standard recognised approaches for analysing and interpreting data that can provide comparison between different sites and estuaries, changes over time and an evaluation against guidelines and targets.

Data can be summarised using basic statistical tools. A simple measure of the typical state of an estuary is to determine the central tendency of the data. The central tendency of the data can be found using summary statistics such as the median or the mean.

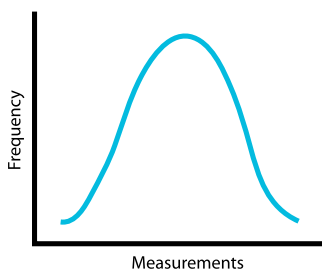


Figure 32 Normal distribution

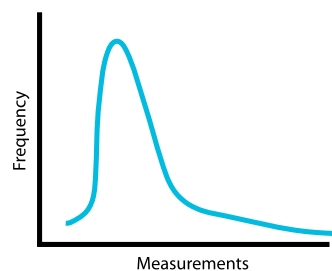


Figure 33 Skewed distribution

4.2.1 Summary statistics

The distribution of data is important in understanding central tendency. The graphs below show the data as a frequency distribution (that is the frequency or number of times a particular measurement was taken). Data may be evenly distributed (often called normal distribution) or can be skewed, with more measurements at one end of the range of results (Figure 32 & Figure 33).

Water quality data generally has a skewed distribution – most of the time the level is similar. If there is a change in water quality data it is generally for a short period of time. For example, turbidity measurements are generally low in a healthy estuary when fresh water inflows are low. Any sediment that has entered the estuary will quickly settle out of the water column. Rainfall in the catchment will increase sediment transportation to the estuary resulting in increased turbidity levels. When rainfall ceases, sediment transport from the catchment rapidly decreases and turbidity in the estuary will fall. Turbidity may increase 10, or even 100 fold during these events. Figure 36 illustrates this situation.

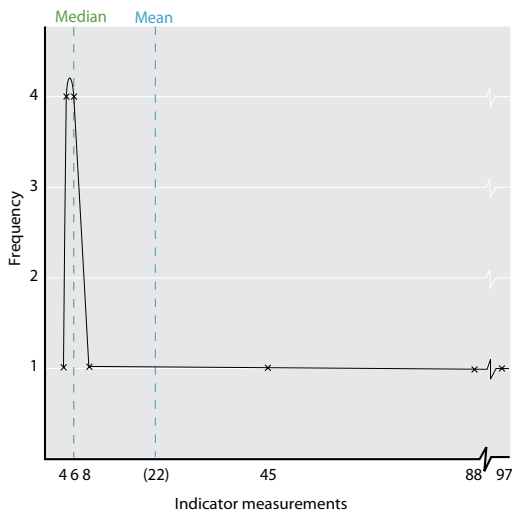


Figure 34 Frequency distribution, median and mean values of a hypothetical data set

Calculating the mean

Calculating the mean (or average) requires adding together all the data points then dividing the total by the number of data points. For example, consider the following 13 results:

5, 5, 6, 6, 4, 6, 97, 6, 5, 5, 45, 88 and 5

Adding them all together and dividing by 13 obtain the mean value of these results:

$$(5 + 5 + 6 + 6 + 4 + 6 + 97 + 8 + 5 + 6 + 45 + 88 + 5) \div 13 = 22$$

Calculating the median

The median is also known as the '50th percentile', as it is the half way point in the data i.e. 50 per cent of the way from the lowest to the highest data point. The median of a set of figures is obtained by arranging them all from the lowest number to the highest and taking the middle value. Using the same 13 results, the median is found to be 6:

4, 5, 5, 5, 5, 6, 6, 6, 8, 45, 88, 97

The frequency distribution of this hypothetical data set (Figure 34) illustrates how the data are bunched at the lower end of the scale and how this affects the mean and median.

As can be seen above, if the data set is highly skewed, that is the data are not evenly spread, then the mean and median are markedly different. If in the above example the high values are eliminated the mean and median become almost the same.

Mean: $(5+5+6+6+4+6+8+5+6+5) \div 10 = 5.6$,

Median 4, 5, 5, 5, 5, 6, 6, 6, 8

Calculating percentiles

In addition to identifying central tendency, percentiles are often used. Percentiles are based on the number of data points that fall below the percentile. For example a 25th percentile is the value below which 25 per cent of the observations fall and the 75th would be below which 75 per cent of the data fall. In the original data set above the:

25th percentile would be 4, 5, 5, 5, 5, 6, 6, 6, 6, 8, 45, 88, 97

75th percentile would be 4, 5, 5, 5, 5, 6, 6, 6, 6, 8, 45, 88, 97

In addition to percentiles, the highest and lowest values in a data set can be important in identifying the range in values and extreme events.

Using time series

As discussed above, variability is a natural part of the aquatic environment, and typically there is a 10-20 per cent difference between consecutive water quality measurements. For example, salinity may be measured at 500 $\mu\text{S}/\text{cm}$ (a result indicating freshwater), and changes of up to 100 $\mu\text{S}/\text{cm}$ four weeks later may be due simply to natural variation and not a significant change in the aquatic environment. There will be more substantial changes following floods, after long dry periods and after entrance opening. For example, turbidity may go up tenfold during a flood event and salinity can increase 100 fold as freshwater inflows decrease and marine water inflows dominate the estuary.

Displaying the data in a time series provides a picture of change over time. Time series plots are useful to illustrate seasonal patterns, major events or when one-off high or low levels are measured. Figure 35 illustrates long term patterns in dissolved oxygen in the Painkalac Creek estuary, near Aireys Inlet. Note the month to month variability and that levels were generally between 60 per cent and 80 per cent saturation. Of concern are the low level in May 2007 and the very high level in September 2007. While not at dangerous levels, both suggest a potential issue, which may have warranted further investigation. For example, both high and low dissolved oxygen levels may occur when the entrance is closed. During these conditions, and with low inflow or outflow of water, turbulence and turbidity will be low, which favours algal growth. A major bloom can develop if these conditions remain for extended periods of time. During daylight hours oxygen is produced by the algae and dissolved oxygen levels in the water increase. Overnight and on cloudy days, however, oxygen is consumed and levels in the water decrease.



Painkalac Creek, Great Ocean Rd Bridge

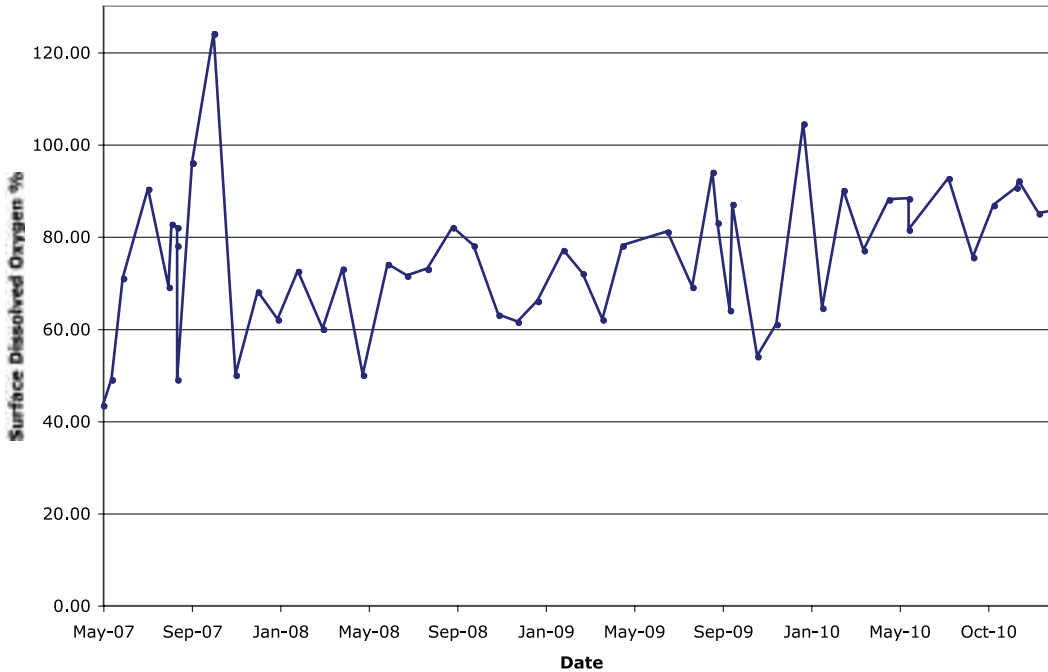


Figure 35 Surface dissolved oxygen levels (% saturation) in Painkalac Creek estuary, Great Ocean Road, Aireys Inlet. (source: EstuaryWatch, Corangamite CMA)

While only two years of data are presented in Figure 36, it clearly shows that during this time turbidity was generally low (usually less than 5 NTU), except on one occasion where it was around 10 times higher. Why this occurred can be assessed using the other data and observations recorded at the time, although further investigation may be warranted to fully understand why it occurred. It is likely that the cause was a short term event like a flood or disturbance of bottom sediment.

Painkalac Creek, Great Ocean Rd

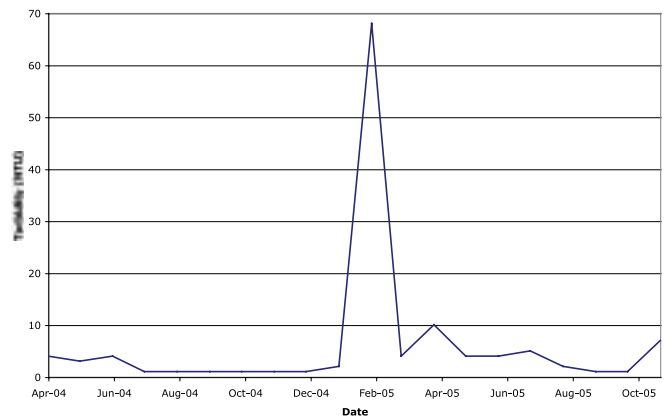


Figure 36 Bottom turbidity levels (NTU) in Painkalac Creek Estuary, Great Ocean Road, Aireys Inlet (source: EPA Victoria)



Trend lines (Figure 37) can also be added to time series graphs to establish if there have been substantial increases or decreases of parameters over time. For the clearest picture, a long time period is required to show changes. Usually less than five years will not provide a good assessment. Figure 37 illustrates the use of a trend line, where dissolved oxygen levels in Painkalac Creek estuary show an increase over the four years of monitoring. While the increase is not likely to be harmful to aquatic life, it suggests closer scrutiny is warranted.

4.3 Key questions for interpreting water quality data

- How good or bad is the water quality of the estuary compared to others?
- How does water quality change over time?
- What are the local issues or threats to the estuary?

Painkalac Creek, Great Ocean Rd Bridge

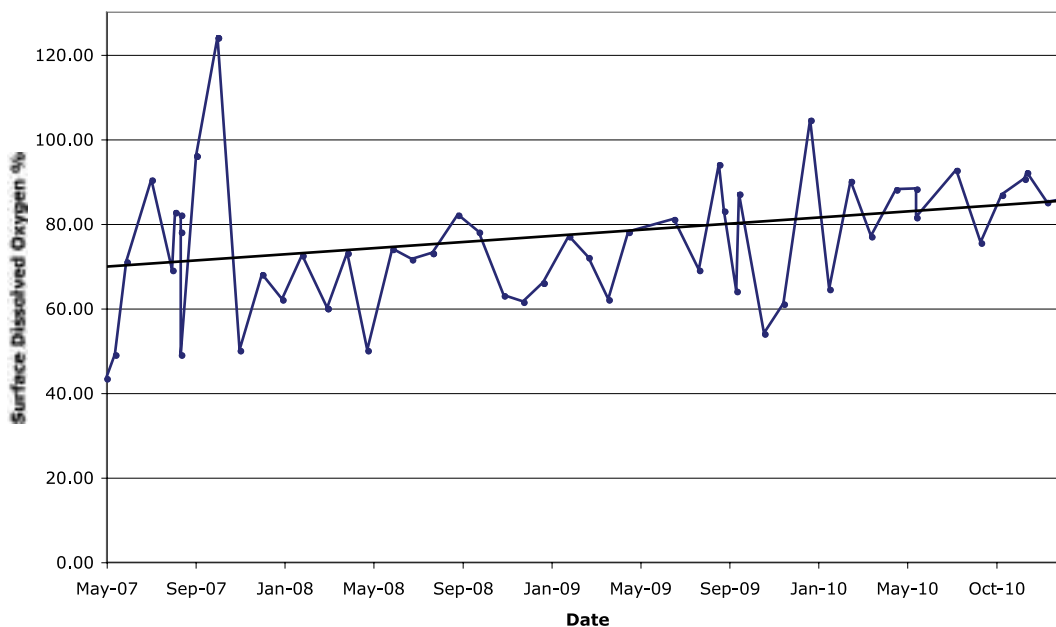


Figure 37 Surface dissolved oxygen levels (% saturation) in Painkalac Creek estuary, Great Ocean Road, Aireys Inlet. Black line is trend line (source: EstuaryWatch, Corangamite CMA)



5.1 Introduction to estuary hydrodynamics

As explained earlier, estuaries are locations within the environment where saline marine waters and freshwater interact. How this interaction manifests is governed by the shape of the estuary, the driving forces that affect the circulation and origin of water.

Estuaries have freshwater sources from their catchment inflow in their upper reaches and a saline tidal water source at the sea boundary. The study of the relationship between these two sources of water and how they mix is broadly referred to as the study of the hydrodynamics of the estuary. A principal consideration of estuary hydrodynamics is the difference in the density of salt water and freshwater. Without the influence of external mixing, seawater will sink under freshwater. Fresh water has a density of 1000kg/m^3 (at 20°C) whilst seawater has a higher density of approximately 1027kg/m^3 (at 20°C).

Understanding this interaction within an estuary is key to understanding the expected water quality.

The competing forces of freshwater and saltwater define the ecological character of the estuary and the potential water quality ranges that can be expected during monitoring.

There are multiple states of estuarine salinity, stratified, partially stratified and mixed (Figure 38 below). An estuary may be one salinity state the majority of the time or move between states for various time periods depending on the influence of freshwater inflows and entrance condition.

5.1.1 Estuary entrance

To gain an appreciation of an estuary and water quality fluctuations it is critical to understand how an estuary is affected by changes to the cross section of the entrance to the sea, this in-turn influences the volume of seawater that can enter the estuary during a tidal cycle.

The entrance berm is the sand that closes the estuary entrance. By collecting data on the cross section of the entrance and berm heights, the water quality data at that point in time can be put into context. Additional information on sea state, tidal phase during the data collection period and water depth within the estuary (potential indicator of storm surge) provides guidance on factors that may alter water quality. Storm surge, large waves and on-shore winds in particular can deliver additional saltwater and sand into an estuary entrance rapidly changing observed physical water quality parameters.

Conversely, during an estuary closure, where a sand berm develops across the seaward entrance, saltwater is prevented from entering the estuary. In this situation freshwater continues to enter the estuary from the river and either overlies the saltwater further stratifying the estuary or mixes diluting the salt concentration. The processes by which estuary closures occur are summarised in section 5.2.

Stratified conditions

Stratified estuaries are characterised by a distinct increase in salinity with water depth (Figure 38a). Stratification occurs when catchment inflow is sufficient to produce a plume of low-density fresh water (0ppt) which can flow over higher-density seawater (35ppt), and where tidal currents and waves are not strong enough to mix the water column. Such conditions can lead to anoxic and hypoxic events because bottom waters can become isolated from dissolved oxygen enriching processes, including gas exchange across the water surface and photosynthesis by plants in shallow water. Hypoxic conditions are when dissolved oxygen levels are considered low ($<2\text{-}3\text{ mg/L}$) whereas anoxic conditions are when there is a complete lack of oxygen (0mg/L).

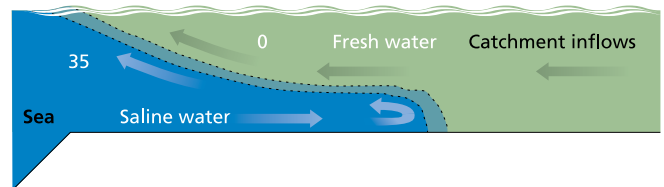


Figure 38a A highly stratified estuary. Salt wedge formation with limited mixing across the salt water – fresh water interface

Partially mixed conditions

When an estuary is partially mixed, tidal currents, wind or flow generate turbulence and promote vertical mixing (Figure 38b&c). However, the currents are of insufficient strength to fully mix the water column, and salinity varies both vertically and horizontally. This is often referred to as the development of a salt wedge.

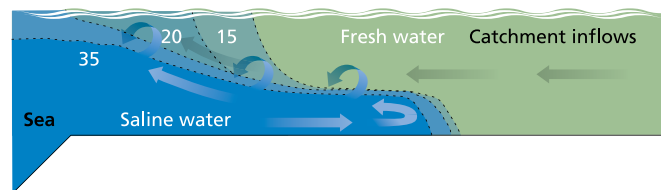


Figure 38b A partially stratified estuary with salt wedge formation. Increased mixing across the salt water – fresh water interface

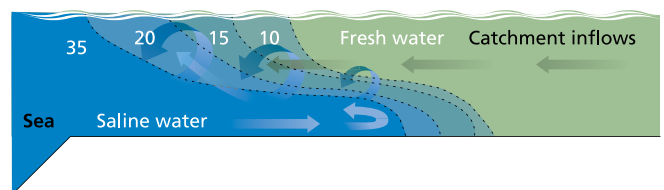


Figure 38c A partially stratified/mixed estuary with salt wedge



Fully mixed conditions

Fully mixed conditions occur in estuaries where tide, river or wave energy produces enough turbulence to mix the water column completely (Figure 38d). In this case, salinity is uniform through the water column, but varies between the riverine and oceanic ends of the estuary.

Of particular interest to EstuaryWatch are the mechanisms within an estuary that create one or all of three of the states described above and how they may influence the water quality results observed within a particular estuary.

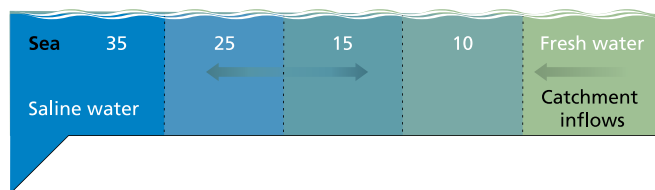


Figure 38d Totally mixed estuary

5.1.2 Stratification formation

Stratification can occur in an estuary with an entrance either open or closed to the sea. In the closed scenario, seawater that has entered the estuary when the entrance was either open or overtopped by waves becomes trapped under the freshwater in the deeper parts of the estuary.

If the entrance is open, saltwater from the seaward estuary boundary is pushed into the estuary on the rising tide. This saltwater is heavier than freshwater, sinks under the fresh water and travels along the bed of the estuary on the incoming tide. As the tide goes out, saltwater close to the seaward boundary drains from the estuary, however, much of the saltwater has travelled further up the estuary into deeper parts and does not fully drain out. The fresher surface water flows out on the outgoing tide toward the sea. This process is repeated during each tidal cycle and is known as salt wedge or halocline development. The halocline is a point in the water column where salinity changes rapidly with depth.

Figure 39 demonstrates a salinity profile and salt wedge development in an estuary over a tidal cycle. Sea water is represented in the colour red with the ocean boundary to the right of the frame. The top picture displays the saltwater on the high tide displacing the blue coloured fresh water from right to left. The second picture is during the low tide and salt water can be seen to have remained on the bed of the estuary with fresh water flowing over the saltwater out to sea.

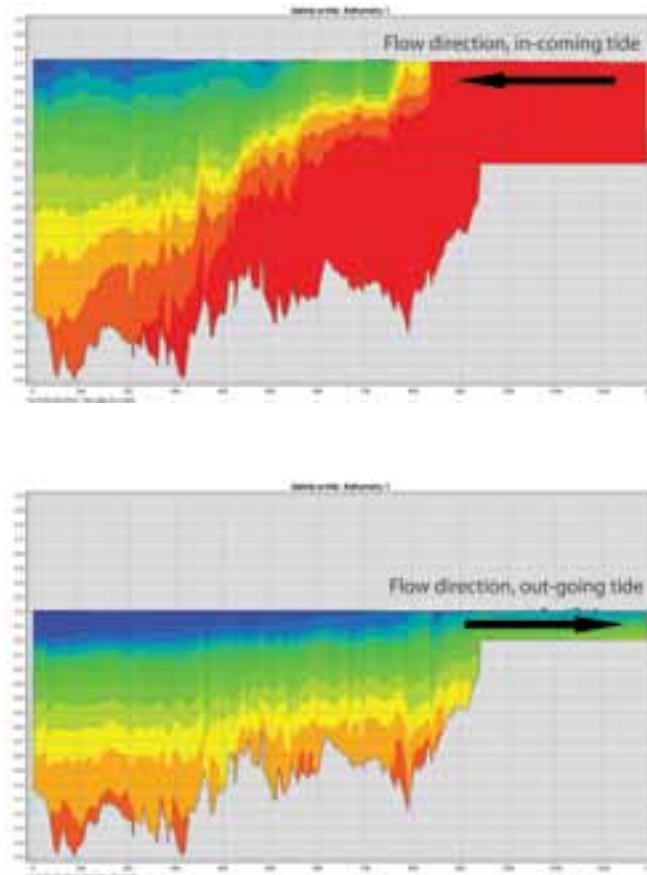


Figure 39 Salt wedge development in long profile on the incoming tide (top) and outgoing (bottom). Red colour represents salt water and blue is fresh water, colours in between are graduations between fresh and saline

Where the salt wedge is located within the estuary depends on the combination of the tidal range, entrance opening, the freshwater inflow and the topography of the estuary. The key determinant is the freshwater inflow. The volume of inflow to an estuary from rivers, again assuming a simple non-turbulent estuary, will determine how far the salt wedge progresses into the estuary. The higher the freshwater inflow and the shallower the estuary, the more difficult it is for salt water to travel up the estuary. In high freshwater flows the salt water can be completely flushed from the estuary (0-1.5ppt), whilst in very low fresh water inflow conditions the estuary can become almost marine (35ppt). For this reason there can be a wide variation in the results that EstuaryWatch volunteers measure throughout a year.



Understanding the characteristics and seasonality of the inflows to the estuary being monitored will assist in gaining an appreciation of whether the water quality results that are being recorded are outside the range that could raise concerns for estuary health, whether the estuary is changing over time or due to natural annual variation. Figure 40 below shows the winter dominated high flows in the Gellibrand River, a natural annual variation. To successfully interpret the water quality in an estuary you must first collect, and understand, how these drivers of estuary hydrodynamics impact upon the estuary.

Average Daily Flow - Gellibrand River (Burrupa)

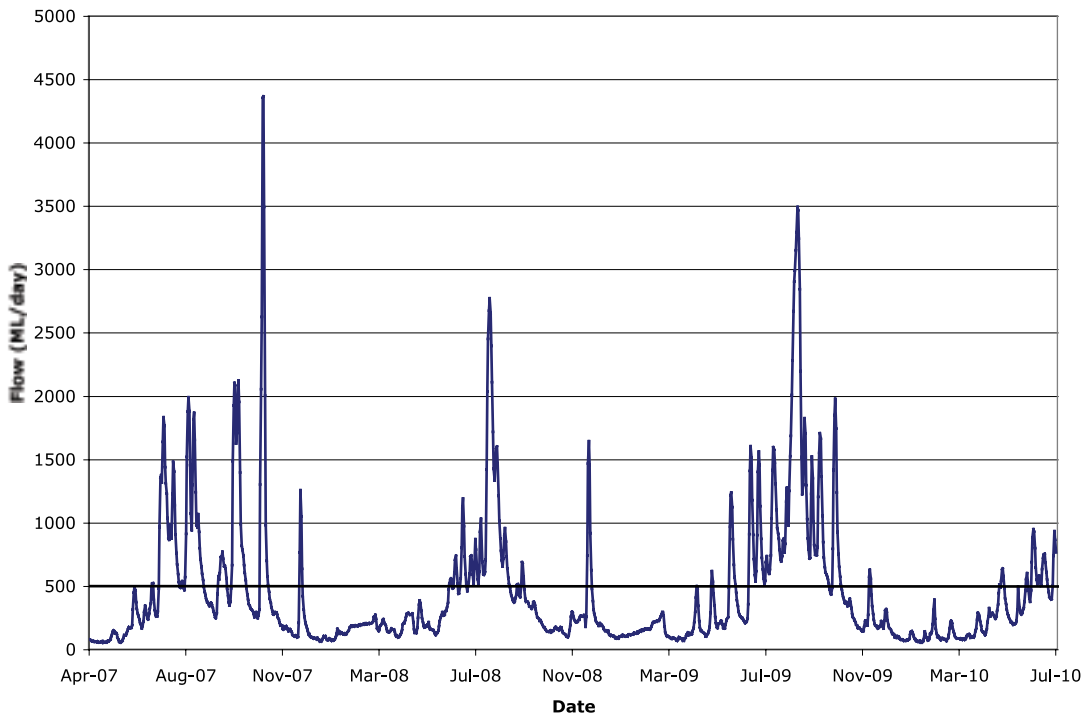


Figure 40 Flows in the Gellibrand River at Burrupa 2007 to 2010 (Victorian Government)



5.2 Berm dynamics and geomorphology

A large number of estuaries on the Victorian coast intermittently close when sand builds up at the entrance preventing tidal exchange and the outflow of water. This process is natural in many estuaries; however it influences the water quality within an estuary and needs to be considered in terms of the analysis of EstuaryWatch collected data. A key feature of the EstuaryWatch monitoring program is the assessment of the entrance condition. Gaining an appreciation of the factors that affect the growth or recession of the berm at a particular estuary assists with understanding the processes that occur within that estuary.

Sand is delivered to the estuary entrance through a number of mechanisms, including waves and along shore currents. Waves carry sand onshore in suspension and along the bed when the waves are angled parallel to the beach. As waves break at an angle to the beach, or there is an along shore current, there is a net transport of sand along the beach. Sand is deposited in the entrance and there is a continual supply of sand forming a flood tide delta (deposit of sand) in an area of low energy inside the entrance.



Figure 41 Berm closing the mouth of the Painkalac Creek Estuary

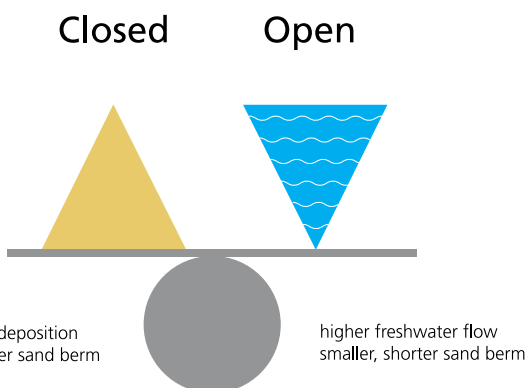


Figure 42 Equilibrium diagram of estuary entrance



Figure 43 Offshore reef exacerbates sand build-up (Anglesea River Estuary)



Figure 44 Headland reduces sand build-up (Thompson Creek Estuary)

The size and shape of the waves influences the ability they have to mobilise sand. If the sand supply exceeds the ebb tide water's ability to scour the sand away, there will be an increase in the berm volume. The greater the along shore sand transport and the wave deposited sand the greater outflow that is required to keep the equilibrium of an open estuary. Figure 42 graphically represents the process, as sand supply increases beyond the fresh water flow required to scour there is a tendency towards closure.

Sand transport and deposition can be exacerbated or reduced by the influence of offshore or near shore structures; therefore each estuary needs to be considered in its own right. In Figure 43 it can be seen that the waves refract around the rocky reef and create an area of deposition at the estuary entrance. In this situation the beach is further built up by the net west to east along shore sand transport.

However, the estuary in Figure 44 has a headland that prevents significant build-up of sand by intercepting the sand and bypassing the entrance. In the latter case very low flows are required to maintain an open entrance because the direct sand supply to the entrance is so low.



5.3 Salinity mixing process

The conceptual model of estuary stratification is straight forward; salt water sinks under fresh water and the tidal salt wedge moves backwards and forwards with the tides, in reality estuaries are not that simple. There are a multitude of other factors that influence the degree to which an estuary stratifies or becomes mixed.

5.3.1 Depth-width ratio

The depth-width ratio plays an important role in stratification and mixing. A riverine reach of an estuary, Figure 45 and Figure 46 below, has a lesser surface area subject to wind generated turbulence compared to a lagoon, and is therefore less able to become mixed due to wind generated forcing. Additionally, the area of contact between the fresh and salt water, by volume, is greater in a lagoon, facilitating mixing.



Figure 45 Riverine reach (red) and lagoon reach (blue) (Barham River Estuary, Apollo Bay)

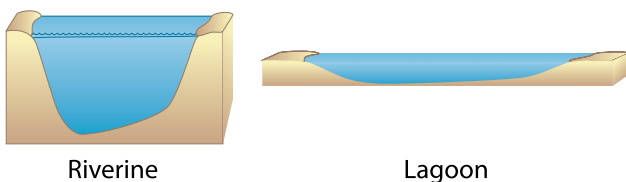


Figure 46 Cross sectional estuary shapes; Riverine (A) and Lagoon (B)

5.4 Types of mixing

There are a number of ways the waters within an estuary can mix or stratify.

5.4.1 Vertical mixing

Vertical mixing occurs at three levels: from the surface downward by wind forces, from the bottom upward by boundary generated turbulence (estuarine and sea boundary mixing), and internally by turbulent mixing caused by the water currents which are driven by the tides, gravity, wind, and catchment inflow.

As wind travels across the surface of water it pushes the water in the direction of the wind. The greater the surface area of a water body the greater the ability wind has to create movement of the upper water layer. As the surface water moves, water from below replaces it at the surface. If this water is saltwater then it becomes mixed with the freshwater, breaking down the stratification. If the wind action is across an area large enough to generate waves then this turbulence also acts to break down the stratification.

As the action of the wind has an effect on the surface, the shallower the water is, the less wind is required to mix the water column. Figure 47 and Figure 48 show diagrammatically the effect wind has on shallow and deep water estuaries.

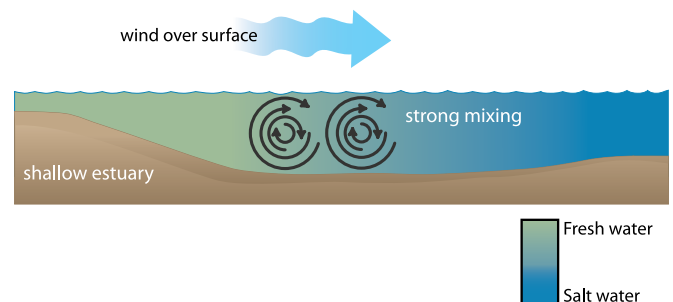


Figure 47 Wind and boundary turbulence in a shallow estuary creates rapid mixing and lack of defined halocline

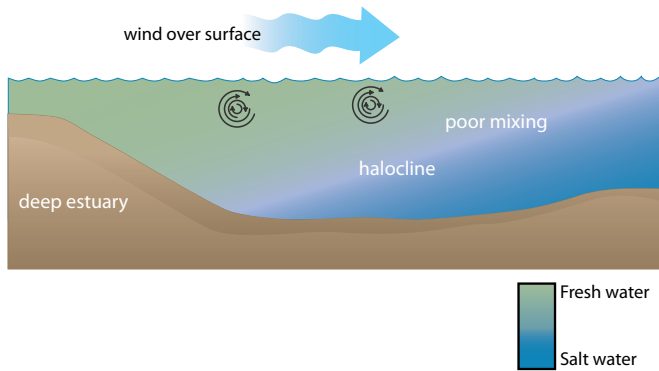


Figure 48 Wind and boundary turbulence in a deep estuary has limited mixing

5.4.2 Bed and banks mixing

The second action that causes mixing is the turbulence caused by water moving over the bed and banks of the estuary (Figure 49). As with wind, the ability of this action to mix the salt and freshwater depends upon the depth and shape of the estuary.

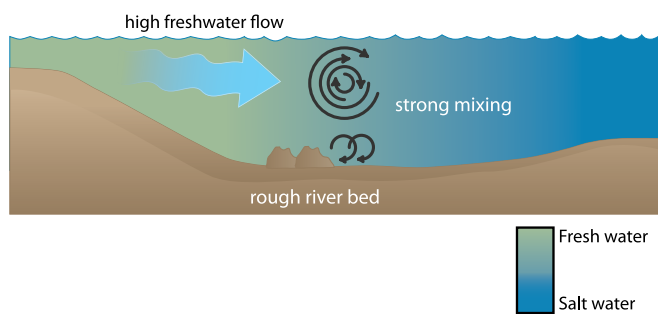


Figure 49 High flow velocities and bed diversity create turbulence and mixing which leads to poorly defined halocline

5.4.3 Mixing by flow

The third mechanism is reliant upon the velocity of the flow from both freshwater and tidal inflow, with further influence from bed topography. Higher flow velocities create additional mixing at the boundary between fresh and salt water. A topographically diverse bed with barriers to the smooth flow of water will create more turbulence than a smooth bed.

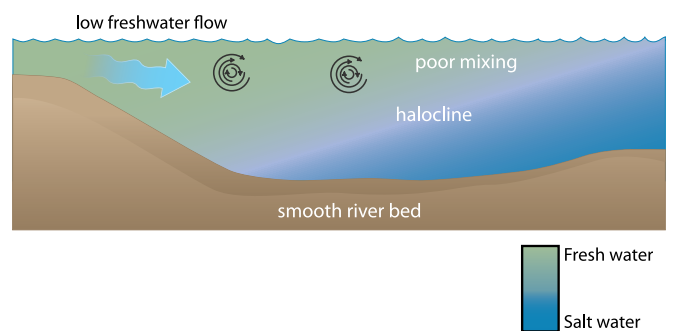


Figure 50 Low flow velocity and uniform bed creates little turbulence and mixing, a well defined halocline is apparent

5.4.4 Thermal mixing

Another form of stratification can occur in estuaries that do not rely on the inputs of saltwater. Thermal stratification is when the surface layer of the estuary heats up, typically during summer. The density of water changes with temperature. Warm water is less dense than cold water; therefore warm water will float above cold water. The density difference between warm and cold water can inhibit mixing in the same way that salinity does, and the same issues can arise with the cold bottom layer becoming oxygen depleted.

5.5 Key questions to understand estuary dynamics

- What is the river flow into the estuary at the time of monitoring?
- Is it high tide or low tide at the time of monitoring?
- Does the estuary entrance close up?
- How deep is the estuary during monitoring?
- Is the estuary or section of estuary lagoonal or riverine?
- Is the estuary exposed to high wind or flows? Is the bed of the estuary irregular?



This chapter seeks to assist EstuaryWatch groups to understand the type of estuary being monitored. Secondly, it will assist in determining whether the observed water quality data collected is within estuary expectations according to the scenario it most closely adheres to.

6.1 Interpreting data for your estuary

Estuary shape, size, source of water and larger scale geomorphic factors will combine to affect water quality and water circulation. Estuaries are dynamic systems and will change seasonally, over daily tidal cycles and due to events such as floods and droughts. This section describes the major estuary scenarios (conditions) an EstuaryWatcher can encounter and the likely water quality to expect under these scenarios.

At every location it is important to identify:

- whether the shape of the channel is wide and shallow (lagoon) or narrow and deep (riverine).
- whether the estuary entrance is open or closed to the ocean
- whether there is a high or low flow entering the estuary from the upstream catchment.

Recording observations will assist in the analysis of data into information. Documenting observations will also improve the understanding of how the estuary functions under certain conditions.



Figure 51 Recording data on an EstuaryWatch photopoint monitoring form

The flow chart below provides a decision tree and summary of expected conditions. EstuaryWatchers can use this flow chart to guide their interpretation of data collected. Riverine and lagoon estuary types that are closed and have high flow are not a recognised scenario. High flows are expected to break through a sand berm therefore, a closed estuary with high flows is short-lived (0.5-1 day).

Key

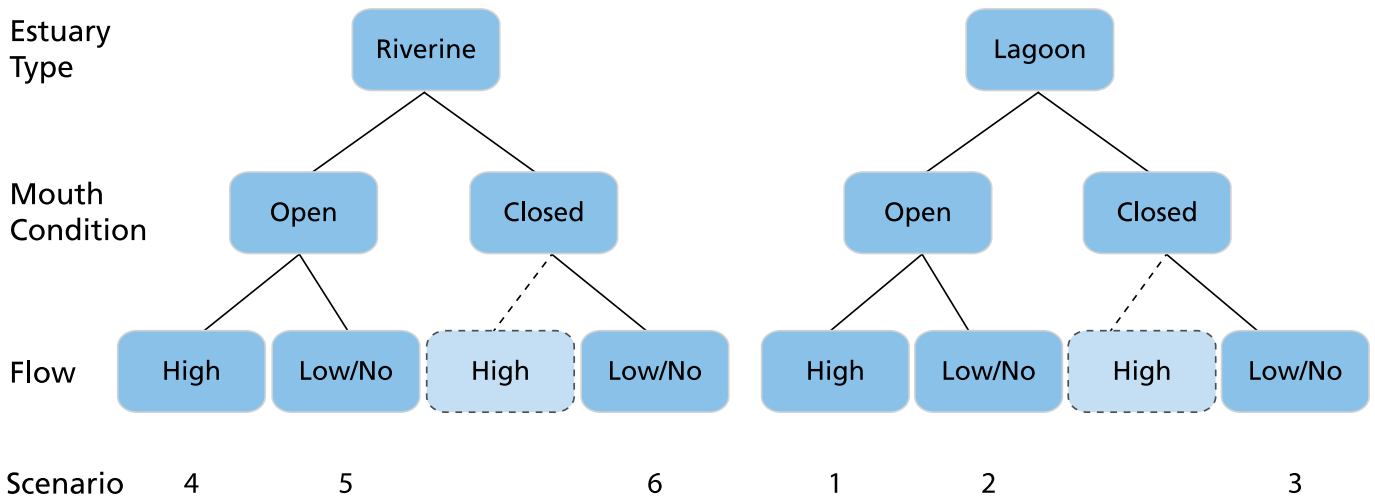


Figure 52 Flow chart to identify relevant scenario for your estuary of interest



6.1.1 Scenario 1 – Open lagoon with high flow



Figure 53 The Hopkins River Estuary. An example of an open lagoon estuary with high flow

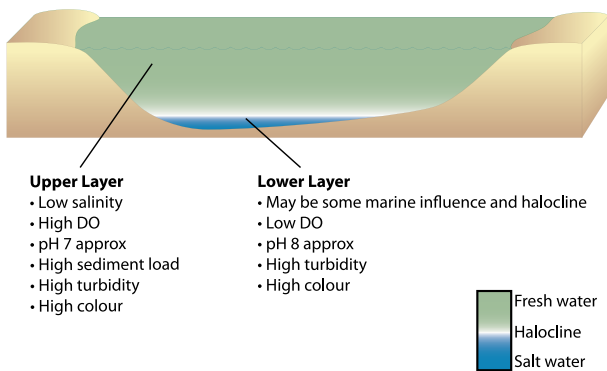


Figure 54 Cross section representation of an open lagoon with high flow

Water regime: High freshwater inflows bring low salinity water and can flush out saline marine water. If the lagoon is shallow it may become almost entirely fresh given sufficient river inflow. In limited cases there may be some minor saline influence in the deeper parts of the lagoon as a result of the tidal inflow.

Dissolved oxygen (DO): During high flows dissolved oxygen concentrations will reflect conditions of upstream waterways. In general freshwater DO should be between 85 per cent and 110 per cent saturation. Depending on the system, the land use in the catchment and the period since the last high flow there may be large amounts of organic matter mobilised from deep holes and floodplains upstream during high flows. Micro-organisms process the organic matter. As these micro-organisms respire they consume oxygen, reducing the DO.

> DO is likely to be just under 100 per cent saturation under this scenario.

pH: Freshwater pH is generally lower than seawater, so during high river inflows, freshwater will begin to dominate and estuary pH will decrease. Fresh water pH should not be below 6, and generally will be 6.5 to 7.5 during high flows. A pH less than 5 may lead to toxic effects.

> pH is likely to be around 7 for most of the time under this scenario.

Turbidity: The turbidity of rivers in high flow is usually very high, as high as 200 NTU. Turbidity in the lagoon may be lower than the river upstream due to sedimentation processes removing some sediment and reducing the turbidity. Where rivers contain high levels of very fine sediment that tends not to settle out (termed colloidal), turbidity may remain high until marine flows begin to dominate the lagoon. Salt water can rapidly decrease turbidity by dilution and facilitating sedimentation. Wind or flow driven re-suspension can resuspend fine sediment in shallow lagoons.

> Turbidity is likely to be moderate, between 10 and 30 NTU for most of the time under this scenario.

Colour: The perceived colour of the water during high river flows is likely to be dominated by colloidal material. The true colour of a water sample can be measured after all suspended material is removed. As flow increases, rivers pick up coloured material draining from areas adjacent to the river where leaves and other plant material accumulate and break down. This process generates tannins and lignins that will turn the water tea coloured. As river flows increase, this will be diluted.

> Colour is likely to be low, that is clear, for most of the time under this scenario.



6.1.2 Scenario 2 – Open lagoon with zero or low flow



Figure 55 The Lake Connewarre section of the Barwon River estuary, an example of an open lagoon with zero or low flow

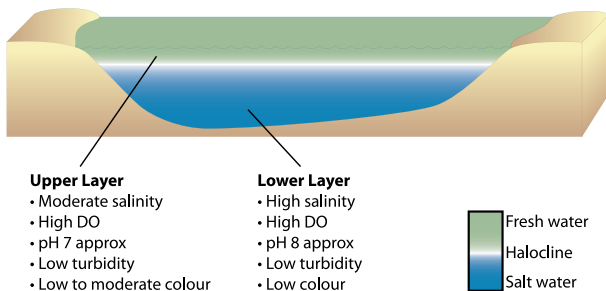


Figure 56 Cross section representation of an open lagoon with zero or low flow

Water regime: Low freshwater inflows bring small amounts of low salinity water into the estuary. When fully open, there will be a large tidal influence and the water levels will rise and fall with the tides. This influence gradually diminishes as the entrance closes. The lagoon may become almost entirely mixed due to winds, or if there is little wind a small freshwater layer may form on the surface. This scenario tends to dominate in estuaries with little sand transport at the estuary entrance.

Dissolved oxygen (DO): In low flow conditions DO concentrations in estuarine lagoons are primarily a function of in-estuary processes. Oxygen is generated by plants and algae in the water column as well as being mixed into surface waters from the atmosphere. An estuary in good condition will typically have DO concentrations between 85 per cent and 110 per cent saturation with daily variation related to photosynthesis. Lower concentrations than these indicate presence of an unusually high oxygen demand from the decomposition of organic matter. Much higher (daytime) and lower (night time) concentrations will occur during an algal bloom. DO is generally constant with depth but estuaries with dense submerged vegetation may show a peak near the bottom.

> DO in this scenario is likely to be consistent with depth with concentrations between 85 and 110 per cent saturation.

pH: The pH of marine waters is usually between 8 and 8.4, and as marine waters dominate the estuary the pH would be expected to be between 7 and 8.4. If there were a surface lens of fresh water present, however, the pH in the lens would be much lower, probably between pH 6 and 8, and most likely around pH 7.

> pH is likely to be between 7 and 8.4 for most of the time under this scenario.

Turbidity: Marine waters generally have low turbidity less than 1 NTU. Rivers during low flows should be also low, less than 5 NTU in natural or near natural catchments, and around 10 NTU in slightly modified catchments. Turbidity in the lagoon therefore, should also be low, less than 5 NTU. The freshwater lens may have a slightly higher turbidity but not more than 10 NTU. If the estuary is very shallow and there are strong winds, bottom sediments could be stirred up, however this would settle quickly once the winds abate.

> Turbidity is likely to be low, that is less than 10 NTU, for most of the time under this scenario.

Colour: Marine waters generally have almost no natural colour. Rivers during low flows also lack colour except rivers from urban catchments or small streams draining wetlands. Estuarine colour, therefore, should also be low, although a freshwater lens may have a slightly higher turbidity. Mixing, however, would result in almost no colour.

> Colour is likely to be low, that is clear, for most of the time under this scenario.



6.1.3 Scenario 3 – Closed lagoon with zero or low flow



Figure 57 The Aire River Estuary near the mouth entrance, a good example of a closed lagoon with zero or low flow

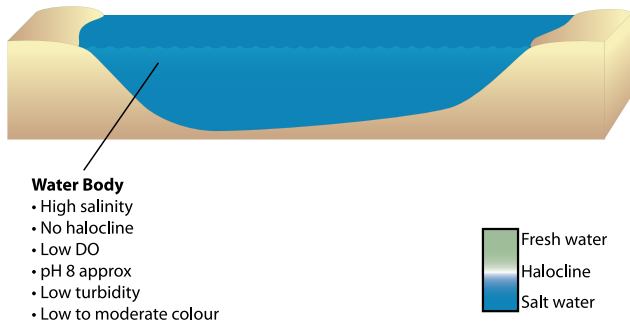


Figure 58 Cross section representation of a closed lagoon with zero or low flow

Water regime: Just prior to the entrance closing, marine inflows would have dominated the water regime in the estuary and with little freshwater inflows salinity would be high and the estuary is likely to be well mixed. Under this scenario the estuary will gradually close from the sea, and when the estuary entrance finally closes, the marine influence becomes minimal and internal processes will drive water quality. This scenario tends to dominate a substantial part of the year in many estuaries with small catchments.

During prolonged closure, and especially during summer months, evaporation may increase salinity to above seawater levels, that is, the water becomes hypersaline (>35ppt). Hot weather may also cause thermal stratification, where the surface layer becomes warm and therefore less dense and as with saline stratification this cuts off the surface from bottom layers. Usually this will only occur during the day and not persist. In shallow lagoons turbulence is likely to break up thermal stratification.

Dissolved oxygen (DO): In a closed lagoon with mixed waters large vertical gradients in DO are not likely to occur. Concentrations will generally be between 85 per cent and 110 per cent saturation with daily variation related to photosynthesis. This scenario is one in which algal blooms are most likely. If a bloom is occurring DO will be observed in substantially higher (daytime) and lower (night time) concentrations. Lower concentrations can also indicate presence of an unusually high oxygen demand. DO is generally constant with depth but estuaries with dense submerged vegetation may show a peak near the bottom while systems with net oxygen consumption in bottom waters will show a slight decrease in DO with depth.

- > DO in this scenario is likely to have concentrations between 85 per cent and 110 per cent saturation.

pH: When the entrance closes, the waters in the estuary will essentially be marine, therefore pH should be well above 7. A surface lens of freshwater under this scenario is unlikely so the surface pH should be the same as deeper in the water column. Under closed conditions, where turbidity is low, phytoplankton levels may increase substantially. Photosynthesis by algae will remove carbon dioxide from the water column, and when phytoplankton levels are very high this may increase pH in an estuary. Phytoplankton productivity will be limited by nutrient availability. Wind action can limit phytoplankton growth as it breaks up blooms and most species will not grow at their optimum rate except in calm waters. High productivity by other plants, in particular macrophytes (including seagrasses) and filamentous algae, may also lead to low carbon dioxide and higher pH.

- > pH is likely to be high, at least greater than 7, for most of the time under this scenario.

Turbidity: When the entrance closes, water in the estuary is essentially marine and will initially have low turbidity. Internal processes will drive turbidity once the entrance is closed, in particular phytoplankton density, which will cloud the water, increasing turbidity.

Sediment processes under anoxic conditions may also contribute by releasing organic matter particles that will cloud the bottom waters and potentially also the surface water when the estuary is mixed by wind.

- > Turbidity is likely to be low, that is less than 10 NTU, for most of the time under this scenario.

Colour: When the entrance closes, waters in the estuary are essentially marine and will initially have low colour. Internal processes will drive colour once the entrance is closed. Phytoplankton will cloud water but this is not true colour. Decaying phytoplankton release cell contents that may add true colour. Sediment processes during anoxic conditions may release dissolved organic carbon from the sediments adding true colour to the bottom waters. Wind mixing will increase surface colour.

- > Colour is likely to be low, that is clear, for most of the time under this scenario.



6.1.4 Scenario 4 – Open riverine with high flow



Figure 59 The Gellibrand River Estuary during a period of very high flow in August 2010. A good example of an open riverine estuary with high flow

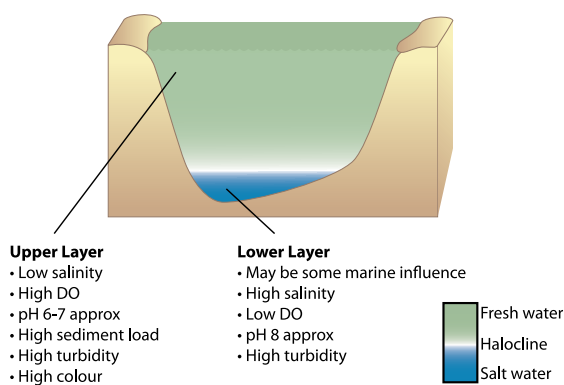


Figure 60 Cross section representation of an open riverine estuary with high flow

Water regime: High fresh water inflows can potentially flush out saline marine water. Riverine estuaries however, are narrow and generally deeper than lagoons, even during high freshwater flows, a deep saline water layer may still exist. Tidal effects are likely to be small as the freshwater inflow overwhelms the tidal cycle. This scenario tends to only occur for very short periods of time following heavy rainfall. An assessment of monthly rainfall patterns at your estuary will give an indication of the seasonality of the high flow conditions.

Dissolved oxygen (DO): Freshwaters above the halocline will have dissolved oxygen concentrations that reflect conditions of upstream waterways in this scenario, with relatively little change due to estuarine processes. In general, fresh water DO should be between 85 per cent and 110 per cent saturation in these waters. Depending on the system, the land use in the catchment and the period since the last high flow, there may be large amounts of organic matter mobilised from deep holes and floodplains during high flows. In stratified systems this material can sink into deeper saline waters. Decomposition of this organic matter consumes oxygen and may result in low oxygen concentrations in both surface and bottom waters, particularly as flows reduce. DO concentrations below 80 per cent may be a sign of unusual oxygen demand in surface waters and concentrations below 50 per cent are likely to present a challenge to estuarine animals. In stratified conditions it is not unusual to observe a peak in DO around the halocline, related to a plate of algae at that part of the water column.

> DO is likely to be just under 100 per cent saturation in surface waters under this scenario and is likely to decrease to 60 per cent and below in bottom waters where there is persistent stratification. If an estuary is fully flushed with freshwater a gradual decrease in DO from the surface to the bottom would be expected.

pH: Freshwater pH is generally lower than seawater. During high river inflows, freshwater will begin to dominate and estuary pH will decrease at the surface. In general freshwater pH should not be below 6 and generally will be 6.5 to 7.5 during high flows. A pH less than 5 may lead to toxic effects. Bottom water however may remain saline and the pH is likely to be much higher, at least greater than pH 7 and maybe as high as 8.5.

> Nonetheless, pH is likely to be around 7 for most of the time under this scenario.

Turbidity: The turbidity at high river inflows is usually very high, even as high as 200 NTU for short periods of time. Turbidity levels in surface waters in riverine estuaries are likely to be similar to the freshwater levels, that is, around 20-50 NTU for most of the time under this scenario. Deep layers of water with high salinity are relatively clear and should be well below 10 NTU when the surface is at 20 to 50 NTU.

> Turbidity is likely to be moderate, ie. less than 20 NTU, for most of the time under this scenario.

Colour: The true colour of riverine estuary water will be similar to river water. The perceived colour of the water during high river flows is likely to be dominated by turbidity. The estuary picks up coloured material draining from upstream areas adjacent to the river where leaves and other plant material accumulate and break down generating tannins and lignins, which will turn the water tea coloured. As river flows rise, this will be diluted and all but removed from the water. Turbidity will dominate the perceived colour.

> Colour is likely to be low, that is clear, for most of the time under this scenario.



6.1.5 Scenario 5 – Open riverine with zero or low flow



Figure 61 The Werribee River Estuary. An example of an open riverine estuary with zero or low flow

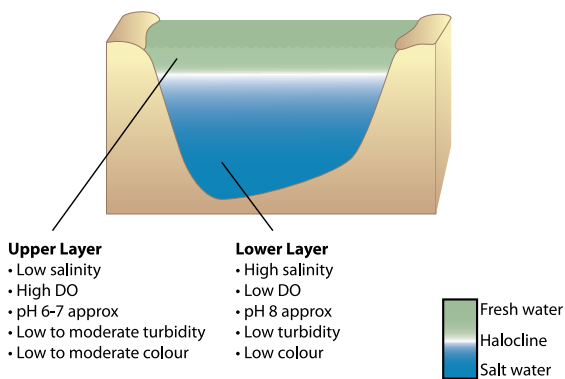


Figure 62 Cross section representation of an open riverine estuary with zero or low flow

Water regime: Low river inflows will lead to a freshwater layer over a layer that is high in salinity. As riverine sections or whole estuaries are narrow and deep, mixing is unlikely to occur and the fresh water layer will remain. At very low flows, the freshwater layer may be reduced to a lens at the head of the estuary. When fully open, marine inflows will be substantial and the bottom waters will be refreshed each tide cycle. As a result the tidal range will be substantial and reach far upstream.

Dissolved Oxygen (DO): When stratified, there is little mixing of DO into bottom waters and the main source of any oxygen is from photosynthesis within the bottom layer or replenishment of bottom waters from the marine environment. The amount of in situ photosynthesis depends on the depth of the halocline and the clarity of overlying water. The greatest chance of reduced oxygen in bottom waters comes when the entrance is largely closed, there is little marine exchange and stratification is maintained. In this scenario dissolved oxygen in surface waters should still range between 85 per cent and 110 per cent saturation but bottom waters can have concentrations ranging from supersaturation (>100 per cent saturation) where they are shallow enough for photosynthesis to concentrations close to zero saturation. As concentrations fall below 50 per cent saturation, conditions become challenging for estuarine animals and at concentrations closer to zero, phosphorous may be released from sediments.

> Under this scenario DO of fresh surface waters should be in the range of 85 per cent to 110 per cent saturation but concentrations of oxygen in bottom waters will be variable, depending on marine influence, in situ photosynthesis and oxygen demands in waters isolated from the atmosphere.

pH: Even low freshwater inflows will maintain a freshwater layer so the pH of the surface water will remain around pH 7 and should not be below pH 6. A pH less than 5 may lead to toxic effects.

> Under this scenario marine waters will dominate the water column below the freshwater layer and pH will be much higher, up to pH 8.4.

Turbidity: Marine waters generally have low turbidity, less than 1 NTU, and rivers during low flows turbidity should be also low, less than five in near pristine catchments, and around 10 NTU in slightly modified catchments. Estuarine turbidity, therefore, should also be low, less than 5 NTU, in both the freshwater layer and the marine bottom waters. The freshwater may have a slightly higher turbidity but not more than 10 NTU.

> Turbidity is likely to be low for most of the time under this scenario with both the fresh water surface layer and marine bottom waters less than 5-10 NTU.

Colour: Marine waters generally have almost no colour, and rivers during low flows are also low except in urban catchments or those small streams draining wetlands.

> Colour is likely to be very low, that is clear, for most of the time under this scenario.



6.1.6 Scenario 6 – Closed riverine with zero or low flow



Figure 63 The Painkalac Creek Estuary when there is a berm completely across the mouth. A good example of a closed riverine estuary with zero or low flow

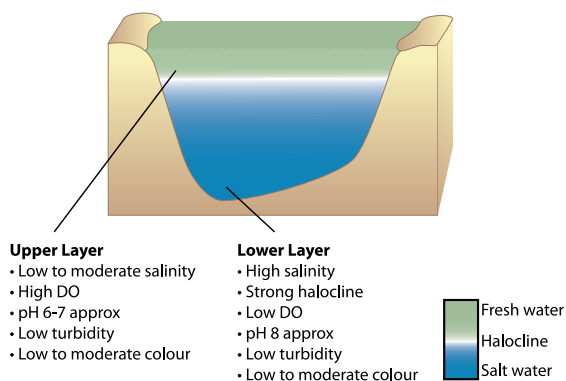


Figure 64 Cross section representation of a closed riverine estuary with zero or low flow

Water regime: Zero river and marine inflows will lead to no waters refreshing an estuary that is closed riverine with low flow. Under this scenario internal processes will drive water quality. As riverine estuaries are narrow and deep, mixing is unlikely to occur therefore a thin freshwater layer will remain. As the estuary is closed there will be no tidal influence. Under this scenario bottom waters are cut off from not only inflows but from the atmosphere. This scenario tends to dominate a substantial part of the year in many estuaries with small catchments.

Dissolved oxygen (DO): When stratified, there is little mixing of DO into bottom waters and the main source of any oxygen is from photosynthesis within the bottom layer. The amount of in situ photosynthesis depends on the depth of the halocline and the clarity of overlying water. While a substantial freshwater layer remains on the surface of the estuary, isolation of bottom waters is greatest.

In this scenario dissolved oxygen in surface waters should still range between 85 per cent and 110 per cent saturation, with a greater range when there is high phytoplankton production. Bottom waters can have concentrations ranging from supersaturation (>100 per

cent saturation) where they are shallow enough for photosynthesis, to concentrations close to zero saturation. As concentrations fall below 50 per cent saturation conditions become challenging for estuarine animals and at concentrations closer to zero, phosphorous may be released from sediments. As the freshwater layer becomes thinner and more brackish with mixing, differences between surface and bottom DO concentrations will diminish. Lower DO concentrations at the bottom due to decomposition of organic matter are likely to remain.

- > Under this scenario DO in fresh surface waters should be in the range of 85 per cent to 110 per cent saturation but concentrations of oxygen in bottom waters will be variable, depending on in situ photosynthesis and oxygen demands in waters isolated from the atmosphere.

pH: In general, the top layer is likely to be brackish, so pH should be at or above 7, while the bottom marine water should have higher pH, up to 8.5. Where turbidity is low, phytoplankton levels may increase substantially. Photosynthesis by algae will remove carbon dioxide from the water column, and when phytoplankton levels are very high this may increase pH in an estuary. Phytoplankton productivity will be limited by nutrient availability, but in the bottom waters nutrients may be released to the water column if they become deoxygenated, potentially fuelling algal productivity. A blanket of filamentous or colonial algae may cover the sediments, harvesting nutrients from the surface of the sediment. If light is not limiting then the biomass of the algae will build up and again affect carbon dioxide levels in the water and therefore pH.

Sediment processes can also directly alter pH as deoxygenation leads to the generation of hydrogen sulphide and other chemical changes which tend to lower pH.

- > Under this scenario, pH is potentially variable, although most of the time it is likely to be higher than pH 7.

Turbidity: Inflows prior to entrance closure would be very low in turbidity. Internal processes will, however, drive turbidity once the entrance is closed.

Phytoplankton density will cloud potentially both the surface and bottom waters. Sediment processes under anoxic conditions may also contribute by releasing organic matter particles that will cloud the bottom waters.

- > Turbidity is likely to be low for most of the time under this scenario, less than 10 NTU.

Colour: Colour is likely to be low in both surface and bottom waters when the entrance closes. Internal processes will drive colour once the entrance is closed. Phytoplankton will cloud water but this is not true colour. Sediment processes during anoxic conditions may release dissolved organic carbon from the sediments adding true colour to the bottom waters.

- > Under this scenario, colour is likely to be low, that is clear, for most of the time in the surface waters, but as this scenario persists, colour will increase in the bottom waters.



When interpreting EstuaryWatch data the aim is always to gather information about the health of your estuary. It then follows that you will draw conclusions from this information, which can be difficult.

Nevertheless, identifying scenarios that may explain patterns in the data or causes of change are important as these can identify the need for further investigation or management actions. The assessment and interpretation of data helps define the quantity and type of information that is required to allow conclusions to be confidently made. It is not scientifically correct to make assumptions or guesses and present these as support for conclusions. The data must support your conclusions and be interpreted as outlined in this manual.

Using the interpretation guidelines in this manual, EstuaryWatchers and estuary managers can work towards better understanding our estuaries and making informed management decision. This is good news for the health of Victoria's estuaries!





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Daily, seasonal and longer-term fluctuations in weather and inflows impact on estuary conditions leading to substantial variability in environmental data. However, external and human induced influences may also change conditions. The use of control charts is a new approach to assessing aquatic systems condition. Control charting takes the natural causes of variability into consideration, removing their effect and reducing the overall natural data variability. In this way we can more easily detect patterns or shifts in environmental variables that may be a result of environmental or human induced change.

Control charts allow the user to compare environmental measurements taken in an estuary with what would be expected for an estuary in good condition. EPA Victoria has developed estuary control chart models for the surface and bottom for four water quality indicators; dissolved oxygen, turbidity, total phosphorus and total nitrogen (EPA Victoria, 2011). Each control chart provides a graphical record of the recent measurements of the chosen indicator, and allows comparison of the actual measurements with a statistical prediction.

Estuary managers and other users with regular access to measurements of environmental variables can use control charts. The control chart models are available in an Excel spreadsheet from EPA Victoria, along with instructions for their use.

To test estuaries, water quality and environmental data collected at an estuary are used to calculate expected values and the prediction intervals, or control limits, using the relevant control chart model. Each control chart provides a graphical record of the recent measurements of the chosen indicator, and allows comparison of the actual measurements with a statistical prediction (expected value) and the prediction intervals (a range 10 per cent outside the prediction).

These measurements may indicate less than desirable environmental conditions. If measurements remain outside the prediction range for a period of time, this suggests a need for further exploration of factors that may be affecting the estuary, such as prolonged low river flows. A measurement above the guideline single-sample value should trigger investigation such as further sampling or, where the likely cause has been identified, management intervention.



Prediction intervals may in some cases appear high compared to the single-sample guideline value or compared to other estuaries. This is because the models, although derived from reference estuary data, use actual measurements from the estuary being investigated.

If data for all the parameters needed for a model is not available, no expected values or prediction intervals can be generated. At these times the single-sample guideline values (EPA, 2011) should be used to assess condition. Further information on the models, and their development, can be found in Environmental water quality guidelines for Victorian riverine estuaries (EPA, 2011).



The information presented here demonstrates how to present EstuaryWatch water quality data in a time series to gain an understanding of estuary processes and identify trends.



Figure 65 The Gellibrand River Estuary

Gellibrand River Estuary – riverine shape

Flow and salinity

Patterns: The estuary is stratified in the majority of flows yet becomes fully flushed at flows of over 800ML/day. The salinity at the bed is close to seawater for the majority of the flows with salinity at the surface increasing substantially at flows below 100 ML/day.

In March 2008, a period after an artificial opening of the estuary and during low flows there was a sudden increase in salinity at the surface. Low summer in-flows from low rainfall (exacerbated by water extraction for domestic use), and a tidal system with a scoured entrance, created a marine dominated estuary followed quickly by another closure.

Another artificial opening on May 11, 2008 briefly flushed the estuary as noted by the sudden reduction in bottom salinity. The bottom salinity returned to a saline state on the return tide and was then flushed again with a 700ML/day flow on July 5, 2008 (Figure 66), the last point in the series.

Gellibrand River - Ocean Rd Bridge

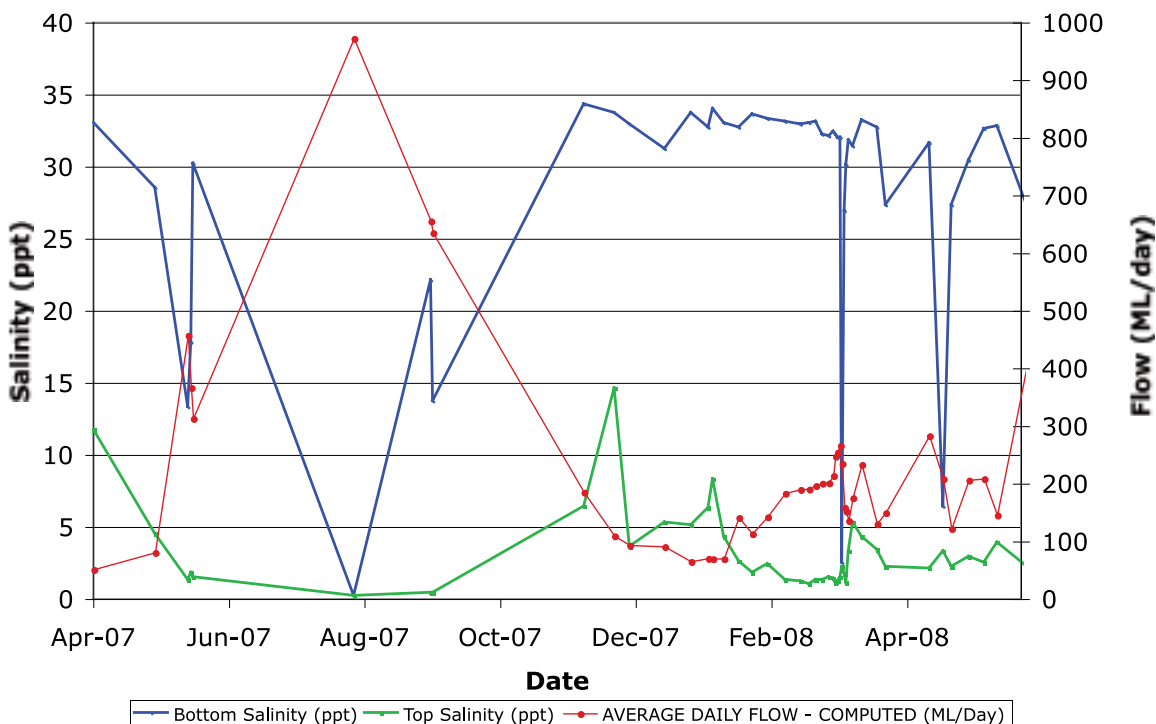


Figure 66 Flows and salinity in the Gellibrand Estuary



Dissolved Oxygen

Environmental water quality guidelines for Victorian riverine estuaries (EPA, 2011): The Gellibrand River estuary did not meet the EPA estuary guidelines for healthy ecosystem function for surface or bottom waters between 2007 and 2010 (Table 2) for dissolved oxygen. Median levels in the surface water were nonetheless indicative of oxygen levels that should provide adequate protection of aquatic life, that is, they are not likely to result in ecosystem damage. Estuary bottom waters often have much lower oxygen levels than surface waters (EPA, 2011). Bottom waters are expected to be lower than surface waters but in 2008 the result indicates a potential threat to aquatic life. The low oxygen may be the result of the substantial accumulation of oxygen demanding substances on the bottom (for example kelp after a large storm), or a major salinity difference between surface and bottom waters that persists. There is no information on organic matter build up but for most of 2008 the salinity difference between surface and bottom was substantial, ie. less than 10 ppt and 35 ppt respectively. Cutting off the bottom waters from the surface leads to lower oxygen interchange and the gradual lowering of oxygen in the bottom waters due to oxygen demand from the sediments.

Please note that when interpreting oxygen concentration from singular readings you must take into consideration the percentage saturation of the entire water column and that above and below the halocline. If a high proportion of the water column either below or above the halocline is deoxygenated, fish species (and other ecological components) with specific salt tolerances will find it difficult to survive.

Table 2 Annual and long term dissolved oxygen medians (50th percentiles) for Gellibrand River estuary 2007- 2010 (Old Coach Road Bridge, Princetown. EstuaryWatch Data)

	Surface (% saturation)	Bottom (% saturation)
EPA guideline (annual median)	90	65
Long term median (2007-2010)	72	51
2007 annual median	65	48
2008 annual median	63	44
2009 annual median	75	61
2010 annual median	76	60

Patterns: Surface dissolved oxygen levels are generally above 60 per cent saturation, however, on several occasions it was less than 50 per cent and on one occasion less than 20 per cent (Figure 67). In general dissolved oxygen was high in 2007 but in 2008 were variable and generally very low (Figure 68).

In April 2008 when surface dissolved oxygen levels dropped to less than 20 per cent saturation, the bottom waters were also less than 20 per cent saturation (Figure 68). At this time bottom salinity also dropped significantly in a short space of time and this suggests that a mouth opening event occurred. A rise in flow after the event corresponded in a rise in salinity and dissolved oxygen values back towards the median (Figures 67 and 68). Trends in surface waters, however, suggest that dissolved oxygen levels have been improving over the period of measurement (Figure 67).



Surface Dissolved Oxygen

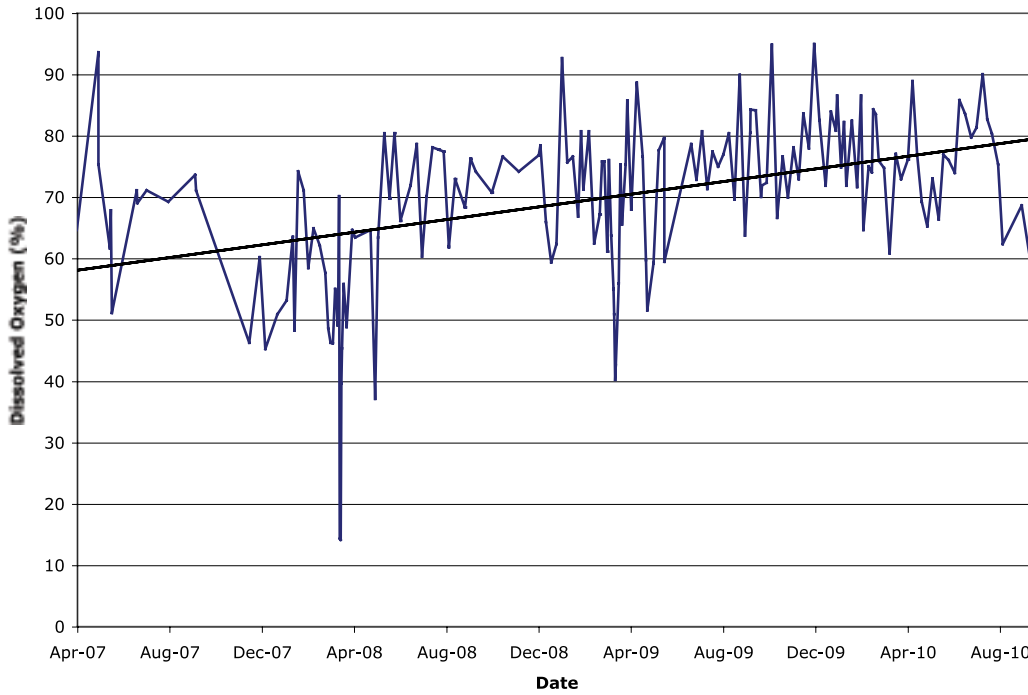


Figure 67 Dissolved oxygen (% saturation) in the surface of the Gellibrand River estuary 2007 to 2010 (source: EstuaryWatch)

Gellibrand River - Ocean Rd Bridge

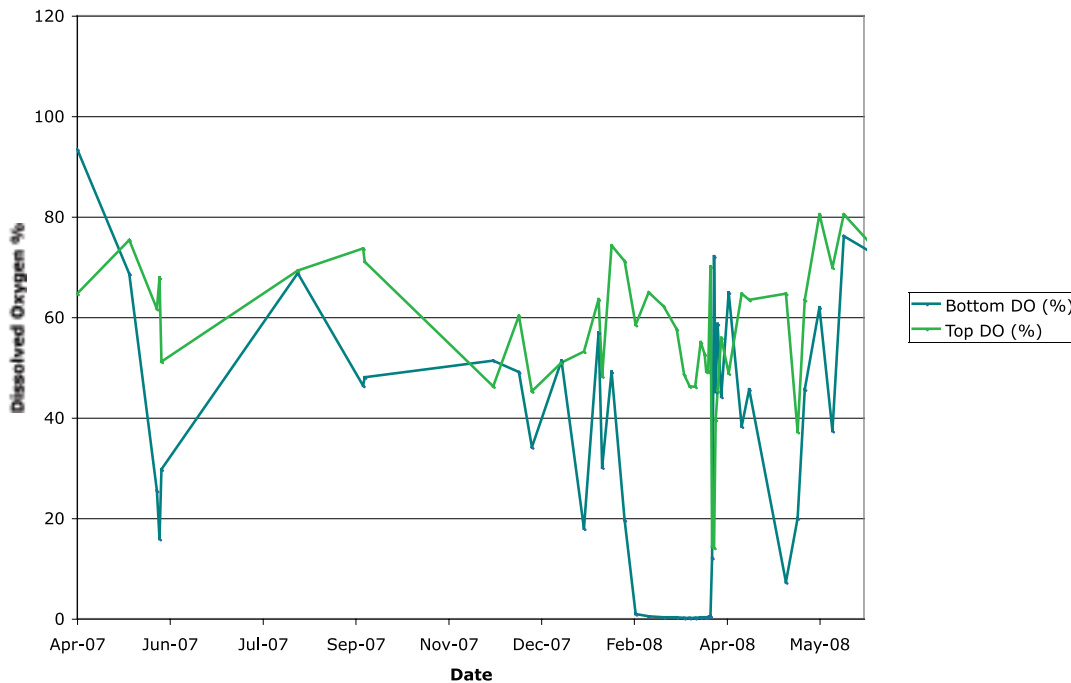


Figure 68 Dissolved oxygen (% saturation) in the surface and bottom waters of the Gellibrand River estuary 2007 to 2008 (source: Estuary watch)



Turbidity

Environmental water quality guidelines for Victorian riverine estuaries (EPA, 2011): The Gellibrand River estuary has not met the EPA estuary guidelines for healthy ecosystem function for surface or bottom waters (Table 3). However, the annual medians calculated are based on data using a method with a detection limit of 10 NTU and when a <10 NTU is found in the data set half the value is used (as recommended by EPA Victoria), that is 5 NTU. The EPA guidelines recognise that under low flow most healthy estuaries are very clear, usually less than 5 NTU and usually only in flood times is it higher.

Table 3 Annual and long term medians (50th percentiles) for Gellibrand River estuary 2007- 2010 (Old Coach Road Bridge, Princetown. EstuaryWatch Data)

	Surface (NTU)	Bottom (NTU)
EPA guideline (annual median)	5	7
Long term median (2007-2010)	13	13
2007 annual median	13	13
2008 annual median	13	13
2009 annual median	18	18
2010 annual median	13	13

Patterns: Surface and bottom waters had very similar levels of turbidity (Figure 69). Often levels in bottom waters are lower than surface due to the source of water; clearer marine on the bottom and more turbid river water on the surface.

There is a general pattern of higher flows in winter and spring and lower over summer (Figure 70). Turbidity follows a similar seasonal pattern (Figure 69). The very high turbidity levels in both surface and bottom waters in July and August 2010 (Figure 69) are a result of a major regional flood.

Trend lines suggest that there is an increasing trend in turbidity in the estuary (Figure 69). However, if the very high levels in July and August 2010 are removed, the trend disappears. The issue here is that with only four years of data, sudden large changes in levels will potentially create a false trend. Trends are best assessed with larger data sets, preferably ten years of data.



Gellibrand River - Ocean Rd Bridge

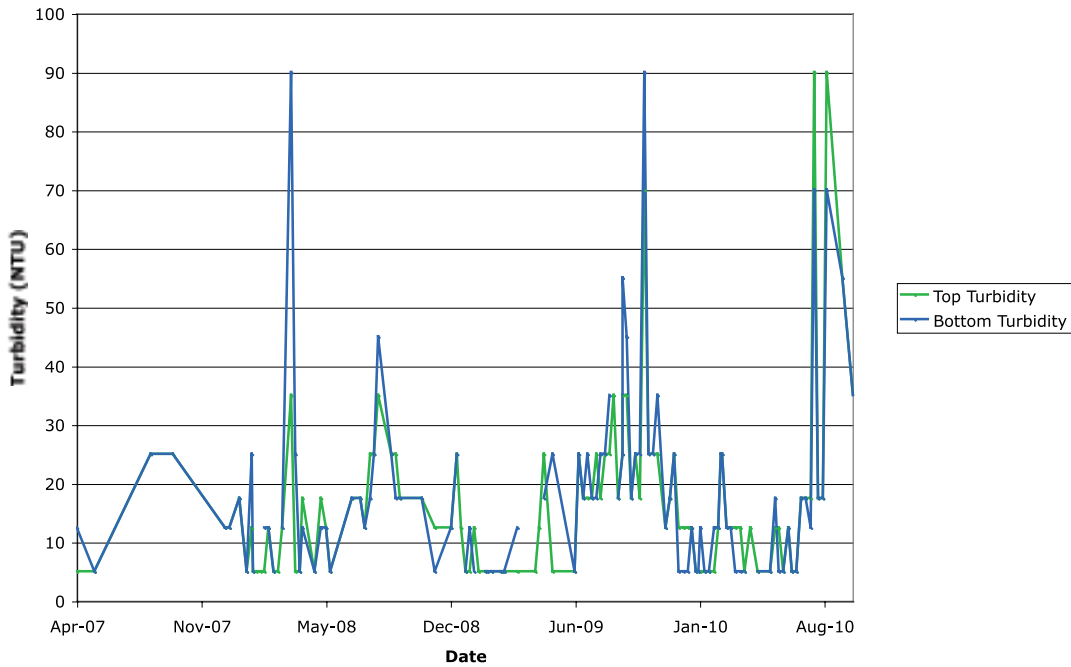


Figure 69 Turbidity in the surface and bottom waters of the Gellibrand River estuary 2007 to 2010 (source: Estuary watch Database)

Average Daily Flow - Gellibrand River (Burrupa)

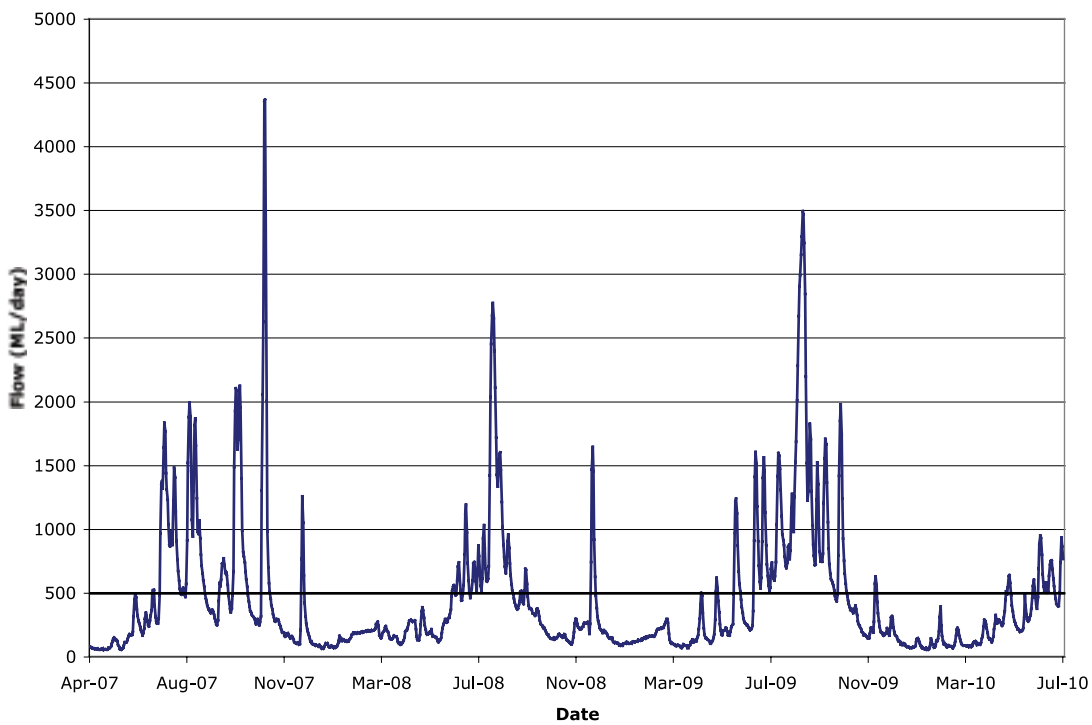


Figure 70 Flows in the Gellibrand River at Burrupa 2007 to 2010 (Victorian Government)



Acidic – pH less than 7.

Alkaline – pH greater than 7.

Anaerobic – living or active in an environment where free oxygen is absent.

Anoxic – areas of marine or freshwater that are depleted of dissolved oxygen.

Berm – is the sand that closes the estuary entrance.

Blackwater – event when deoxygenated, organically rich waters enter a river from floodplain wetlands, backwaters or tributaries.

CMA – Catchment Management Authority

Colloidal material – fine sediment that does not settle.

Dissolved oxygen – oxygen dissolved in water. Usually measured in milligrams per litre (mg/L or ppm) but can also be presented as per cent saturation.

EEMSS – Estuary Entrance Management Support System

Electrical conductivity (EC) – is a measure of how well a material accommodates the transport of electric charge. EC is used to estimate the concentration of dissolved salts.

EPA – Environmental Protection Agency

Estuary – semi-enclosed body of water where salt water from the sea mixes with freshwater flowing from the land.

Forel-Ule Scale – method used to determine the colour of water.

Future Coast – is a Program led by the Victorian Department of Sustainability and Environment in partnership with the Department of Planning and Community Development. Its purpose is to coordinate policy framework that recognises the responsibilities of other organisations that have a role in planning for and managing the impacts of climate change on Victoria's coast.

Halocline – an area of transition from lower to higher salinity with increasing depth.

Hydrodynamics – describes the timing and volume of fresh and sea water and how it mixes through the water profile.

Hydrological regime – describes the long-term spatial variation in the volume, depth, frequency and salinity of water in an estuary.

IEC – Index of Estuary Condition

Lignin – a polymer related to cellulose that forms the woody cell walls of plants.

Macrophytes – an aquatic plant that grows in or near water.

Microphytes – microalgae found in freshwater and marine systems.

Microphytobenthos – benthic microalgae.

NTU – National Turbidity Unit

pH – The pH of water is a measure of its acidity or alkalinity. The actual component of the water being measured is its concentration of hydrogen ions (H⁺).

Residence time – refers to the period of time that water may be enclosed in a lagoon.

Salt Wedge – a wedge-shaped intrusion of salty ocean water beneath freshwater in an estuary.

Saturation – the point at which the amount of oxygen entering and leaving the water is equal. The water contains 100 per cent of the oxygen it should be able to hold at that temperature.

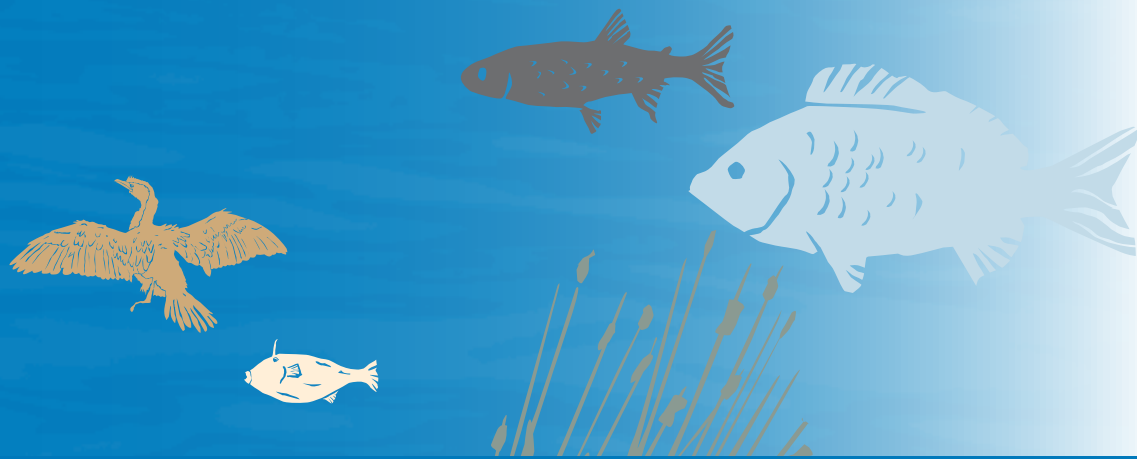
Stratification – occurs in a poorly mixed estuary due to the presence of separate layers of surface freshwater and lower strongly saline water. The boundary between the two layers is the halocline.

Supersaturation – per cent saturation of dissolved oxygen concentration that is greater than 100 per cent saturation.

Tannin – a compound found in bark.

True colour – is measured when all suspended material is removed from the water body.

Turbidity – visible cloudiness due to suspended material in water causing a reduction in the transmission of light.



EstuaryWatch

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