GUIDELINES

ENVIRONMENTAL WATER QUALITY GUIDELINES FOR VICTORIAN RIVERINE ESTUARIES

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INTRODUCTION

What is the purpose of these guidelines?

The environmental water quality guidelines for riverine estuaries will support the sustainable management of Victoria's estuarine ecosystems. They provide a framework and tools for assessing the environmental condition of riverine estuaries.

In this document there are guideline values that describe the condition of reference-quality estuaries and these can be used as an indicator for assessment of other estuaries. This publication describes their development and use.

Why is there a need for these guidelines?

Since estuaries are at the bottom end of catchments, they are subject to the impacts of changes throughout that catchment.

As many catchments in Victoria are degraded, many estuaries are potentially at risk. Few would be considered to be in a natural or near-natural condition (SOE 2001, NLWRA 2002, Deeley and Paling 1999).

The major threats to Victoria's estuaries include increased sediment, reduced oxygen levels, reduced freshwater inflows, chemical contaminants, physical changes and habitat modification (Table 1). Algal blooms and reduced bottom oxygen levels may occur as ecological responses to changed conditions, and may themselves pose a threat to estuary plant and animal communities. In addition, impacts from climate change may have profound effects on estuarine ecosystems.

Water quality objectives for estuarine ecosystem health in Victoria are included in the *State Environment Protection Policy* (*Waters of Victoria)* (SEPP (WoV)) (Govt. Vic. 2003). These were taken from the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC and ARMCANZ 2000a). The ANZECC guidelines are largely based on data collected from large, well-mixed estuaries that are essentially marine, and are not appropriate for the considerably smaller, stratified, riverine estuaries in Victoria.

* This replaces publication 1347, released July 2010.

What are the guidelines' scope and limitations?

The guidelines have been developed for riverine estuaries in Victoria and are not appropriate for assessing large lagoon systems, salt marshes or embayments. The guidelines were based on data from estuaries in western and central Victoria.

Spatial and temporal data are limited for estuaries and only a restricted number of issues (threats) have been addressed by these guidelines. Those issues for which we have robust water quality data and relatively good understanding include oxygen stress and nutrient and sediment impacts. Given the absence of sufficient data to develop specific guidelines for toxicants and temperature impacts, the *Australian Water Quality Guidelines* (ANZECC and ARMCANZ 2000a) have been used to provide guidance.

What is an estuary?

Historically, the term 'estuary' has been applied to the lower tidal reaches of a river (Lauff 1967); that is, where freshwater meets seawater. In more recent times it has, incorrectly, been applied to any coastal body of water that is semi-enclosed, such as the arms of a bay. The influence of freshwaters on these coastal environments is minimal and they should not be considered truly estuarine. More information on estuary classification, conceptual models and environmental management can be found on the OzCoasts website (www.ozcoasts.org.au).

In the context of these guidelines, riverine estuaries are the lower reaches of rivers that undergo substantial salinity change due to the mixing of freshwater with seawater.

In general, the upper sections of an estuary look like a lowland river – deep and meandering with slow flows – while the lowest section is often, but not always, broad and shallow, due to the formation of a sand barrier at the mouth. Estuaries may be permanently or periodically open to the sea, with salinities that vary from almost fresh to hypersaline. Environmental condition within estuaries may be stable over long periods of time or change frequently and rapidly.

Figure 1 shows a conceptual model of the factors affecting water quality and ecosystem health in

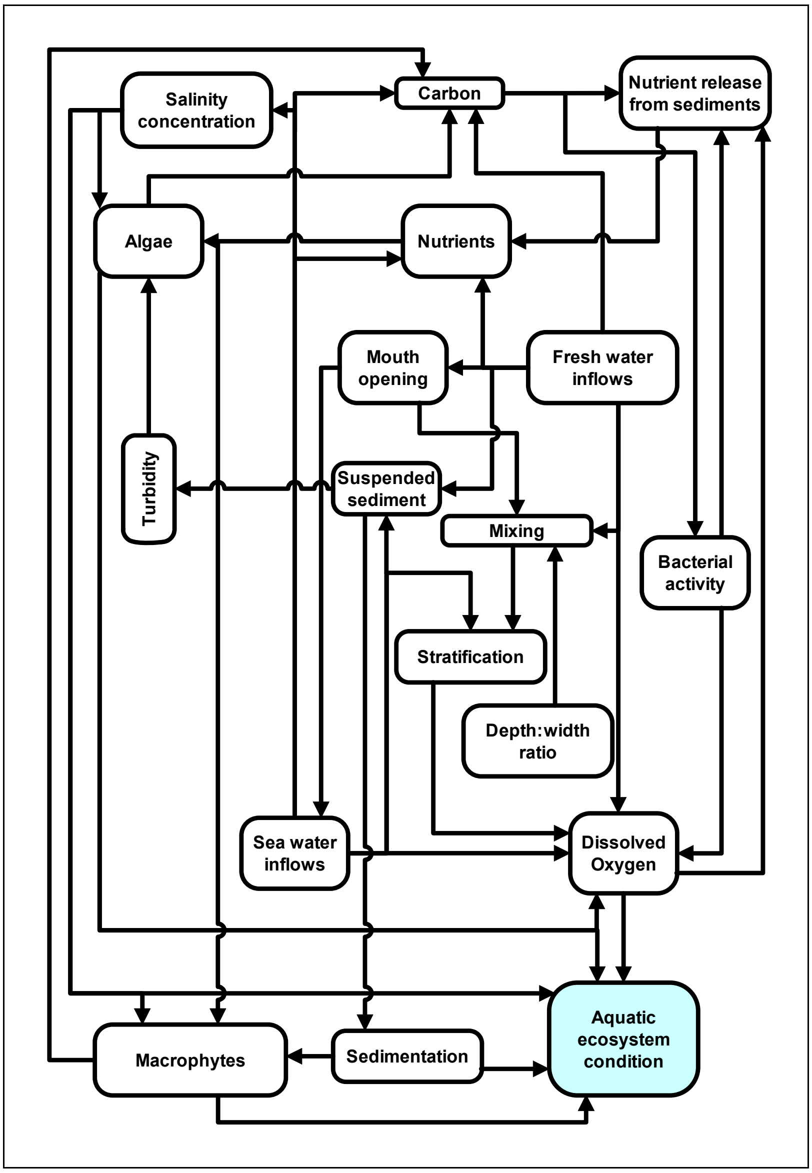

Figure 1: Conceptual model of water quality factors affecting the aquatic ecosystem condition of riverine estuaries

estuaries. Two of the major influences on estuarine condition are the timing and duration of bar opening and the volume and timing of freshwater inflows. Both affect water quality in an estuary (Figure 1).

When a bar is open, freshwater and salt water will meet and either mix or stratify into a fresh surface layer and saline bottom layer. When closed, many estuaries will mix, although deep, narrow upper sections of such estuaries tend to remain stratified for long periods of time. Freshwater inflows bring plant nutrients, carbon and sediment, all vital for estuary function. If the volume of water is sufficient, this will not only result in mixing of the estuary, but can also open a closed bar. All of these changes are critical to the biological communities in estuaries.

The relationships between many of the physical, chemical and biological components of riverine estuaries are represented in Figure 1. For more information on the nature of estuaries see Lauff 1967, Morrisey 1994, Allanson and Baird 1999, and Snow and Taljaard 2007.

What are the implications of climate change?

Victoria's climate is changing. By 2030 annual average temperatures in Victoria are expected to warm by around 0.8 °C, with an increase in the length of hot spells and longer, more severe droughts (CSIRO and BoM 2007, VCCAP 2007b).

Total rainfall is projected to decrease in most of the state, with spring and winter rainfall most affected (DSE 2008). Although there is likely to be less rainfall overall, heavy rain events are likely to increase and the largest increases are likely to be along the coast (Abbs et al. 2006). Less rain and warmer temperatures will lead to a decrease in run-off to our rivers and streams, leading to lower average flows (Jones and Durack 2005).

Globally, sea level is projected to rise by between 18 and 59 centimetres by 2100, with the rise off the east coast of Australia expected to be above the global average (IPCC 2007).

Estuaries and coastal systems are vulnerable to a number of aspects of climate change:

- sea-level rise, leading to an increase in coastal erosion and saline intrusion into estuaries, wetlands and groundwater
- rainfall decrease, which causes reduced freshwater flow and run-off, leading to increased salinity and eutrophication
- temperature rise, causing increased evaporation and water temperatures, which affect estuarine circulation patterns
- changes in winds and oceanic current circulation
- changes in land environments, such as local land level changes as a result of groundwater extraction and land use changes.

Smaller estuaries, typical of many of those along the Victorian coast, have been identified as much more vulnerable to environmental change than larger ones (Reddering and Rust 1990).

Climate change may have a profound effect on the functioning of estuaries and on the distribution and diversity of plant and animal communities that live in them. To manage estuaries in a changing climate, we need to:

- better understand how estuaries function
- assess the condition of Victorian estuaries
- model how climate changes may affect ecosystem function in the future.

Programs to monitor environmental quality will provide important data to guide estuary management under changing conditions. These guidelines are a step towards a better understanding of estuaries, providing a basis for further development of our knowledge of estuarine systems and guidance for management. The control charting tool that is introduced here provides a flexible approach to improve data interpretation. The models on which the control charts are based can be recalibrated as more environmental data become available and conditions change.

BACKGROUND DATA

Water quality monitoring program

To determine water quality guidelines, long-term reference site data are needed. The Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC and ARMCANZ 2000b) use at least two years of data. The objectives for rivers and streams in SEPP (WoV) are based on more than 10 years of water quality and biological data (EPA Victoria 2003 a, b and c).

The estuaries studied in the development of these guidelines were part of several studies undertaken by EPA between 1995 and 2005. Not all estuaries in Victoria were sampled, particularly those in the far east of the State.

EPA undertook intensive studies in Tidal and Kennett rivers and Mordialloc Creek from 1995 to 2001. The aim of these studies was to assess and evaluate methods of monitoring riverine estuaries, including water quality, sediment quality and biological methods. Spatial and temporal variability were also investigated. Much of this work has been reported in Barton (2006).

From these studies we developed a broader program of monitoring water quality in estuaries.

Three estuaries, of the Curdies, Aire and Gellibrand rivers, were sampled for five years from 2001 to 2005. Five additional estuaries, of the Barham, Powlett, Franklin, Albert and Tarra rivers, were sampled for two years from 2003 to 2005. A further 22 estuaries (see Table 2) were sampled twice yearly from 2000 to 2003.

Figure 2 shows the locations of the estuaries investigated as part of the development of these guidelines.

One site was located in each estuary, with an additional site located in the immediate upstream freshwater reach. At each site, measurements were taken or water samples collected for analysis for the following:

- dissolved oxygen
- salinity (electrical conductivity)
- pH
- redox potential
- temperature
- total phosphorus
- filterable reactive phosphorus
- total Kjeldahl nitrogen
- nitrate and nitrite
- turbidity
- suspended solids
- total organic carbon
- chlorophyll-*a*.

Measurements or water samples were taken from the surface and close to the bottom in the estuaries. In

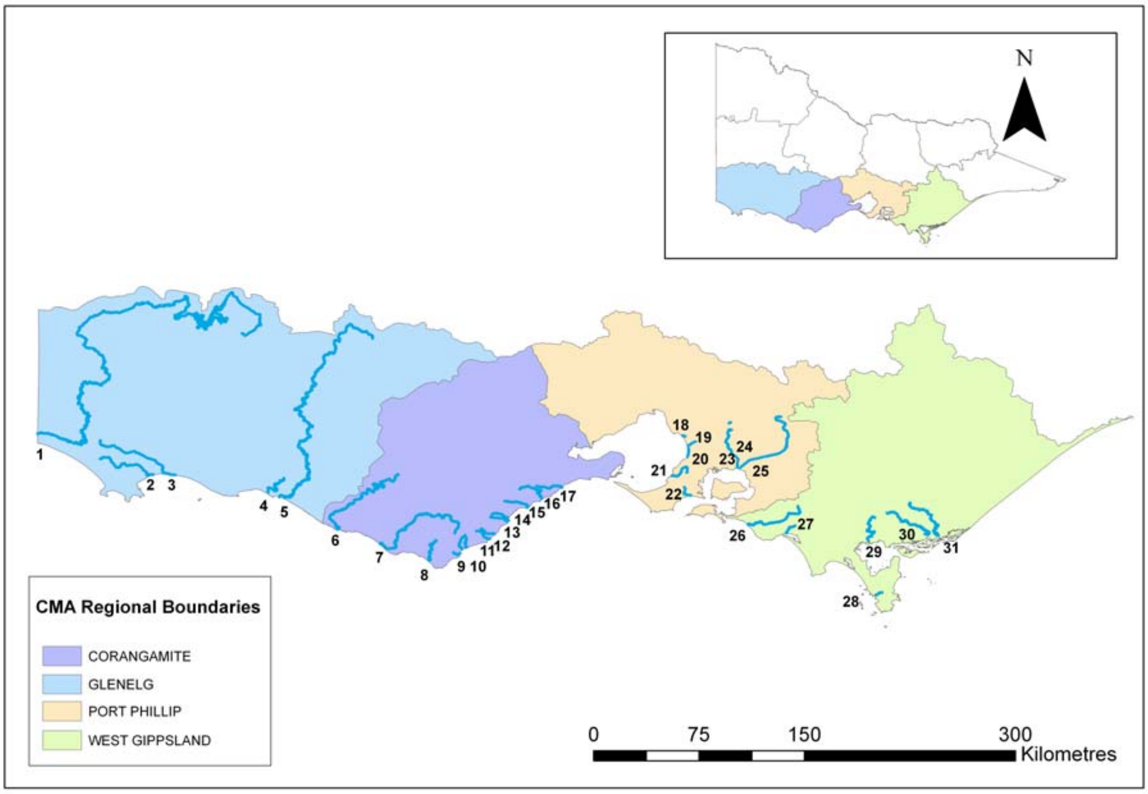

Figure 2: Location of estuaries sampled as part of the development of the guidelines. Numbers on map refer to estuaries listed in Table 2.

addition, information on halocline depth, inundated area (or estuary height) and degree of mouth opening were collected. Depth profiles for dissolved oxygen, salinity, pH, redox and temperature were also taken at each estuary.

At each of the freshwater sites, in-situ measurements of turbidity, conductivity, dissolved oxygen, pH and temperature, and water samples for nutrient analysis were taken and, where available, inflow volume was obtained from the nearest gauge.

Biological monitoring program

Biological monitoring has been widely used to assess the health of aquatic environments, particularly rivers and streams. It provides better information on the longer term conditions in an ecosystem than a single snapshot of water quality, reflecting the overall chemical and physical conditions over time, and ecosystem response to a variety of pollutants and water quality changes.

Unfortunately, there are few studies of Australian estuarine biological communities, particularly in small riverine estuaries. Bacteria, algae (including benthic microalgae, phytoplankton and macroalgae), zooplankton, seagrass, macroinvertebrates and fish have been used in various monitoring programs, but none of these components alone provides a single measure of estuary condition. Differences in substrate, geomorphology, inundation history and other physical aspects of estuaries, together with the differing distribution patterns of plants and animals, mean that there is a large variation in the communities that live in different estuaries and different locations in a single estuary through time (Deeley and Paling 1999; Moverley and Hirst 1999).

EPA sampled macroinvertebrate communities in a small number of riverine estuaries over several years, ranging from the relatively unimpacted Tidal River in Wilsons Promontory National Park to Mordialloc Creek in bayside Melbourne. However, at this stage, there are inadequate data and understanding to set biological guidelines for riverine estuaries.

An estuary with little catchment modification and good freshwater and marine inflows is likely to have good water quality. We would expect it to support a relatively vigorous and diverse community of plants and animals, which could include representatives of:

- phytoplankton and zooplankton, which play major roles in the estuarine food web
- fringing vegetation (saltmarsh, wetland, reeds, rushes)
- submerged vegetation (seagrass, macroalgae)

- macroinvertebrates, including a range of taxa and functional groups, such as crustaceans (amphipods, isopods, crabs, prawns), molluscs (bivalves and snails), worms (nemerteans, polychaetes) and insects
- fish.

DEVELOPMENT OF THE GUIDELINES

Risk-based approach

Environmental agencies and resource managers are adopting risk-based approaches as the best way to protect aquatic ecosystems. Such assessments provide an explicit and transparent process for making management decisions for complex ecosystems that may not always be fully understood.

A risk-based approach was developed under the National Water Quality Management Strategy (ANZECC and ARMCANZ 2000a). This approach was used as the basis for the development of the SEPP (WoV) environmental quality objectives (Gov. Vic. 2003; EPA Victoria 2004).

Under this approach, environmental quality objectives are no longer a simple pass/fail number, which ignored spatial and temporal variability and, most importantly, the complexity of aquatic ecosystems. The environmental quality objectives now represent trigger values at which there is a potential risk that adverse ecological effects may occur.

Sites that meet all the SEPP (WoV) environmental quality objectives are identified as having a low risk. Where the environmental quality objectives are not met, a risk-based investigation may be conducted to ascertain if there is a risk of adverse impacts on the ecosystem (Section 'Assessment', Figure 6).

The risk-based investigation framework provides a process for evaluating the likelihood of adverse effects to the ecosystem – that is, an assessment of risk to the ecosystem. This risk-based approach has been used in the development of these guidelines.

For more information on the risk-based approach and risk-based investigations see EPA Victoria 2004.

Indicators

Water quality indicators are useful measures of ecosystem health when they relate to threats to ecosystem values (ANZECC and ARMCANZ 2000a). They have formed an integral and reliable part of monitoring and assessment programs for rivers and streams for many years and should provide the same for riverine estuaries. Water quality indicators are considered to be the best currently available indicators for assessment of the potential threats (hazards) to the beneficial uses (values) of the aquatic ecosystems of riverine estuaries. The major threats and potential indicators are listed in Table 1.

Spatial and temporal data are limited and, as a result, we have considered only a limited number of threats for which we have robust water quality data, and relatively good understanding, in these guidelines. The indicators for which preliminary estuary guidelines have been developed are: dissolved oxygen, total phosphorus, total nitrogen, turbidity, pH and toxicants (Table 1).

While biological indicators would be ideal as direct measures of ecosystem condition, they have not been included in these guidelines because there were not enough data to develop appropriate biological indicators.

**Table 1: Threats and potential indicators for riverine estuaries.
Threats and indicators addressed in these guidelines are shaded.**

Threat	Potential indicators			
Reduced oxygen levels	Dissolved oxygen	Biota[1]		
Excessive plant growth	Algae	Chlorophyll-*a*	Plant nutrients	Biota
Increased sediment levels	suspended particulate matter	turbidity	Sedimentation	Biota
Acid drainage	pH	Biota		
Toxic chemicals	Toxicants	Biota		
Heated water effluent discharges	Temperature	Biota		
Reduced flow or altered flow regime	Biota	Change in salinity regime	sedimentation	
Changes to the physical nature of the estuary (including artificial bar opening)	Biota			
Removal of habitat within the estuary	Biota			
Floodplain clearing and drainage	Biota			
The introduction of exotic pest species	Exotic or pest species	Biota (endemic)		
Overfishing	Targeted fish species	Biota		

1 Biota means one or more of fish, invertebrates, macrophytes or algae.

Table 2: Assessment of reference condition in 31 riverine estuaries in Victoria and data availability of data for each estuary (arranged from west to east). Map reference refers to the numbers used to locate estuaries in Figure 2.

Estuary	Catchment and estuary modification*	Freshwater water quality**	Freshwater biological health***	Reference estuary	Data availability	Map Reference
Glenelg	Minimal	Moderate	R	Yes	Biannual	1
Surrey	Intermediate	Good	B****	Yes	Biannual	2
Fitzroy	Intermediate	Moderate	B****	Yes	Biannual	3
Merri	High	Poor	B	No	Biannual	4
Hopkins	High	Poor	B	No	Biannual	5
Curdies	Intermediate	Poor	B	No	Monthly – 5 years	6
Gellibrand	Intermediate	Moderate	R	Yes	Monthly – 5 years	7
Aire	Minimal	Good	R	Yes	Monthly – 5 years	8
Barham	Intermediate	Good	R	Yes	Monthly – 2 years	9
Skenes	Intermediate	Good	R	Yes	Biannual	10
Kennet	Minimal	ND	R	Yes	Biannual	11
Wye	Intermediate	ND	R	Yes	Biannual	12
St George	Minimal	ND	R	Yes	Biannual	13
Erskine	Intermediate	ND	R	Yes	Biannual	14
Painkalac	Intermediate	Good	ND	No	Monthly – 2 years	15
Anglesea	High	ND	C	No	Biannual	16
Spring	High	Moderate	B	No	Biannual	17
Mordialloc	High	Poor	ND	No	Biannual	18
Patterson	High	Poor	ND	No	Biannual	19
Kananook	High^	Poor	ND	No	Biannual	20
Balcombe	Intermediate	Poor	C	No	Biannual	21
Merricks	Intermediate	Moderate	ND	No	Biannual	22
Cardinia	Intermediate	Moderate	ID	No	Biannual	23
Deep	Intermediate	Poor	ID	No	Biannual	24
Bunyip	Intermediate	Moderate	ND	No	Biannual	25
Powlett	Intermediate	Poor	B	No	Monthly – 2 years	26
Screw	Minimal	Poor	B	No	Biannual	27
Tidal	Minimal	Good	B****	Yes	Biannual	28
Franklin	Minimal	Good	R	Yes	Monthly – 2 years	29
Albert	Intermediate	ND	R	Yes	Monthly – 2 years	30
Tarra	Intermediate	Moderate	ND	No	Monthly – 2 years	31

ID – Insufficient data. ND – No data.

* From Barton 2006.

^ Kananook was not assessed by Barton, but it is entirely surrounded by urban development.

** Assessed against SEPP (WoV) water quality objectives (Gov. Vic 2003):
Good – consistently meets objectives.
Moderate – close to meeting the objectives and at times may meet objectives.
Poor – almost never meets objectives and at times is substantially below objectives.

*** Assessed against SEPP (WoV) (Gov. Vic 2003):
R – Reference quality.
B – Below reference quality.
C – Well below reference quality.

**** These sites were assessed as having good water quality, minimally impacted, and being only marginally below reference condition for biological health. As a result these estuaries are representative of the best available estuaries and have been included in the group of reference estuaries.

Reference estuary selection

Trigger values – concentrations of water quality parameters above or below which there is a risk of adverse biological effects – are preferably determined from known cause-effect information. This information is not available for riverine estuaries. Where no cause-effect information is available, triggers can be determined using reference site data that, in effect, become the benchmark condition (ANZECC and ARMCANZ 2000a).

Data from reference sites have been used to calculate single-sample guideline values ('trigger values').

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Reference sites should ideally be either unimpacted or little changed, however very few estuaries in Victoria are in natural or near natural condition. Many are highly influenced by urbanisation, reduced inflows or contaminants, and the choice of reference estuaries must include the best available (ANZECC and ARMCANZ 2000a). Reference estuaries were selected using several criteria:

- minimal to intermediate catchment modification
- minimal to intermediate physical modification to the estuary
- good water quality and biological health in the inflowing river or stream, measured at a site immediately upstream of the estuary.

Objective and dependable guidelines for ecosystem health are available for rivers and streams (Gov. Vic. 2003). It is likely that, if the inflowing stream is assessed as healthy, then the estuary should also be healthy, as long as the estuary is minimally modified. Table 2 summarises this assessment.

While the conclusions drawn are based on a number of assumptions, the assessment is consistent with the approach previously used to develop guidelines for inland waters in Victoria.

THE GUIDELINES

These guidelines provide preliminary water quality guideline values and a tool to allow estuary managers to improve their understanding of estuaries. Both methods use the data from the reference sites. The guidelines use summary statistics to determine an annual percentile and a single-sample level (where both are required) for individual measurements.

The second part of this guidance uses control charting to provide users with a graphical tool to detect patterns in the measurements of estuary environmental variables.

Where there is a lack of data for toxicants, the guidelines for riverine estuaries (Table 3) are taken from ANZECC and ARMCANZ (2000a).

Guideline values

We calculated percentiles of the pooled data from all reference sites for each indicator (Appendix 1). These percentiles were used to set annual guideline values and single-sample levels (Table 3).

For the annual guideline trigger value, the median (50th percentile) was chosen. The rationale for the use of a typical value from reference sites is that it provides a reasonable value to achieve for all estuaries. This same procedure was used to develop the SEPP (WoV) water quality objectives (EPA Victoria 2003a and b) and is consistent with the approach used to develop the National Water Quality Management Strategy's Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000a).

Single-sample levels were also developed from the pooled reference site data. The rationale is that the upper and/or lower levels measured at reference sites should provide a good representation of these upper and/or lower levels for all estuaries. The 90th and/or 10th percentiles of the long-term data were used to assign guidelines for single-sample levels.

A single-sample level has been specified for total phosphorus, total nitrogen, turbidity, Chlorophyll-*a*, dissolved oxygen and pH (Table 3). The single-sample guidelines can be used in conjunction with the control chart models to present a visualisation of the condition of an estuary (see Figures 3 to 5).

These guidelines are trigger values which represent levels at which there is a potential risk that adverse ecological effects may occur, and a risk-based investigation may need to be conducted.

A tool to improve understanding of estuaries

All environmental data is inherently variable. Daily, seasonal and longer-term fluctuations in weather (rainfall, temperature, solar radiation, wind, storms), chemical changes and interactions between members of the biotic community and their surroundings - all impact on local conditions. These can be considered as natural causes of heterogeneity in environmental measurements. There are also changes in environmental factors that are not random, and are the result of some underlying environmental change.

The use of control charts reflects a new approach to assessing condition in aquatic systems. Control charts have been used in other applications, for example in engineering and manufacturing, but their application to environmental data is relatively new. Control charting allows us to take the natural causes of variability into consideration, adjusting for their effect and reducing the overall variability of the data. 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 make effective use of whatever historical and reference data are available. More information on general methods of control charting can be found in Montgomery (2005).

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. To do this, we used the data from reference condition estuaries to develop statistical models of the relationships between the key parameters. The control charts use these relationships and the data from a test estuary to model an expected value for the parameter.

Table 3: Preliminary annual median and single-sample guideline values for riverine estuaries

Indicator	Single-sample[1]		Annual median[2]	
	Surface	Bottom	Surface	Bottom
Dissolved oxygen (% saturation)	70–110	15–110	90	65
Total phosphorus (mg/L)	0.1	0.3	0.05	0.07
Total nitrogen (mg/L)	1.5	1.7	0.5	0.6
Turbidity (NTU)	18	26	5	7
pH (pH units)	6.9–8.3	6.8–8.2	7.0–8.0	7.0–8.0
Chlorophyll-*a* (µg/L)	6	9	1	2
Toxicants	T (99%)[3]	T (99%)[3]	NA	NA
Sediment toxicants	ISQG Low[4]		NA	

1 Set for any individual measurement

2 Annual median calculated with a minimum of 10 samples collected at a monthly frequency

3 T (99%) – Refer to the values listed in the National Water Quality Guidelines Table 3.4.1 99% species protection (ANZECC and ARMCANZ 2000a)

4 ISQG Low – Refer to the values in the National Water Quality Guidelines Table 3.4.1 Interim Sediment Quality Guidelines (ISQG) Low (ANZECC and ARMCANZ 2000a)

NA – Not Applicable

This helps us to understand whether the change we may see in a particular result is expected, given both the inherent variability and dynamic nature of estuaries, and the conditions prevailing in the estuary at the time.

Development of the models for control charts

We used a combination of approaches, such as regression analysis and general linear modelling methodology, to model expected values of water quality indicators.

The modelling process used reference site data to explore the variables that might affect the water quality indicators. We selected explanatory variables if they were ecologically meaningful and practical to measure.

A number of variables used by Barton (2006) to classify estuary type and condition were tested, including estuary orientation and location, estuary modification, catchment and estuary size and land use. None of these factors were found to be significant in the models.

The models selected were those which explained a significant proportion of the variation, using ecologically meaningful and readily measurable variables. We used the models to calculate expected values for the water quality indicator. Prediction limits were then calculated based on the expected value. We calculated the average predictive error for each indicator in order to give a prediction band of constant width around each prediction.

Based on expert opinion, the prediction limits were set allowing that even an estuary in reference condition would have one measurement in 10 outside the 'normal' range. The prediction intervals for dissolved oxygen were set at 10 per cent and 90 per cent, since both very high and very low dissolved oxygen levels are of ecological significance. For total nitrogen, total phosphorus and turbidity we used an upper prediction interval of 90 per cent, since high levels are of much greater environmental significance.

In total, eight regression models were built for surface and bottom levels of dissolved oxygen, turbidity, total phosphorus and total nitrogen. A model for Chlorophyll-*a* was attempted, but the model could not explain a significant proportion of the variation in Chlorophyll-*a*. The regression models are intended to be refined periodically as more data become available. Table 4 shows the parameters used in the current models.

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Table 4: Parameters required in the control chart models.
(For example, a control chart model for surface dissolved oxygen requires the following parameters: bottom dissolved oxygen, surface and bottom turbidity, bottom pH, surface and bottom conductivity and stratification status)

Parameter measurement required		Control chart model							
		Dissolved oxygen		Total nitrogen		Total phosphorus		Turbidity	
		surface	bottom	surface	bottom	surface	bottom	surface	bottom
Dissolved oxygen	Surface		✓			✓	✓	✓	✓
	Bottom	✓			✓	✓	✓	✓	✓
Total nitrogen	Surface			✓ *	✓				
	Bottom			✓					
Total phosphorus	Surface						✓		
	Bottom					✓			
Turbidity	Surface	✓		✓		✓	✓		✓
	Bottom	✓		✓	✓	✓	✓	✓	
pH	Surface								
	Bottom	✓	✓						
Conductivity	Surface	✓	✓	✓	✓				
	Bottom	✓	✓						✓
Stratified		✓	✓						
Mixed			✓					✓	
Month			✓	✓		✓			
Daily average flow over the previous week								✓	✓
Daily average flow over the previous month				✓ *					
Mouth open status					✓		✓		

* Lagged values, that is, values from the previous month

Using control charts

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).

Figure 3 shows an example, with the expected value of the indicator based on the model and, in this case, the upper prediction limit. The single-sample (Table 3) guideline value is also given on the chart.

Measured data points (shown as coloured symbols) should be within the prediction interval. When the measurements are outside the prediction interval – but below the single-sample guideline value – it indicates that there may be a developing issue with water quality. When the measurement is above the single-sample guideline value (shown in red), the guideline has been 'triggered'. In these cases further investigation may be warranted.

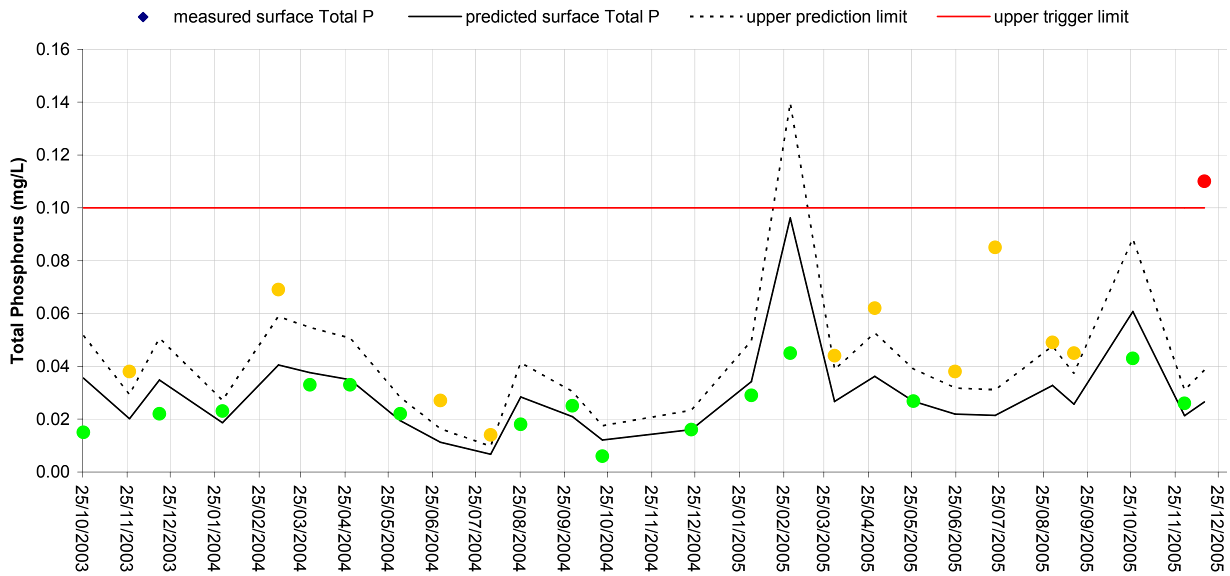

Figure 3: Surface total phosphorus measurements and predictions for Painkalac Creek estuary 2003-05. Green – below the upper prediction limit and the guideline single-sample value. Orange – outside the prediction limits, but below the guideline single-sample value. Red – above the guideline single-sample value.

In the example in Painkalac Creek estuary (Figure 3), the predicted surface total phosphorus varies from around 0.01 to 0.14 mg/L. Many of the monthly measurements were below the predicted level, or at least below the upper prediction limit. These are shown in green on the chart. Measurements outside the prediction limits but below the proposed guideline single-sample value are shown in orange.

These measurements may indicate environmental conditions that are less than desirable. 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 to other estuaries. This is because the models, although derived from reference estuary data, use actual measurements from the estuary being investigated.

For example, predicted levels of total phosphorus in surface waters of the Curdies River (Figure 4) are much higher than those predicted in Painkalac Creek (Figure 3). The Curdies River has much higher turbidity than the reference sites (and Painkalac Creek). The model predicts that phosphorus will be high, as high phosphorus is associated in part with high turbidity.

However, this does not mean that these levels of phosphorus in the Curdies River are acceptable. The single-sample guideline level is consistently exceeded and would trigger further investigation. The annual medians also exceed the 0.05 mg/L annual median guideline. The resource manager can use this information to inform management decisions.

If data for all the parameters needed for a model are not available, no expected values or prediction intervals can be generated. In those circumstances the single-sample guideline values (Table 3) should be used to assess condition.

For example, in Figure 5 model predictions for total nitrogen in the surface waters of Painkalac Creek could not be generated, so the single-sample guideline value (1.5 mg/L) should be used as the trigger for further investigation.

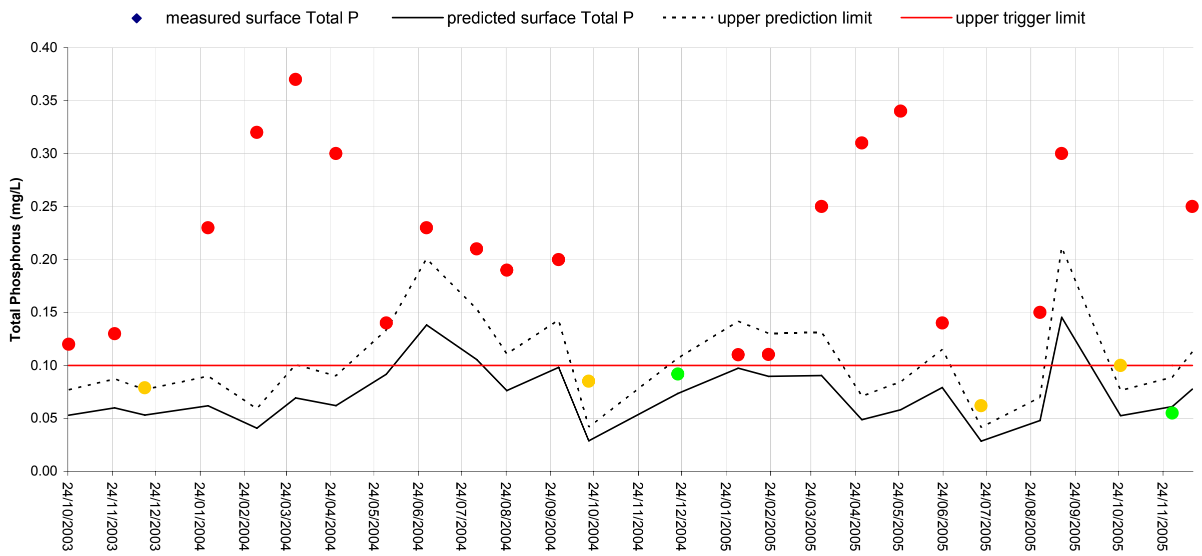

Figure 4: Surface total phosphorus measurements and predictions for Curdies River estuary 2003-05. Green – below the upper prediction limit and the guideline single-sample value. Orange – outside the prediction limits, but below the guideline single-sample value. Red – above the guideline single-sample value.

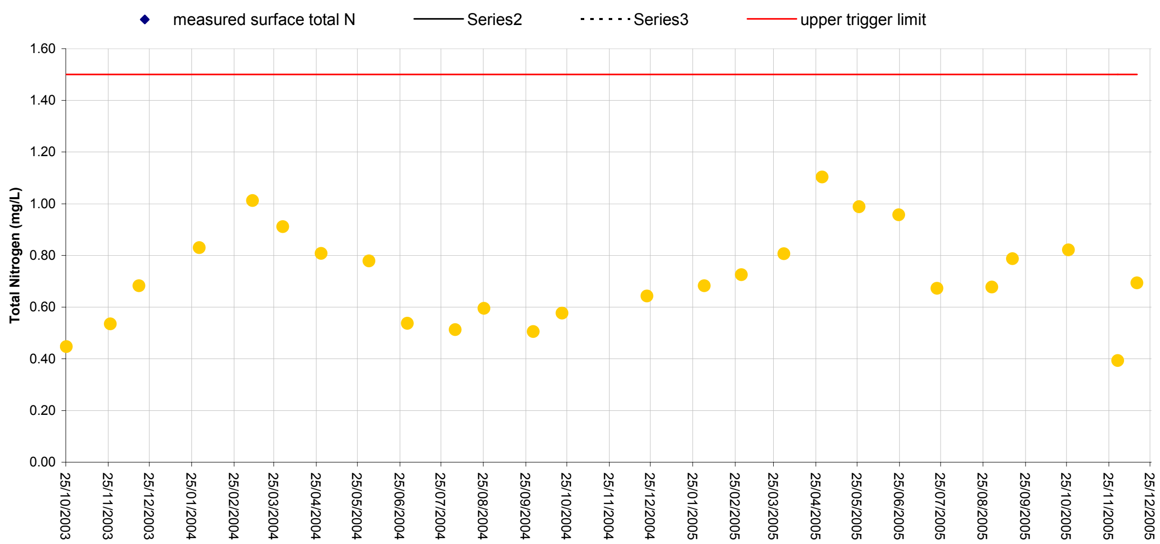

Figure 5: Surface total nitrogen measurements in Painkalac Creek estuary 2003-05. Note: Model predictions could not be generated. Single-sample guideline value is used for the assessment. Orange – below the guideline single-sample value.

USING THE GUIDELINES

Monitoring

The recommended monitoring requirements of these guidelines are outlined below (Table 5). The calculation of percentiles requires monthly sampling and at least 10 sample data points. While a single sample can be assessed using a control chart model, monthly sampling over a period of a year or longer is encouraged, as this takes into account seasonal variations in water quality.

Assessment

There are two separate components to the guidelines: single-sample and annual medians. The control charts provide additional information to help in the assessment of risk to the environment. The best assessment of risk uses both the guidelines and the control charts. To ensure a low risk to the ecosystem, both guidelines should be met and the measurements should fall within the prediction limits in the control charts. If there are insufficient data to calculate the control chart limits, the median and single-sample guideline values may still be used to assess risk to the system.

If either of the guidelines is exceeded there may be a potential risk to the ecosystem and further investigation may be required to assess the level of risk (Figure 6).

The size and detail of the investigation will vary depending on the potential level of impact, prior investigations and understanding of the risk, regional priorities and the acceptability of the risk. The investigation should be linked to the development and implementation of risk management actions. For more information on the risk-based approach and risk-based investigations, see EPA Victoria 2004.

Table 5: Water quality monitoring requirement for riverine estuaries

Sampling frequency	Monthly
Assessment period	Annual
Indicators (10 cm below the surface and 10 cm from the bottom)	Dissolved oxygen saturation
	Water temperature
	pH
	Turbidity
	Total phosphorus
	Total nitrogen
	Chlorophyll-*a* (optional)
Other model requirements	River discharge
Additional estuary information to aid interpretation	Mouth opening (open, partially open and closed)
	Halocline depth or salinity readings taken at regular depth intervals (e.g. 0.5 m)
	Inundation area or estuary height
	Depth profiles
Additional data for urban estuaries	Toxicant in waters
	Toxicants in sediments

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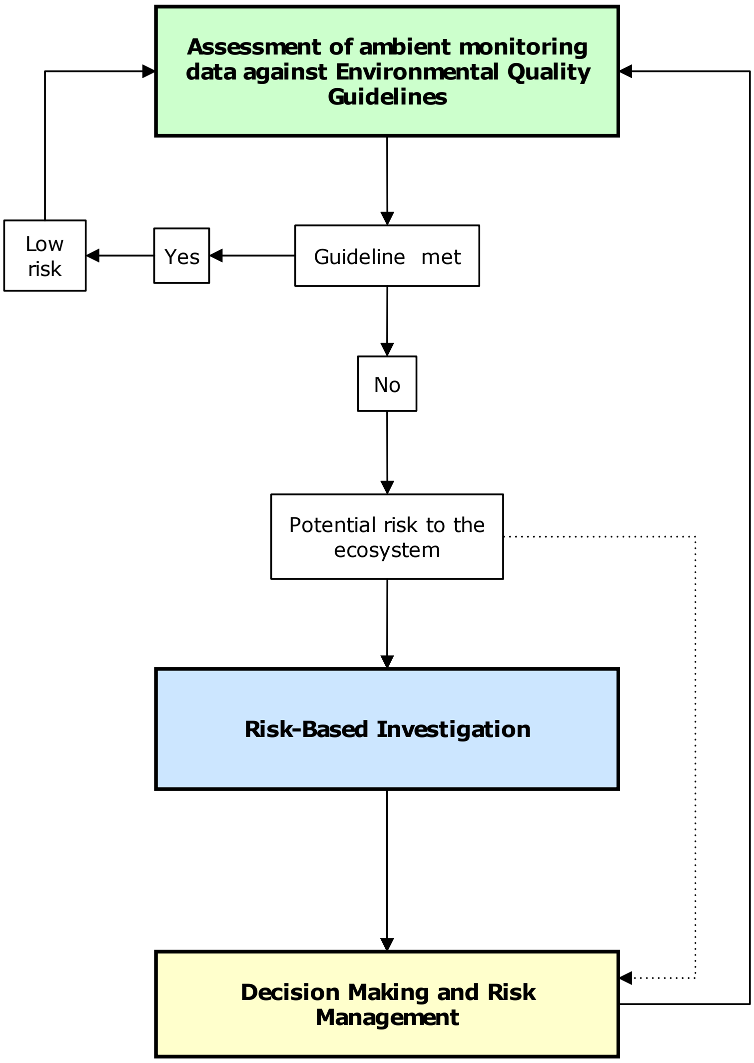

Figure 6: Framework for risk-based assessment

SUMMARY

Estuaries are subjected to substantial environmental pressures. Many Victorian catchments are highly degraded and most estuaries can be considered to be potentially at risk, with few in natural or near-natural condition. These guidelines have been developed to provide a framework for assessing the water quality in riverine estuaries and to assist in management decisions to protect or improve the health of estuaries.

This is the first time environmental water quality guidelines specifically for Victorian riverine estuaries have been presented. The estuaries used to develop the guidelines represent the broad range of estuary types. However, not all Victorian estuaries have been sampled and measurements have not been collected under all environmental conditions – for example, following floods, bushfires or storm surges.

Control charts are a new way of looking at environmental data. They are flexible, allowing the addition of new sampling data to update the charts, and provide a clear visual output to guide management decisions. As more data are collected, they can be used to refine the models on which the control charts are based, and, possibly, to develop models for additional parameters.

The water quality guidelines can be refined as additional regular monitoring data becomes available. This will enhance our understanding of estuaries and their processes and provide the basis for the sustainable management of estuarine environments.

EPA encourages estuary managers and community groups to use the control charts and models. We welcome any feedback, which will assist in further development of these management tools.

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APPENDIX 1: SUMMARY STATISTICS FOR REFERENCE ESTUARIES

	Dissolved oxygen		pH		Total phosphorus		Total nitrogen		Turbidity		Chlorophyll-*a*	
	mg/L		pH units		mg/L		mg/L		NTU		µg/L	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
Minimum	16	1	6.4	6.4	0.012	0.01	0.05	0.09	0.2	0.5	0.05	0.05
Maximum	143	163	10.5	10.6	2.4	1.5	6.01	6.04	61	269	20	47
10th percentile	68	12	6.9	6.8	0.019	0.029	0.35	0.41	1.6	1.7	0.5	0.5
25th percentile	81	33	7.2	7.1	0.029	0.042	0.45	0.56	2.7	3.1	0.5	0.5
50th percentile	93	68	7.4	7.5	0.043	0.067	0.65	0.81	4.4	6.4	0.9	1.6
75th percentile	103	93	7.9	7.9	0.066	0.13	0.96	1.20	8.1	13	2	3.8
90th percentile	110	106	8.3	8.1	0.098	0.31	1.48	1.70	18	26.1	5.3	8.9
Count	162	161	162	161	164	162	164	162	158	161	102	101

For a list of the estuaries included in this analysis, see Table 2.