Victorian Index of Estuary Condition

Recommended themes and measures

April 2009

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April 2009

A report from the project "*Developing a framework for an Index of Estuarine Condition*" funded by the Department of Sustainability and Environment (Vic).

This report should be cited as:

Arundel, H.P., Pope, A.J., and Quinn, G.P. (2009) *Victorian Index of Estuary Condition: Recommended themes and measures*. Report by the School of Life & Environmental Sciences, Deakin University for the Department of Sustainability & Environment. Warrnambool, Vic.

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Summary

Deakin University was engaged by the Department of Sustainability and Environment to develop an Index of Estuary Condition (IEC) for evaluating the environmental condition of Victorian estuaries. The Index will ultimately complement the existing Index of Stream Condition (ISC) by providing a consistent statewide assessment of the environmental condition of estuaries. This will better enable:

- Estuarine condition to be reported at regional, state and national levels.
- Prioritisation of resource allocation.
- Strategic evaluation of management interventions in estuaries.

Workshops involving participants with expertise in a variety of disciplines were convened to integrate learnings from assessment programs currently being developed interstate and overseas. This report synthesises and builds on the output from those workshops which:

- Identified key components (themes) of estuaries that contribute to estuarine condition.
- Contributed to development of a broad conceptual model for Victorian estuaries
- Identified possible measures of each theme

In keeping with the sub-indices of the ISC, six themes were identified for use in the IEC: Physical form, Hydrology, Water quality, Sediment, Flora and Fauna. Several measures within each theme are recommended to assess estuary condition (Table A).

Implementation of particular measures in the IEC partly depends on the investment required to both collect and interpret the required data. With regard to data collection, each measure was assessed according to whether there is an established sampling procedure, how frequently data need to be collected and the level of expertise required for collection and processing. For interpreting the data, measures were scored on whether baseline condition is established and whether descriptions and scores are developed which reflect the extent of deviation from that condition. These scores were used to indicate which measures are feasible to implement immediately and which require further investigation (Table 8).

A trial of the recommended IEC measures in a selection of estuaries is recommended as it would provide an opportunity to test the measures and their suitability for application statewide. It is suggested that the trial is conducted in estuaries subject to various levels of threats within each of the four estuary classes described by Barton *et al*. (2008)

Table A Summary table of draft IEC themes and possible measures. Numbers assigned to measures are consistent with those used throughout the report. For some measures there are several components.

PHYSICAL FORM	HYDROLOGY	WATER QUALITY	SEDIMENT	FLORA	FAUNA
1. Changed Bathymetry 2. Sediment load (current vs natural) 3. Upstream Barriers (presence, type & location) 4. Lateral Connectivity (No. & type of artificial structures on foreshore)	5. Marine Exchange 5 a) mouth openings (AHD & number) 5b) structures and behaviours (dredging & training walls) 6. Freshwater Flow a)ISC Hydrology mod index) b1).no. of structures (dams) (standardised by catchment area) b2). No. of licences (extraction)-volume relative to MAF 7. Salinity Regime	8. Water Clarity (turbidity) 9. Dissolved Oxygen (mg/L & %)	10. Sediment Particle size 11. Bank Erosion (ISC method) 12. Sediment Respiration Rate (incubated core tubes)	13a) Aquatic Macrophytes (% change from historical/present) 13b) Aquatic Macroalgae (i)% cover, ii) no. of blooms) 14. Fringing Macrophyte (extent & condition) 15. Microphytobenthos (Phaeophytin &/or Chl a) 16. Phytoplankton (Chlorophyll a)	17. Naturalness of Fish - trophic level &/or estuary use 18. Naturalness of Birds

1 Introduction

Deakin University was engaged by the Department of Sustainability and Environment to develop an Index of Estuary Condition (IEC) for evaluating the environmental condition of Victorian estuaries. The Index will ultimately complement the existing Index of Stream Condition by providing a consistent statewide assessment of the environmental condition of estuaries. This will better enable:

- Estuarine condition to be reported at regional, state and national levels.
- Prioritisation of resource allocation.
- Evaluation of management interventions in estuaries.

The IEC is consistent with the assets-based approach to natural resource management adopted by the Victorian Government (Annett & Adamson, 2008).

This project builds on several recent projects and existing programs (Appendix 1). These have generally focused on identifying the assets or values of estuaries and potential threats to those values.

1.1 Project brief

The objectives of the IEC project, as listed in the project brief, were to:

- Develop/assess conceptual models of links between estuarine components. This required descriptions of:
    - Estuarine environmental assets
    - Threats to those assets
- Identify those assets and/or threats that may provide a measure of estuarine condition
- Provide a range of scores and interpretations for each variable to reflect a range of estuarine conditions
- Provide a draft framework that will include the sub-indices, metrics, relevant reference conditions and scoring, rules for addition of metrics and sub-indices and possible condition classes
- Recommend any further work necessary to test and validate the draft IEC

Development of the IEC was further guided by the requirements of the Department of Sustainability and Environment. These include that where possible the IEC will:

- align with the Index of Stream Condition (ISC) and hence if possible and appropriate be based on a similar series of sub indices
- align where possible with the national assessment framework (Framework for Assessment of River and Wetland Health (FARWH))
- be consistent with the assets-based approach adopted for natural resource management in Victoria
- provide environmental assets and threats for the River Values and Environmental Risk System (RiVERS). The RiVERS database is a risk based priority setting program, which supports each regional River Health Strategy. (An expansion of this system to estuaries and wetlands is currently underway and RiVERS(II) will combine the environmental, social and economic asset and threat data for rivers,

wetlands and estuaries and will form the basis for the allocation of State funding for management activities to improve waterway health.)

- Include measures that:

  - are applicable state-wide

  - characterise the condition of the estuary

  - are influenced by management decisions

  - are cost effective

  - are scientifically defensible

  - have established reference conditions

  - where possible are measures of condition (state) rather than pressure (threats)

Although the IEC should be applicable state-wide it is acknowledged that scoring methods for particular measures may need to vary for different estuary types.

It should be noted that the measures recommended for inclusion in the draft IEC will require further field-based testing, refinement and validation of scores to provide optimal integration methods to reflect estuarine condition.

2 Development of the IEC

2.1 Method

Development of the IEC involved two stages of consultation with scientists with expertise in a broad range of aspects of estuarine ecology. Two workshops were convened to engage researchers from within Victoria, interstate and overseas. Participants in each workshop are listed in Appendix 2.

Participants at Workshop 1 identified:

- the main components (themes) of Victorian estuaries that influence their condition;
- possible measures of each theme;
- links between themes (and between measures); and
- relevance of measures to different estuary types.

The ISC themes (or sub-indices) were used as a starting point for discussion. The list of themes and measures produced was not restricted to condition of estuarine biota. Where biotic condition could not be directly described or measured, pressures, acting as a surrogate or proxy for condition, were included.

When partitioning the natural environment into themes, allocation of aspects of the environment to particular themes was not always straightforward as some content may be applicable to more than one theme. The content of each theme was broadly described in order to:

- evaluate the contribution of each theme to ecological condition and

- avoid duplication or omission of key aspects of estuarine ecology.

A conceptual model was developed that showed the main estuarine themes, their content and the direction of influence of one theme to another (Appendix 3).

The output from Workshop 1 and a background paper including a description of assessment programs employed in other state, national and international programs were provided to participants in Workshop 2.

Participants in Workshop 2:

- reviewed the themes (from Workshop 1);
- reviewed and revised the list of all possible measures of each theme;
- assessed each measure against given criteria (see Section 2.3.1. for list of criteria). As a first cut, measures were assessed against the first two criteria. Only measures that scored highly against these measures were considered further.
- assessed the suitability of selected measures for all estuaries and noted characteristics of estuaries which may influence their scoring; and
- provided descriptions for selected measures if condition was very poor and if condition was excellent.

The output from both workshops was reviewed and synthesized and the results form the basis of the themes and measures recommended in this report

2.2 Themes

The themes represent the key components of estuaries that contribute to their ecological condition (Figure 1). As per the ISC, it is proposed that each theme contributes equally to the final IEC score. Therefore each theme will ideally be of equal importance to ecological condition of an estuary and be applicable across Victorian estuaries as a whole.

Six themes were identified for assessing estuarine condition

- **Physical form**. The physical structure of an estuary includes depth, bed, banks and the presence of structures that alter connectivity to adjacent marine and freshwater ecosystems and connectivity of the estuary to riparian areas and any associated wetlands
- **Hydrology.** The hydrological regime of an estuary includes timing and volume of freshwater, marine and groundwater inputs, which in turn affect stratification patterns in the estuary.
- **Water quality**. Water quality including parameters such as dissolved oxygen, nutrients, suspended matter, salinity and temperature.
- **Sediment.** The sediment of an estuary includes features of sediment quality such as nutrients, toxicants and dissolved oxygen; and aspects of physical structure such as particle size, erosion, sedimentation and sediment transport.
- **Flora.** The flora of an estuary includes microphytes and macrophytes associated with the water column and sediment in the subtidal, intertidal and riparian areas. This theme also includes microbial communities
- **Fauna.** The fauna of an estuary includes fish and birds as well as meiofauna and macrofauna associated with the sediment, water column and plants.

Characteristics of biotic condition may be reflected in abundance, presence, absence, distribution, activities and interactions of estuarine biota in and with their environment. While ultimately ecological condition is represented by naturalness of ecological processes and estuarine biota, in many cases aspects of condition may need to be assessed by surrogate measures in abiotic themes. This is because of the inherent complexity of estuarine systems and logical and logistical difficulties in precisely measuring and interpreting biological effects where no pre-impact data exist.

The content and rationale for inclusion of each theme in the IEC is discussed in Section 4.

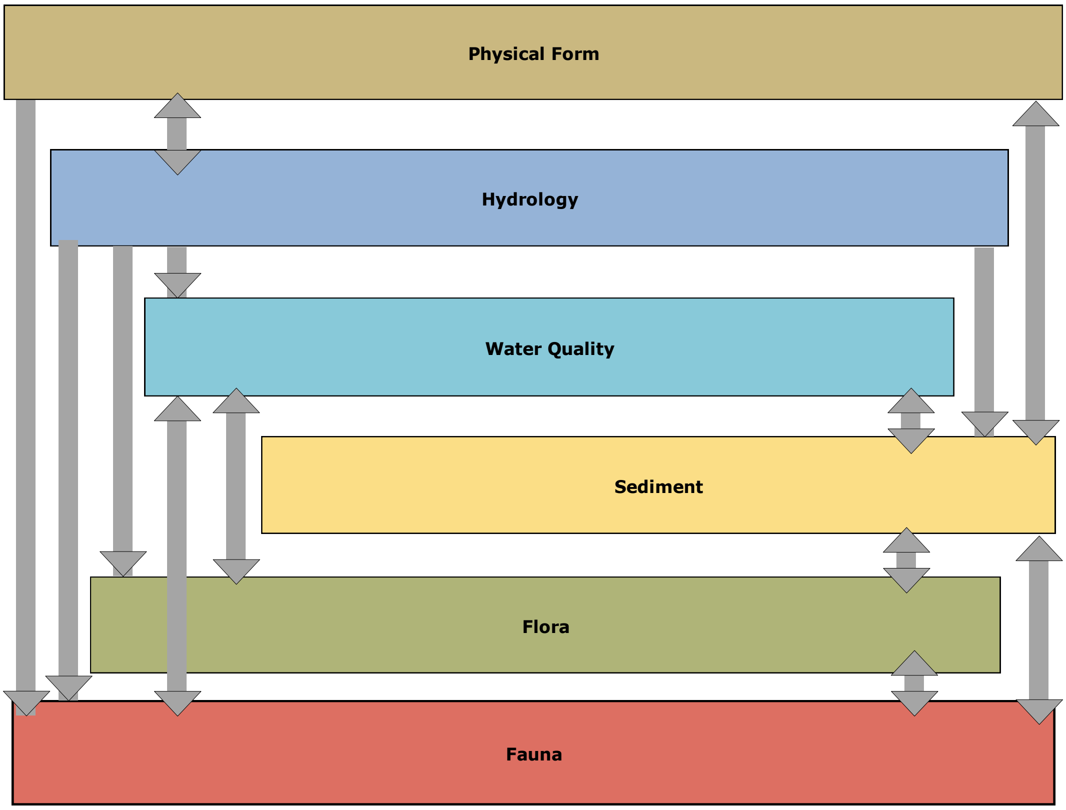

Figure 1. Relationship of themes that contribute to the ecological function of estuaries. Arrows represent the direction of influence of one theme on another.

2.2.1 Comparison with the ISC

The Index of Stream Condition (ISC) is used to assess the condition of rural rivers and streams in Victoria (Department of Sustainability and Environment 2006). It is practical that the IEC align, where appropriate, with the ISC to enable consistency in reporting and efficiencies in field assessments and data collection.

Six themes are recommended for the IEC compared with five ISC sub-indices (Table 1). Four ISC sub-indices Hydrology, Water quality, Physical Form and Biota (IEC 'Fauna') were considered (with different measures) applicable to assessment of estuarine condition.

The IEC theme 'Flora' is broader than the ISC 'Streamside zone'. It includes not only riparian habitat but also instream vegetation, phytoplankton, microphytobenthos and microbial communities

A new theme 'Sediment' is recommended for the IEC. This reflects the importance of both sediment quality and movement to estuarine condition. Estuaries act as sinks for sediment and associated nutrients and toxicants and therefore integrate the effects of human activity over time. The inclusion of this theme is supported by recent studies in Victoria (Barton 2006) and Tasmania (Edgar *et al.*, 2000; Edgar & Barrett, 2002) that suggested sediments were likely to provide useful indicators of estuarine condition.

2.2.2 Comparison with the FARWH

The National Water Commission under the National Water Initiative (NWI) is developing the national Framework for the Assessment of River and Wetland Health (FARWH) as part of the Australian Water Resources 2005 project. The FARWH (Norris *et al.*, unpub.) will guide the national assessment of river and wetland health. The FARWH is being designed to include data currently being collected at a state level. This will avoid duplication in data collection and reporting at a regional, state and national level.

The draft FARWH, proposes 6 indices, or themes, for the assessment of river and wetland health (Table 1, Appendix 5). With the exception of 'Catchment disturbance' all components of the FARWH would be captured in the IEC.

Table 1. Comparison of themes used in the Draft IEC, ISC and FARWH (themes in italics were recommended for consideration if FARWH was to be used in estuaries (Arundel & Mount, 2007))

Draft IEC	ISC	FARWH
Hydrology	Hydrology	Hydrological change
Physical Form	Physical Form	Physical form and processes
Water Quality	Water Quality	Water (and soils) quality
Sediment		
Flora	Streamside Zone	Fringing zone
Fauna	Biota	Biota
		Catchment disturbance

2.3 Measures

Various characteristics of biota are used to measure ecological function of a system. Barton (2003) highlighted that selection of indicators for use in Victorian estuaries is hindered by lack of information about biotic characteristics such as 'biomass, productivity, nutrient cycling, species richness and diversity, food web complexity, niche specialisation, spatial diversity, size distributions of organisms and their life styles, disease prevalence and mortality rates'. Further she noted that for Victorian estuaries clear causal relationships between changes in biotic indicators and stressors resulting from human activity have not been clearly established.

In developing the IEC it was therefore necessary to include a range of abiotic measures that from studies interstate and overseas have been shown to influence biotic condition measures. The draft IEC therefore includes measures that are a combination of condition and surrogate measures.

In keeping with the ISC in which each sub-index consists of several indicators, each theme in the IEC includes several measures that represent different aspects of ecological condition. A range of potential measures of each theme was identified to ensure all aspects of ecological condition were comprehensively represented.

2.3.1 Criteria for evaluating measures

The potential measures were evaluated against a range of criteria to ascertain their usefulness as indicators of estuarine condition. These criteria included:

1. Suitability for state-wide application in Victoria

Requirements of the IEC include that measures are suitable for state-wide application and therefore suitable for assessment of all Victorian estuary types. It should be noted that scoring of particular measures could be modified when applied to different 'types' of estuaries.

2. Correlation to ecological condition

The proposed measure should be conceptually linked to the condition of the estuary. Where possible a direct measure should be used but it is acknowledged that measures may need to be included that have an indirect link to condition.

3. Link to management

Measures are most valuable when we can link current condition, and changes in condition, to potential manageable threats. For estuaries, the main threats to estuarine condition are likely to be catchment land-use patterns, flow regime (including environmental flows as a restoration tool), urban and coastal development around the estuary, recreational (e.g. fishing, boating) and commercial (e.g. industry) use, climate change, pest species and estuary entrance management.

4. Cost effectiveness

Measures need to be assessed in a cost-effective manner. Costs associated with assessment programs include staff time and expenses associated with the field and/or laboratory, staff expertise and /or training required, establishing data collection protocols and any further development that may be required to relate a measure to ecological condition.

5 Available data

The availability of existing data will influence cost effectiveness and hence our choice of measures. Such data can indicate past and current conditions and are important for detecting trends in estuarine condition. In addition, existing data can provide measures of variation which are required when designing sampling programs to detect temporal and spatial patterns.

6. Temporal and spatial scales

Measures should be assessed over temporal and spatial scales that reflect their natural variability and the scale of their responses to threats of interest. A range of measures may need to be selected to detect short-term responses to threats but also longer-term trends in characteristics with slower turnover times.

7. Scoreable

For each measure a range of scores should be assigned that represent increasing ecological condition. These scores must be directly comparable through time.

2.3.2 Baseline condition

Where possible the condition of estuaries will be assessed in the IEC using a referential approach. Ideally the observed condition should be compared with the reference condition of that estuary in a state undisturbed by humans. Unfortunately such a comparison is not possible for many of the recommended measures due to the high degree of existing disturbance of Victoria's estuaries and a lack of pre-disturbance data. Consequently, reference will equate to (in many instances) best available. Various approaches will be required for establishing the baseline condition against which future condition is measured. These include:

1. Natural or pristine reference estuaries. Estuaries compared with pristine estuaries of equivalent type and location.

2. Current individual estuary data – data used to establish contemporary baseline for each estuary from which extent of future changes are measured.
3. Current statewide estuary data - contemporary baseline derived from distribution of data statewide. For example, condition scores allocated to various percentiles.
4. Historical data. Condition compared with known condition prior to European settlement.
5. Modelling of past conditions. Condition compared to predicted condition prior to European settlement.
6. Expert opinion. In the absence of reliable Victorian data, reference or baseline condition generated using expert opinion based on anecdotal observations, data from other locations and/or incomplete data sets. This method can be used in combination with other methods or in the short-term while data are being collected.

The method recommended for determining the baseline condition of each measure is noted in Table 7.

It is also important to note that a reference condition is not necessarily the same as a target for restoration. This is particularly important in the context of irrevocably altered systems and in the presence of driving processes that are related to changes in climate. Where such factors are present, a historically undisturbed reference condition may not be appropriate or even realistic target condition for ecosystem restoration.

3 Spatial application

Any tool that assesses condition of a natural system should have clearly defined spatial boundaries and scales at which it can be applied. For the purpose of the IEC it was necessary to:

- determine the size and type of estuary to be included in assessments; and.
- establish protocols, if required, for dividing the estuary into sections e.g. upper and lower

For the IEC, estuary selection and longitudinal boundaries were guided by those estuaries considered in Barton *et al.* (2008), that is estuaries:

- are at least 1km long, or have lagoonal lengths of at least 300m;
- include surrounding animal and plant communities that are affected by waters of the estuary;
- include tributary estuaries that run into Corner Inlet, Gippsland Lakes, Western Port and Port Phillip bays and fulfil the above length criterion; and
- have substantial variation in salinity due to the mixing of marine and fresh waters.

A list of estuaries recommended for the IEC based on these criteria is shown in Appendix 4, some of which have their own sub-estuaries (that share a mouth but have a substantial and separate catchment and estuarine water body). Of these 97 estuaries, 67 have associated upstream ISC or IRC sites.

It was suggested that the IEC should include sections of estuaries, analogous to reaches in the ISC that can be assessed independently of each other. Two types of section are proposed for development of definitions based on either riverine or lagoonal shape (Figure 2). An individual estuary may consist of either of these or a combination of (usually) one lagoonal section and one or more riverine sections. Some of the measures listed in Section 4 can be scored for individual sections or reaches while others can only be scored for the estuary as a whole (but can then be applied to each section). While estuaries can have an influence on nearshore marine environments, the IEC will not attempt to assess the condition of these regions.

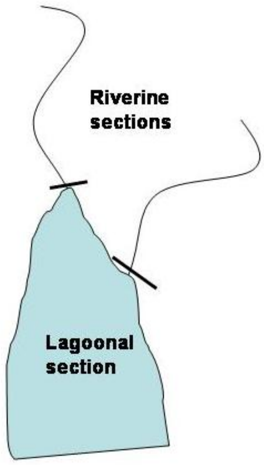

Figure 2. A schematic example of the estuarine sections proposed for use with the IEC. Two riverine sections are shown attached to a lagoonal section with boundaries shown as heavy lines.

A list of Victorian estuaries that will be included if recommended criteria are used is appended (Appendix 4). The list includes all estuaries currently adjacent to reaches assessed using the ISC as well as larger sub-estuaries.

4 Recommended IEC themes & measures

For each IEC theme, the following section describes the theme content and recommended measures. It includes a brief rationale for selection of each measure noting its importance to ecological condition and how the measure is affected by anthropogenic activities.

If available, the data collection method to support each measure is described along with any relevant studies that may assist further development of the measure. The descriptions of poor and good condition should be viewed as tentative. For most measures, further data collection, collation and analysis are required to establish baseline condition.

In some cases several measures are suggested for a particular content area. Following further investigation a preferred measure may be identified or the measures may be integrated to provide a single score. The recommended measures are assigned numbers which correspond to those in Table 7.

4.1 PHYSICAL FORM

This theme considers modifications to the physical environment of estuaries that are important to ecological condition. Alterations to physical form are relatively common and can influence ecological condition both indirectly and directly and via multiple pathways. The measures recommended for this theme are:

- Changed Bathymetry
- Changed Sediment Load
- Upstream Barriers
- Lateral Connectivity

4.1.1 Rationale

Physical form includes the overall morphology of an estuary as well as the physical characteristics of its littoral region. Measures included in this theme relate to altered sedimentation rates and physical barriers that reduce connectivity to lateral and upstream environments. Downstream, or marine, connectivity is included as a measure in the 'Hydrology' theme. There is some overlap between 'Physical Form' and the 'Sediment' theme, the distinction being that physical form addresses larger scale processes such as gross changes in bathymetry and sediment loads from catchments, whereas the 'Sediment' theme focuses on processes at finer scales.

Measures in this theme address aspects of the physical environment of an estuary that can fundamentally alter the nature of estuarine ecosystems. Such alterations may include the removal or addition of particular habitat types and changes to the timing and rate of movements of plants and animals between habitats.

Over geological time the bathymetry of estuaries typically decreases. In recent times, some Australian systems have filled at an accelerated rate in association with anthropogenic increases in fluvial sediment supply. Other human-influenced changes in bathymetry include increases in landward infilling with marine sediments, particularly in artificially-opened estuaries, and accumulation of sediments associated with water extraction and reductions in scouring flows. Conversely, human activities such as upstream dams and coastal engineering works can decrease sediment supply to estuaries.

The amount of sediment carried by rivers in Australia is thought to have increased many times over in response to land use change and associated erosion. Modelled sediment supply to Victorian streams has increased by between 3 (in the Mitchell Basin) to over 1000 times (in the Bunyip and Portland Coast basins) compared to modeled pre-European inputs on a regional basis (Marston *et al.*, 2001). This pressure can affect ecological condition by changes in the depth and particle size of the estuary bed, transport of nutrients and toxicants, by smothering fauna and by reducing light penetration. In some cases, sediment loads to estuaries may also be decreased, where sediments are trapped by instream structures or where transport of sediments is reduced in association with a reduced flow regime.

Artificial upstream barriers both prevent movement of biota, particularly fish, up & downstream and can also reduce the diversity of estuarine habitat by preventing upstream movement of salt water. Common barriers are weirs and sand slugs from large upstream erosion events.

Lateral connectivity is about linkages across the estuarine shoreline, the presence of fringing habitat and the natural movement of materials and biota between those habitats and the central water body. This measure focuses on artificial structures including levees, infilling, and seawalls. It is linked to other littoral measures such as bank erosion and fringing macrophytes (measures 13 and 14).

4.1.2 Recommended measures

1. Changed Bathymetry

Data Collection

Accurate measurement of bathymetry should occur along cross-sectional transects. Sites of likely deposition including fluvial and flood tide deltas, areas of turbidity maxima, tidal flats and basins should be targeted. Site selection and interpretation of any changes must allow for changes relating to natural movement of features such as channel alignments and delta boundaries within estuaries as well as by sedimentation. Timing of large floods will also be a key contextual factor in this measure.

As part of intermediate level assessments of estuarine flow needs in South Africa, Taljaard *et al.* (2004) recommend that transects be located every 0.5 to 1 kilometre along an estuary and measured on a three-yearly basis. For Victoria, this distance may need to be reassessed in particularly small or homogenous systems while frequency could be based around 6-yearly surveys to align with reporting cycle. A high level of skill will be required to collect data for this measure.

Data Interpretation

Poor: large change from natural + reduction from baseline; Good: close to natural + no anthropogenic change from baseline.

Baseline work to provide contextual information for this measure and for sediment load would include an assessment of the naturalness of the current bathymetry and whether large-scale sedimentation events have occurred. Various dating techniques including use of buried pollen, chemical isotopes and plant and algal remains can provide recent histories of estuarine sedimentation.

The first iteration of this measure will also establish a baseline, reductions from which will score negatively. Systems with large-scale changes in bathymetry from historic anthropogenic sedimentation should be scored lower.

2. Sediment Load

Data collection

Catchment sediment loads can be modelled based on land uses and physical characteristics of catchments and waterways. Sediment load from the portion of the catchment draining directly to the estuary and the estuary itself is harder to estimate and for practical reasons is not recommended for inclusion in this measure at present but is partially captured in Bank Erosion (Measure 11) and Water Clarity (Measure 8). SedNet is an existing example of an approach that can be used to model both current and past catchment sediment loads. This, and any other potential models would need to be assessed in terms of temporal and spatial appropriateness for use in a Victorian IEC. For example, there is increased uncertainty in SedNet estimates of relative load increases when considered timespans are less than 20 years or estimates are made for regions smaller than 3000km^2 when using current national-scale datasets (Wilkinson et al., 2004).

This measure requires modelling of natural loads and modelling and/or measurement of current loads. Contextual information is provided by the history of sedimentation in an estuary and its catchment which also relates to changed bathymetry (1) and particle size (10).

Data interpretation

Poor: large change from natural (NSW>483% increase; Qld>10kg/year/m^3); Good: small/no change from natural (NSW <12% increase; Qld <5kg/year/m^3)

Modelled natural sediment loads to estuaries are required to establish a baseline for this measure. Scores for the measure will decrease with an increasing difference between current and modeled natural loads. In NSW a scoring method based on percentage increase in sediment load from natural has been developed while in Queensland a scoring method based on absolute load has been suggested (Scheltinga & Moss, 2007).

3. Upstream Barriers

Data Collection

Information regarding barriers collected during a field assessment undertaken once in the reporting cycle. The presence of anthropogenic barriers to upstream movement of water or biota is noted in addition to their location relative to estimated natural upstream limit of estuary.

Data interpretation

Poor: Barrier(s) restricting movement of organisms and estuarine water; Good: No artificial barriers at head of estuary.

Scoring is related to presence/absence, distance of the barrier downstream from the 'natural' head', permanency of the barrier and to the degree to which the barrier restricts movement of biota (eg. weir vs sand slug). A recent Deakin University/DSE project has identified the location of existing heads of 83 of the estuaries listed in Appendix 4. Where barriers exist, the locations of natural (or historic) heads will also need identification before this measure can be used.

A tentative scoring system modified from one that was suggested for assessing estuaries in the RiVERS(II) workshop, November 2008 is shown in Table 2.

Table 2. Provisional scoring system for 'Upstream barriers'

	Intermittent or selective interference with movement of biota or water (in typical year)	Completely blocked movement of biota or water (in typical year)
> 50% of estuary area affected	1	0
25-50% estuary area affected	2	1
0<25% estuary area affected	3	1
No barriers to water or biota	4	

4. Lateral Connectivity

Data Collection

The percentage of the estuary perimeter comprising artificial structures such as seawalls, levee banks, jetties, bridges, platforms, should be recorded during a field assessment undertaken once during the reporting cycle.

This measure is also being developed in NSW and has been recommended in Queensland as percentage of estuarine riparian zone modified (Scheltinga & Moss, 2007).

Data interpretation

Poor: Structures present along a high percentage of perimeter. Good: Absent

Scores distributed at equal intervals between 6 and 25 % were calculated based on the distribution of NSW data. This would need to be revised for Victorian estuaries. Refinement of the measure could also incorporate measure 14 (Fringing macrophyte extent) and the types of structure present.

The scoring system in Table 3 was developed at the IEC workshop and modified at the RiVERS(II) workshop November 2008. This could be used pending refinement of this measure for Victorian estuaries.

Table 3. Provisional scoring system for 'Lateral connectivity'

Score	Description
0	>15% of the estuary perimeter has artificial structures OR Wetlands no longer connected to the estuary;
2	1-15% of the estuary perimeter has artificial structures OR Wetlands connected to the estuary but less than natural;
4	Estuary has no artificial structures AND EITHER Wetlands fully connected to the estuary OR No estuarine wetlands exist.

4.2 HYDROLOGY

This theme considers modifications to the hydrology and hydrodynamics of estuaries that are important to ecological condition. Alterations to hydrology of estuaries are common. Changes to both freshwater and marine inputs alter many aspects of the physical and chemical environment of estuaries. Key changes are to salinity regimes and biological connectivity. Measures recommended for this theme are:

- Marine Exchange
- Freshwater Flow
- Salinity Regime

4.2.1 Rationale

Estuaries are defined as places where fresh and marine waters meet and the salinity regime is a key physical factor that influences estuarine ecology. Changes to the relative amounts and timing of these waters entering an estuary can alter the fundamental nature of an estuary. The degree of biological connectivity across salinity gradients and physical structures both within and bounding estuaries is often strongly influenced by adjoining water bodies, both upstream and downstream.

The exchange of water with the marine environment is related to the cross-sectional area of an estuary's mouth through which waters can move. Changes to the natural dynamics of estuary mouths are common. In Victoria entrances of intermittent estuaries are often artificially opened to prevent inundation of low-lying land and structures. This can cause major changes to the ecology of a system over both the short and long term and guidelines for managing these openings have been developed (EEMSS, 2006). Two key aspects of this process are the proportion of openings that are artificial and the height of those openings. Scoring guidelines for percentage time that an entrance is open compared to a natural regime have been developed in South Africa (Taljaard *et al.*, 2004). While such a measure would be comprehensive, it would also require continuous monitoring of every estuary included in the IEC plus an assessment of what a natural regime would have been.

Entrances to permanently-open estuaries are also frequently modified. Typically this involves increasing the cross section by dredging and use of training walls to allow boat passage. This also increases the marine influence in estuaries. In some cases, naturally intermittent estuaries are now permanently open due to such changes.

Fresh water flow requirements of estuaries have been the subject of a national assessment (Peirson *et al.*, 2002) and a Victorian method for determining flow requirements for estuaries (Estuary Environmental Flows Assessment Methodology - EEFAM) is currently under development (Hardie *et al.*, 2006; Lloyd *et al.*, in prep.). At present the measure recommended for use in the IEC where possible is the ISC hydrology score which encompasses changes across several aspects of the flow regime. Further work should assess whether this index of flow alteration needs modification to accurately reflect the likelihood of estuarine condition being affected. Where available, results of an EEFAM assessment should be used in assessing this measure.

Changes in the distribution of salinity through an estuary are a key response to marine and freshwater inputs. The salinity regime in any part of the estuary is a major factor that determines the suitability of that location for biota. It is also a key mediator of chemical processes and so an important contextual, as well as condition, measure. In many systems an increased marine influence has resulted from greater connectivity at the mouth and reduced freshwater flows.

4.2.2 Recommended measures

5. Marine Exchange

Data collection

The method for scoring this measure will vary between estuaries that are intermittently-open and permanently-open. Frequency of assessment should be on approximately a 5 yearly basis but continual records of mouth state and any dredging works will be required. There is the potential for engaging community groups in ongoing monitoring.

South Africa's scoring for artificial mouth opening is based on percentage time that an estuary is opened compared to a reference condition (Taljaard *et al.*, 2004). In NSW, the water level (AHD) when the estuary is opened (independent of specific estuary) is used as a measure.

a) Intermittently-open estuaries:

a1. Artificial mouth openings (% of total openings): Record all openings and whether natural or artificial. Should be scored over entire reporting cycle to account for interannual changes.

a2. Height (AHD) of opening: Record elevation of water within estuary prior to artificial openings.

b) Permanently-open estuaries:

b1. Dredging: Record of whether any dredging has occurred in the mouth of the estuary.

b2 . Training walls: Record presence of training walls at mouth

Data interpretation

a) Intermittently-open estuaries:

a1. *Poor: high % of openings artificial   Good: Low % of openings artificial*

a2. *Poor: Low level Good: high level* (compared with natural height: need to calibrate NSW scoring (from 1.2 to 2.5 m AHD) for Vic estuaries. This could be developed by logging elevations of natural openings across a range of estuaries, including representatives of east, west and south facing groups)

b) Permanently-open estuaries:

b1. *Poor: Dredging present Good: Dredging absent*

b2. *4: no training walls; 0: two training walls*

(b2 modified from NSW which includes an intermediate score for one training wall)

A tentative scoring system for a1. has been modified from a threat-based scoring system developed at the RiVERS(II) workshop (Table 4)

Table 4 Provisional scoring system for 'Marine exchange' percent artificial openings

Score	Description
0	*>50% artificial openings;*
1	*25%-50% artificial openings;*
2	*<25% openings artificial;*
4	*no artificial openings*

These scores will need to be combined with heights (when locally calibrated) in a matrix that weights artificial openings at low elevations as worse for estuarine condition. Should an artificial opening take place primarily for the benefit of the estuarine ecosystem it may be disregarded.

Following initial assessment of scores for permanently-open estuaries intermediate scores for dredging may be desirable, depending on the numbers of estuaries affected and the scales of dredging activity.

6. Freshwater Flow

Data collection

This measure varies depending on the availability of an ISC hydrology assessment of the main reach upstream of the estuary. This is currently available for approximately two thirds of listed estuaries and depends on a long-term (15+ year) record of flow to the estuary.

The ISC hydrology index should be used if available and if there are no major alterations to flow between the ISC site and the estuary. Alternatively for estuaries where no ISC assessment is available the presence of activities or structures that alter quantity or timing of flow should be documented; these include dams and licensed extraction.

As this measure depends on long time series, it should be assessed once per reporting cycle. A high level of skill is required to derive the measure.

Data Interpretation

Scores for this measure are based on a reference of a natural flow regime.

A) Estuaries with applicable ISC Hydrology Index

a) *Poor: 1 Good:10*

B) Estuaries without applicable ISC Hydrology Index

b1. No. of structures (dams) standardised by catchment area

b2. No. of licences (extraction) - volume relative to Mean Annual Flow

b1. *Good: 0 Poor: >x density of dams* (Calibrate against ISC scores from equivalent catchments)

b2. *Good: 0 Poor: high proportion of MAF.* (Calibrate against ISC scores from equivalent streams)

Direct translation of scores from the ISC sub-index should be used with caution as no specific assessment of their relationship to estuarine condition has been made. In future, the availability of multiple EEFAM assessments may allow some calibration of the ISC hydrology index to estuarine flow requirements.

7. Salinity Regime

Data Collection

Depth profiles at fixed sites along the length of the estuary measured on spring and neap and high and low tides (for open estuaries) during high flow and low flow periods. Data should be collected each year and assessed on a six yearly basis to integrate longer term variability. Low levels of technical ability are required to collect data for this measure with higher levels of expertise required for design and coordination of the field component. Similar data is currently being collected in community volunteer programs such as Corangamite CMA's EstuaryWatch program.

Data Interpretation

Poor: Upstream movement of salinity distribution (as a percentage of natural or baseline), Good: no net upstream movement of salinity distribution.

There are many possible distribution patterns of salinity that vary in response to estuary size and shape, prevailing weather, and marine and tidal inputs. Despite this variety of patterns, a common trend associated with reduced freshwater flows and increased marine connectivity is for upstream movements of the overall salinity distribution.

A high level of expertise is required to assess trends in salinity distribution as patterns may be variable on a range of spatial and temporal scales. There may also be differences in the specific changes in pattern depending on the type of estuary which will need to be assessed with development of this measure. Unless there are existing data, the first assessment round will provide a baseline condition. Estuaries with artificially increased baseflows may require a refinement of scoring criteria..

4.3 WATER QUALITY

This theme considers the impact of characteristics of water quality on ecological condition. The measures recommended for this theme are:

- Water clarity – turbidity
- Dissolved oxygen – percent saturation & mg/L

4.3.1 Rationale

Turbidity or cloudiness of estuarine waters is a measure of light scattered and absorbed by particles and molecules. Turbidity is caused by suspended matter, such as sediment, debris and phytoplankton and dissolved organic matter such as humic substances.

The amount of suspended matter is primarily influenced by the condition of inflowing river and marine waters. In addition, factors such as tidal flow, sediment type, depth and orientation contribute to resuspension of particulates by wind-mixing and flow (Snow & Taljaard, 2007). Turbidity can be further influenced by trapping and flocculation of sediment at the halocline and hence levels may vary with the extent of estuary stratification or position of the salt wedge.

Catchment activities which increase the input of fine sediments, organic matter and/or nutrient loads will contribute to raised estuarine turbidity levels either directly or indirectly via stimulated phytoplankton production.

Turbidity affects light penetration and hence primary production and distribution of aquatic plants, particularly submerged macrophytes (Carter & Rybicki, 1990; Adams & Riddin, 2007). These species are more susceptible to reduced light levels than floating macrophytes, phytoplankton and microphytobenthic species (Gama 2007).

Dissolved oxygen is essential for respiration of (aerobic) aquatic biota. Oxygen levels within the estuary are a balance of oxygen input from photosynthesis, aeration (e.g. wind mixing) and inflow (of oxygenated marine and riverine waters) and reduction from respiration and nitrification (i.e. conversion of ammonium to nitrate and nitrite by bacteria in the sediment and water column).

Dissolved oxygen levels, particularly in the bottom waters of stratified estuaries, are often depleted through decomposition of organic matter by microbial activity. This is a natural process and hypoxia and anoxia have been recorded in several 'pristine' estuaries – both intermittently and permanently open (Mondon *et al.*, 2003; Barton, 2006). Anthropogenic activities resulting in increased input of nutrients and organic matter to estuaries are likely to accelerate the process and influence the extent of oxygen depletion. In addition, the limited tidal input in wave-dominated estuaries makes them more prone to hypoxic events. Apart from the direct impact of low oxygen levels on biota, anoxic bottom waters can trigger the release of sediment-bound nutrients and indirectly affect condition by subsequent events such as algal blooms (Pope, 2006).

Elevated nutrient loads are associated with increased primary production of phytoplankton and macrophytes. Algal blooms (Maher, 2001) and excessive growth of macroalgae e.g. *Cladophora,* have been recorded from several Victorian estuaries (Barton, 2006). The increased biomass can result in very high dissolved oxygen levels (> 110 %). The resultant decomposition of the large plant biomass can cause widespread hypoxia (< 2 $mg.L^{-1}$) or anoxia (0 $mg.L^{-1}$) (Becker 2007). Mass mortality of fish (fish kills) have been associated with these events particularly when combined with artificially opening the entrance.

Nutrient concentrations (inorganic and particulate) in estuary waters are the function of a complex suite of physicochemical and biological processes (Appendix 6). They are not recommended as measures as it is difficult to describe or predict how particular levels will affect estuarine condition. In a study of NSW ICOLLs, no pattern of response of nutrient levels to nutrient loads and catchment use was detected (Scanes *et al.*, 2007). Similarly, studies in Victorian estuaries did not detect a biological response (of infauna) to estuarine nutrient levels (Mondon *et al.*, 2003; Barton, 2006).

4.3.2 Recommended measures

National guidelines (ANZECC & ARMCANZ, 2000) recognise the uncertainties in measuring and assessing the link between water quality and biological effects and provide a framework for developing more locally applicable guidelines.

The EPA is currently developing preliminary environmental water quality guidelines for Victorian riverine estuaries (N. Bate, pers comm.). These will identify water quality indicators that best assess the threats (hazards) to the values of aquatic ecosystems of riverine estuaries The indicators use a risk-based approach to develop environmental quality 'trigger' values i.e. a level at which there is a potential risk that adverse ecological effects may occur. Surface and bottom levels of both turbidity and dissolved oxygen are included in the draft guidelines

8. Water Clarity

Data collection:

Turbidity (NTU) and Secchi depth (m) are most commonly used to measure water clarity. Both methods need to be calibrated against a direct measurement of light penetration e.g. vertical variation in PAR (Photosynthetically Active Radiation, in spectral range from 400 to 700 nanometers that is useful for phoyosynthesis), to understand the implications of the values on ecological condition of the estuary. Secchi discs are cheap and easy to use but their usefulness is limited particularly in stratified estuaries with different clarity in surface and bottom waters.

Approximately monthly collection is recommended. However water clarity measurement during high flow events should be avoided because of unrepresentative values associated with these events. The position of a salt wedge and extent of stratification should also be considered when designing a sampling protocol as water clarity will often be less in the fresher surface waters compared with more saline bottom waters,.

Qld EPA (Scheltinga & Moss, 2007) have established sampling protocols for measuring water clarity using turbidity and Secchi depth. The protocols provide detailed procedures including requirements for temporal and spatial replication, calibrations and methods for taking measurements from boats or shore-based.

A medium level of skill is required for data collection of this measure because of the knowledge and experience required for use, maintenance and calibration of turbidity meters.

Data interpretation

Turbidity levels Poor: > 20 NTU (based on NSW and Vic data); Good: < 6 (Victorian EPA 5 (surface)-7 (bottom); NSW 6)

Natural turbidity levels are influenced by the type and size of particles and hence will be affected by a range of estuarine characteristics such as tidal flow, soil type, geology, slope, orientation, prevailing wind direction, depth and width. These factors will need to be taken into account when setting baseline conditions for particular estuaries and site specific baseline conditions may need to be considered.

The turbidity values provided above should be seen as a guide. Validation of the condition scores associated with different turbidity levels and Secchi depths will be required following further investigation and establishment of baseline conditions.

Qld EPA (Scheltinga & Moss, 2007) provide scoring categories (1-5) for turbidity and Secchi depths based on percentage of zones or sites that exceed guideline

9. Dissolved Oxygen

Data Collection

Dissolved oxygen levels are reported as oxygen concentration (mg/L^{-1}) or percentage saturation (%). Oxygen solubility (mg/L^{-1}) is affected by salinity and temperature, but percentage saturation measurements are independent of both factors. Percentage saturation is currently recommended for scoring but as most meters provide an output of both units mg/L should be recorded along with temperature and salinity for future reference.

Regular approximately monthly data collections are recommended but timing of collection needs to take into account diurnal variation in dissolved oxygen levels. To assess oxygen sag associated with diurnal variation, regular dissolved oxygen surface measurement (15-20 min intervals for 24 hours) at most vulnerable of 3 sites should be collected during an initial assessment.

In addition to surface measurement, vertical daytime (late afternoon) dissolved oxygen profiles (at 3 sites mid stream) are suggested to detect anoxic bottom waters and algal blooms. This information will also assist with interpreting surface oxygen levels as well as biotic measurements.

There are standard sampling methodologies for dissolved oxygen measurement. A moderate level of skill is required to use, maintain and calibrate equipment.

Data interpretation

Percentage saturation in surface layer Poor: < 50% or >110% saturation Good: 80-100%

Scheltinga and Moss (2007) provide condition scores (1 to 5) for two oxygen indicators. One based on the minimum sustained dissolved oxygen values during the days following an inflow event and the second on a measure of ambient dissolved oxygen i.e. the percentage of zones/sites that exceed QLD EPA guidelines

The percentage exceedance of environmental trigger values identified in the draft Victorian EPA guidelines for estuaries could provide condition descriptions and scores. Condition descriptions also need to accommodate naturally occurring low oxygen levels of some individual estuaries.

4.4 SEDIMENT

Sediments play a key role in the ecology of estuaries and comprise an important habitat as well as being involved in processes such as nutrient cycling, transport and storage of toxicants and light attenuation. The theme links to all other themes and considers aspects of the physical properties, movement and biota of sediments. Measures recommended for this theme are:

- Particle Size
- Bank Erosion
- Sediment Respiration Rate

4.4.1 Rationale

Soft sediments play a substantially larger functional role in estuaries than they do in most streams and rivers. Estuaries are physically shaped by the interaction of river, wave and tidal energy with sediment supply. While estuaries are typically sinks for fluvial sediments, patterns of deposition and erosion within estuaries vary in complex ways through space and time in response to shaping forces, including a range of human alterations.

Estuarine sediments are a habitat that is also a store and a modifier of organic matter, nutrients and pollutants. Key aspects of the trophic dynamics and nutrient cycling of estuaries are mediated through sediment-based processes. Changes to the dynamics and distribution of sediments in an estuary, including the increases in fluvial sediment load measured in the ‘Physical Form’ theme, affect the ecological condition of estuaries via several interlinking causal pathways such as reductions in the light environment (also reflected in water quality), alterations of depths, particle sizes, and mobility of benthic habitats. In this sense, sediments influence recommended measures across all themes.

Changes in particle size in the upper parts of estuaries (away from the flood tide delta) are often linked to patterns of erosion and sedimentation. The proportion of fine sediments in some systems is thought to increase, along with sedimentation rates, as a response to human-related changes in sediment supply and hydrodynamics (see Edgar *et al.* (2000) and NLWRA indicator guideline: *Sedimentation/erosion rates V1, 2008*). Changes in the distribution of fine particles within estuaries between IEC surveys in cores can provide an integrated record of changes in patterns of sedimentation. Particle size is often related to risks to condition from organic matter, nutrients, pollutants, smothering & clogging and habitat change for infauna. Contamination of sediments with metal and organic pollutants has led to a decline in ecological condition in some, typically highly urbanized, estuaries. While there are established techniques for measuring sediment contamination its localised nature and the cost of analyses make such assessments better suited to targeted rather than statewide programs.

In addition to increased fluvial sediment supply, sediments can enter the water column of estuaries from local drainage lines and by erosion of the bank and bed of the estuary itself. In general, while catchment sources are usually dominant, in specific locations the supply of sediment from the estuary bed or banks may also be significant (Scheltinga & Moss, 2007). In systems where non-fluvial sources are significant, bank erosion (which can be linked to increased disturbance of the bankside zone or to reduced fluvial sediment supply) can lead to reduced ecological condition by pathways such as changing the particle size, altering availability and depth of benthic (including intertidal) habitat, reducing water quality and smothering biota. Increased sea levels and frequencies of storm surges that are predicted with climate change are likely to increase overall sediment flux (erosion and deposition) in low-relief coastal regions, including estuaries.

Sediment respiration rate is the rate at which oxygen is consumed by organisms in the sediment. Net respiration is the result of oxygen consumption balanced by oxygen production from photosynthesis. Respiration (and photosynthesis) in estuarine sediments are a key part of nutrient cycling as well as playing an important role in the availability of oxygen in the water column and mediating dynamics of sediment-associated pollutants. High sediment respiration rates are often due to increased decomposition in response to unnaturally increased organic matter loads and eutrophication of estuaries. A common response of benthic communities to elevated inputs of organic matter and nutrients is for these external sources to become the dominant carbon source (i.e. heterotrophic) rather than communities generating organic matter through photosynthesis (i.e. autotrophic).

4.4.2 Recommended measures

10. Particle Size

Data Collection:

This measure uses the proportion of sediments in the top 10cm of the estuary bed that are < 125 µm in diameter (i.e. clays, silts and very fine sands) as a measure of sedimentation. Samples are collected using corers and can be analysed using laser sizing or particle size fractionation techniques. Core diameter will depend on the sample size required for the analytical method chosen.

The measure aims to detect changes in the patterns of particle size throughout each estuary and so should be sampled at low energy locations in the upper, middle and lower parts of each estuary. Eight cores should be taken for analysis from each site for the first survey, following which the number of replicates can be reassessed on the basis of power analyses. This measure is intended to be repeated twice a decade as samples for this measure integrate conditions over time.

Identification of sites on the initial survey will require a moderate level of skill to identify appropriate depositional environments within each portion of the estuary. Similarly moderate levels of skill and specialized equipment will be required for particle size analyses. A range of Australian Standards have been published regarding measurement and representation of sediment particle sizes (e.g. AS 1141.11—1996 for dry sieving of coarser sediments).

Data Interpretation:

Poor condition a >20% increase in the fine fraction by weight compared to the last survey Good condition <20% increase or decrease in the proportion of fines representing good condition

More detailed scaling of this measure will be possible once a baseline dataset is available for a range of Victorian estuary types and conditions. Following collection of such data it is likely that a range of scoring scales will be required for differing groups of estuaries.

This measure was one of several possible measures of sedimentation/erosion recommended as national indicators but for Queensland estuaries it was excluded as impractical for those systems (Scheltinga & Moss, 2007). In South Africa mapping of the distribution and sedimentary composition of shoals in each estuary is combined with particle size information from 6 benthic sites and used as a basis for an expert opinion on the percentage similarity of total intertidal area and sand fraction compared to an undisturbed system (Taljaard *et al.*, 2004).

For Victorian estuaries interpretation of these data will need to take into account influences of estuary type (particularly with respect to the availability of depositional areas and the frequency of scouring). Contextual information for this measure includes major flooding, extended droughts, presence of large dams and the existence of riverine sand slugs.

11. Bank Erosion

Data Collection:

Data for this measure should be collected as per the ISC method for assessing bank stability. This method employs a semi-quantitative assessment of bank stability. It compares sites to sets of pictures linked to scores on a condition scale. A set of photographs that encompasses a range of erosion scenarios appropriate for use in all types of estuaries is required prior to use of this measure. Three sites within each estuarine section (e.g. reach) should be assessed. Photos of the sites being assessed should be taken for reference. Collection of data could be done by relatively unskilled personnel.

Data should be collected once each assessment cycle (~6 yearly) and is best done at low water levels (i.e. low tide, deeply open entrance bar).

Data Interpretation:

Poor: Increased bank instability; Good: Stable, intact banks

Data for this measure will initially be scored on a five point scale as per ISC scoring. The importance of bank erosion as a measure of estuarine condition will vary between estuaries in response to geomorphology (e.g. narrow, riverine estuaries vs broad lagoons) and proportional contribution to suspended sediment concentrations and loads (*i.e.* links to water quality and physical form themes).

Ultimately scoring for this measure should be interpreted in context of the type of estuary and the influence of other sediment sources in the estuary. Bank erosion in some systems may be a response to a reduced fluvial sediment supply disrupting the sediment balance of intertidal areas, in these systems there may be an offsetting benefit elsewhere in the estuary and this measure should be scaled appropriately.

Scaling of this measure should be based on percentile distributions of initial scores for this measure across groups of estuaries.

12. Sediment Respiration Rate

Data Collection

Measurement of sediment respiration using incubated core tubes requires a moderate degree of technical ability for collection and a high degree of skill for interpretation. Recommended techniques are based on a NSW method that is in preparation (P.Scanes pers. comm.).

Core samples for this measure should be of a standard volume and be collected in capped polycarbonate tubes. Five pairs of cores should be taken at each of three sites axially along the estuary from shallow areas (i.e. that are not light limited).

In the lab, pairs of cores should be incubated in light and dark at the ambient temperature of the estuary for 4 hours with constant gentle stirring and measurement of dissolved oxygen concentrations. Light and dark results should then be integrated based on a day length model to give net daily metabolism in µmole O_2/m^2/day

The use of *insitu* benthic chambers was considered in the workshop but has not been recommended due to difficulties with consistency and feasibility when applied statewide.

Data interpretation

Poor:< -105 µmoleO_2/m2/day: i.e. heterotrophic where it is unexpected (e.g. shallow margins with good light) Good: autotrophic to zero (≥0 µmoleO_2/m2/day).

Net respiration of sediments is linked to the microbial benthic community (including microphytobenthos – see measure 15) and to relative proportions and composition of organic matter and nutrients. Changes in particle size (measure 10) can also be associated with changes in benthic respiration.

4.5 FLORA

This theme considers the condition of the flora that occurs in and around estuaries. It includes macrophytes such as saltmarsh, reedbeds, seagrass and macroalgal beds and microphytes such as phytoplankton in the water column or microphytobenthos associated with sediment. Measures selected for this theme are:

- Aquatic macrophyte - extent & macroalgal cover
- Fringing macrophyte - extent & condition
- Microphytobenthos - biomass
- Phytoplankton biomass

4.5.1 Rationale

Native vegetation in Victoria is grouped into Ecological Vegetation Classes. Although species within a particular EVC may vary, the general structure and habitat the EVC occupies is similar. A list of 16 estuarine EVC's– both aquatic and riparian – is provided in EEMSS (2006) (Appendix 7).

Aquatic macrophytes such as seagrass beds form complex ecosystems and act to stabilise sediment and alter water flow. They are highly productive areas that provide habitat for a range of invertebrate and fish species, including nursery habitat for recreational and commercial species. Seagrass is affected by a range of anthropogenic influences, particularly those that alter the light availability, sediment deposition, water movement and salinity regime (see review in Adams and Riddin (2007)).

Macroalgae naturally occur in estuaries, however nutrient supply when combined with a range of physicochemical factors can result in excessive growth of opportunist macroalgae such as filamentous and mat forming species *Enteromorpha* and *Cladophora*. Effects of algal mats on estuarine condition are summarised in Scanlan *et al.*(2007) as creating a hostile physicochemical environment (i.e. low oxygen and high sulphides) in underlying sediment, smothering seagrass beds, impacting on birds, particularly feeding behaviour of waders, interfering with waterway activities such as swimming and boating and causing offensive odours.

Macrophytes in the riparian area such as saltmarsh and reedbeds provide important habitat for invertebrates, birds and fish. In addition to their habitat values they trap sediment and reduce bank erosion (Adams & Riddin, 2007). The main threats to these plant groups are from physical disturbance and altered hydrology. Development pressure around estuaries often results in physical destruction of macrophyte beds in the riparian area by trampling and/or construction of infrastructure. In addition, EVCs have specific requirements/tolerances regarding the length of time they are inundated, period since they were was last inundated and the salinity of the overlying water (EEMSS 2006). EVCs are therefore likely to be impacted by both altering flow to the estuary and activities or structures that change either the entrance opening regime or inundation of the riparian area.

Microphytobenthos refers to the photosynthetic unicellular organisms associated with estuarine sediments. These organisms are important for oxygen production at the sediment surface thereby directly and indirectly influencing nutrient cycling. They also stabilise sediments and are an integral component of food webs (MacIntyre *et al.*, 1996). Chlorophyll *a* and its degradation product, phaeophytin *a,* are used as surrogates for the biomass of these organisms. The ratio of phaeophytin to chlorophyll *a* provides an indication of the amount of decline or growth in microphytobenthos populations (Light & Beardall, 1998). Phaeophytin *a* has been shown to correlate with estuary condition within some Victorian estuary types (Barton 2006). In particular, the condition of the smaller, east-facing estuary type found along the Great Ocean Road east of Cape Otway and along the east coast of the Mornington Peninsula.

Phytoplankton is an important component of aquatic food webs. However, excessive growth often in response to high nutrient levels, coupled with physical factors such as increased temperature and light and reduced flow, can have a negative effect on estuarine condition. Chlorophyll *a* concentrations provide a measure of the biomass of phytoplankton and hence the primary productivity of the system. Phytoplankton blooms can increase turbidity, increase the magnitude of diurnal oxygen changes and in the case of some species of blue-green algae (e.g. *Anaebena, Nodularia* and *Microcystis)* be toxic to aquatic species, wildlife and humans.

4.5.2 Recommended measures

13. Aquatic macrophyte extent and macroalgal cover

Data collection

The importance of aquatic flora to estuarine condition is well recognised and these measures are recommended in many assessment programs. However, lack of standard monitoring protocols and problems differentiating natural changes in macrophyte extent from anthropogenic induced change may preclude their inclusion at this stage. Glenelg Hopkins CMA has recently completed a project mapping the extent of aquatic vegetation in estuaries in the GHCMA region (Sinclair & Sutter, 2008). Learnings from this project and others used overseas and interstate could inform development of a method for state-wide application.

Variation in seagrass extent and cover can occur due to natural changes in water levels associated with flow regimes and entrance condition (Pope, 2006). Both act to alter the amount of potential habitat available for seagrass beds. Development of a monitoring program of these factors may provide information to differentiate natural changes from those associated with human activities.

Frequency of assessment will depend on the results of a monitoring program to determine timing of sampling and the protocol used but will probably only be required every 6 years to coincide with the reporting cycle.

Although the sampling protocol is still to be determined it is likely a high level of skill level will be required for assessment of this measure which will probably involve remote sensing (such as aerial photography or multispectral scanning) in addition to field assessment requiring diving and taxonomic expertise.

Scanlan *et al*. (2007) summarise and review some commonly used techniques for estimating macroalgal cover such as aerial photography, remote sensing and *in situ* methods and highlight difficulties with developing a method for quantifying macroalgal biomass including depth and timing of sample collection. The accuracy and applicability of these techniques need to be tested in Victorian estuaries. Barton (2006) tested *in situ* quadrat methods but found the method did not detect different estuary conditions at the temporal & spatial scale she considered.

Quarterly collection of data quantifying percent cover is tentatively recommended but both the frequency of data collection and the skill level required will need to be confirmed once a sampling method is selected.

Documenting macroalgal blooms may require more regular observations and monthly monitoring is recommended. Concentration of observations during the warmer months should be considered.

Data Interpretation

Percentage change in aquatic macrophyte extent from historical Poor: >20% Fair: 10-20% Good: <10%

While change from historical (i.e pre-European settlement) is recommended, lack of information may require current estuary condition to be the baseline for further assessment. The interval of percentage change selected will be influenced by the resolution of the method used for assessing change. These condition scores assume a 10% mapping error.

The Qld EPA (Scheltinga & Moss, 2007) provide scoring categories (from 1-5) for both change in seagrass extent and change in seagrass cover (both expressed as percent loss per year).

Percentage cover of macroalgae. Poor: >50%; Good: <15%

Scanlan *et al* (2007) developed a decision table which combines use of algal biomass and percentage cover to assign 'Quality status levels (1-5). This was refined by Patricio *et al* (2007) for use when biomass data were not available (scores 1-4). The authors also examined how scores differed if data were collected during different sampling periods. Data from estuaries state-wide is required to confirm the description for good and poor and assign intermediate scores.

Number. of macroalgal blooms Poor 1 or more Good zero

For RiVERS (II) the following scoring criteria were proposed:

Percentage of estuary with excessive instream plant growth: Poor >25%; Good <1%

14. Fringing macrophyte extent and condition

Data collection

A variety of mapping scales and techniques has been employed to quantify the extent of fringing vegetation around Victorian estuaries.

The scale of the state-wide vegetation mapping (EVC layer in the DSE Corporate Geospatial data library) as displayed on the Biodiversity Interactive Maps is generally 1:25 000 or greater. This resolution is too coarse to quantify changes in extent of estuarine EVCs. More detailed vegetation surveys and mapping have been undertaken around some estuaries including maps at a scale of less than 1: 5000 of fringing and aquatic vegetation of estuaries in the Glenelg Hopkins CMA region and statewide mapping of saltmarsh (P. Boon pers comm.)

In addition to mapping macrophyte extent, both projects include an assessment of EVC condition. Sinclair & Sutter (2008) discuss the limitations of both the habitat hectares (Parkes *et al.*, 2003) and the Index of Wetland Condition approach and suggest modifications for assessment of estuarine vegetation. These approaches should be evaluated for state-wide application. Alternatively, or in addition, a condition checklist and scoring method could be developed, potentially in conjunction with one for measure 4 – 'Lateral Connectivity'. The checklist could note the area altered by disturbances and /or the presence of infrastructure likely to affect the condition of fringing vegetation, for example, native versus exotic vegetation, vehicle access, grazing, weirs, culverts etc.

Whatever method is selected, assessment will be required once every 6 years

Data Interpretation

Percent change from historical (pre-European) condition: Good: no change in extent or condition of EVCs and no structures or activities present likely to affect extent or condition. Poor: no remaining fringing macrophytes

Intermediate scores would need to be assigned once data has been collected, collated and analysed to determine the range of values associated with Victorian estuaries.

15. Microphytobenthos

Data collection

Collection methods and analysis techniques for measuring concentrations of chlorophyll and phaeopigments are established (Arar, 1997; Light & Beardall, 1998). Barton (2006) was able to use phaeophytin concentrations to distinguish estuary condition by sampling in spring at two lower estuary sites with five replicates per site. Further work would refine the spatial and temporal replication required and the pigments (or combinations of) which best differentiate estuarine condition.

A high level of skill is required for collection of this measure in the field and analysis in the laboratory.

Data Interpretation

The baseline condition should be derived from data describing the current phaeophytin concentrations in estuaries statewide. The results from a selection of Victorian estuaries (Barton 2006) could provide interim scores for further validation in a trial of the IEC.

16. Phytoplankton

Data collection

Techniques and collection methods are well established for chlorophyll a concentrations (EPA., 2000). The skill level for this measure is rated as high due to laboratory skills required for chlorophyll a concentrations and the taxonomic expertise for cell counts of dominant groups. It is recommended that samples are collected approximately every 6 weeks over the 6 year sampling period with 3 replicates per site. The option of sampling more intensively in summer should be investigated.

Cell counts of dominant phytoplankton groups is not required routinely but samples should be collected and preserved so that they can be processed if chlorophyll concentrations are high

Data Interpretation

Chlorophll a concentrations. Poor: <25th percentile Good: >90th percentile

The preliminary environmental water quality guidelines for Victorian estuaries currently being developed by the Victorian EPA will provide a baseline condition and assist in allocation of condition scores.

The Qld EPA (Scheltinga & Moss, 2007) provide scoring categories (from 1-5) for percentage of sites or zones that exceed QLD EPA guidelines.

FAUNA

This theme considers the condition of fauna that utilize estuaries. This includes vertebrate and invertebrate fauna associated with sediment, plants and the water column. The two measures for this theme are:

- Naturalness of fish - observed to expected
- Naturalness of birds - observed to expected

4.5.3 Rationale

The condition of flora and fauna is the ultimate gauge of how well an estuary is functioning. The composition, distribution and abundance of faunal species, particularly those at higher trophic levels, will be affected directly and indirectly by components of all other themes.

The expected response of fish to anthropogenic disturbance in estuaries, as summarised in Deegan *et al.* (1997), include (possible metrics in brackets):

- Declines in species richness (number and dominance)
- Decline in abundance (number of individuals and biomass)
- Declines in nursery function (number of nursery species; number of estuarine spawners; proportion of nursery species; proportion of estuarine spawners)
- A few tolerant species dominate year-round as less tolerant species are eliminated. (number of resident species increases; proportion of resident species increases;
- Fewer benthic-associated species (proportion of benthic-associated species decreases)
- Loss of higher trophic levels and specialists (proportion of piscivores decreases; proportion of invertivores increases)
- Increase in disease or abnormalities (proportion of disease increases)

Further work is needed to test these predictions, determine which are relevant to fish assemblages in Victorian estuaries and establish a contemporary baseline. The predicted responses generally focus on functional groups or guilds e.g. estuarine use and feeding mode rather than presence or absence of species. Guilds are more likely to be independent of geographic location and natural variation than species assemblages.

Estuaries provide important bird habitat for nesting, foraging and roosting. They also function as drought refuges for many bird species during times of low river flow or rainfall when equivalent habitats inland are not available. As per fish, the use of functional groups is recommended. As part of the EEMSS (2006) project, estuarine birds in Victoria were grouped into guilds based on estuarine use (i.e. water depth and vegetation). It is expected if particular habitats are present then guilds, which utilize those habitats, should be represented.

The ISC employs several indices of freshwater invertebrate communities e.g. AUSRIVAS and SIGNAL, to provide predictable measures of the naturalness of reaches. Attempts to detect a similar response in estuarine infaunal communities have so far not proved successful in Victorian estuaries. The inclusion of infauna as a measurable estuarine asset was reviewed in Arundel (2007). In summary the usefulness of estuarine macroinvertebrate communities in predictive models was found to be limited by:

- Spatial and temporal patchiness (Skilleter & Stower, 2001; Edgar & Barrett, 2002; Barton, 2006);
- Poor correlation between abiotic variables and community structure (Hirst, 2004).
- Low species richness and many uncommon taxa in estuarine assemblages (Moverley & Hirst, 1999);

In a study of Tasmanian estuaries Edgar & Barrett (2000) noted that macrobenthic assemblages varied with human population densities in catchments. They found infaunal species were generally associated with higher population densities and epifaunal species with low densities. This relationship was used to derive an index of anthropogenic disturbance for Tasmanian estuaries. The applicability of this index to Victorian estuaries has not been tested and requires extensive further investigation it has therefore not been recommended for inclusion in the IEC at this stage.

4.5.4 Recommended measures

17. Naturalness of fish (guilds)

Data collection

While some estuaries have been surveyed for fish, there is currently no established sampling protocol or regular monitoring. These need to be developed to standardise sampling and allow comparison of estuaries. The DSE are currently developing a Fish Analysis Support Tool (FAST) for prioritising and assessing works programs on coastal aquatic resources, particularly fish. This program, or the Viridans database, could be a used for storing data related to fish surveys.

Measures of fish communities are incorporated several estuarine assessments including the Biological Health Index (Cooper *et al.*, 1994) used in South Africa and the Estuarine Biotic Integrity Index (Deegan *et al.*, 1997) developed in the USA. The NSW Department of Primary Industries is also currently investigating the application of the Biological Health Index (i.e. fish observed to expected) to NSW estuaries (P.Scanes, pers. comm.).

Several recent studies should assist with categorizing Victorian species into groups according to estuarine use (Deegan *et al.*, 1997; EEMSS, 2006; Elliott *et al.*, 2007; Drew, in prep) and feeding mode (*sensu* Elliott *et al.*, 2007). Although further investigation is required, this information will allow some interim guilds to be identified. Further work is recommended to confirm the groups and investigate temporal and ontogenetic changes in diet. Stable isotopes are a useful tool for tracing the origin of food sources and hence provide information necessary for grouping fish into trophic levels.

Data interpretation

To be developed following collection, collation and analysis of Victorian data. Distribution of this data will provide a contemporary baseline from which condition scores can be derived. The condition of individual estuaries or estuary types may need to be taken into account when allocating scores. For example, naturally turbid estuaries could support lower numbers of fish species in feeding groups requiring visual predation.

18. Naturalness of birds

Data collection

Currently there is no regular monitoring of birds in Victorian estuaries. Before a monitoring program can be established, a protocol needs to be developed to standardise sampling thereby allowing comparison of estuaries

Birds Australia coordinates teams of volunteer bird observers and maintains a database with established quality assessment protocols. This organisation could possibly assist with data collection once a methodology has been established and tested. Summer and winter sampling times are recommended to ensure migratory birds are surveyed.

The guilds identified in EEMSS (2006) are useful for identifying 'expected' bird species for each habitat present.

Data interpretation

To be developed following collection, collation and analysis of Victorian data. Distribution of this data will provide a contemporary baseline from which condition scores can be derived. The extent and condition of particular habitats (based on water depth and vegetation) needs to be taken into account as it is expected that there will be a minimum areal extent of a habitat type before it is considered 'suitable' or available.

Good: More than 2 species in each guild for which suitable habitat is available. Poor less than 2 species in each guild

The recommended score is only a tentative baseline. A sampling method needs to be developed and data collected/collated before scoring levels can be assigned. Scores will need to integrate percentage of guilds represented and number of birds. A decision table may need to be developed to accommodate various combinations. For example, if there are 5 species from one guild but one or none in other guilds.

5 Implementation

5.1 Current Status

The information required and currently available to support implementation of each measure in the IEC is summarised in Table 7. Implementation of particular measures depends on the investment required to both collect and interpret the required data. Details of the abbreviations and scores used in Table 7 & 8 are listed below.

Data collection

The time and cost associated with data collection primarily depend on, whether there is an established sampling procedure, how frequently data needs to be collected and the level of expertise required for collection. While existing data for some measures may be available it is important that a standardised protocol was used for collection to enable valid and accurate comparison over time and between estuaries. Sampling procedures are available for many measures used in studies of specific estuaries or interstate or overseas programs. Generally the protocols have not been tested or compared to identify the most suitable for statewide application in Victoria.

Sampling protocol	
Established:	A recognized sampling procedure is available and applicable for use in Victorian estuaries;
Partially Developed:	Protocols may be available but their applicability to Victorian estuaries is not established.
To be Developed:	Protocol not yet developed.

Frequency	
Annual, quarterly, monthly	Measure requires regular monitoring. Time interval recommended is approximate.
1-off:	Measure needs to be assessed once to align with reporting cycle i.e. every 5 years.
To be Developed	Sampling regime to be determined once protocol developed

Skill level	:
Low	Community involvement possible with minimum training and technical support.
Medium	Opportunity for some community involvement in data collection but extensive training and technical support are required
High	Data collection requires skilled technical staff.

Data interpretation

Interpreting the data primarily relies on the establishment of baseline condition. While some biotic condition measures are recommended for the IEC, all require further work to establish the baseline condition and develop descriptions and scores which reflect the extent of deviation from that condition. For many other measures, descriptions and associated scores have been developed for estuary assessment programs used elsewhere. Their suitability for use in Victorian estuary assessments still requires testing.

Condition descriptions	
Established	Descriptions developed for 5 scoring levels and tested in Victorian estuaries
Partially Developed	Only good and poor conditions have been identified but further investigation is required to assign intermediate scores. Or descriptions developed but applicability to Victorian estuaries not known
To be Developed	Scoring descriptions not yet developed

Baseline condition	
Established	Baseline condition established for Victorian estuaries
Partially Developed	Baseline condition developed for use elsewhere but applicability to Victorian estuaries not known
To be Developed	Baseline condition not yet developed

Cost

For each measure there are costs associated with development to a stage where they can be evaluated for use in an ongoing assessment program and the operational costs associated with ongoing data collection required for scoring each measure.

Development costs are closely related to the current stage of development of sampling protocols, baseline condition and condition descriptions. It is assumed these three factors will correlate with the amount of investment required prior to implementing a particular measure.

Scores were assigned to combinations of the three criteria post hoc (therefore not all combinations are included) and are provided to indicate the relative cost of development of each of the recommended measures.

Table 5**.** Criteria for assigning scores to development costs (or feasibility of immediate implementation). E established PD partially established TBD to be developed. Score: 1 least expensive to 5 most expensive

Score	Sampling protocol	Baseline condition	Condition description
1	E	E	E or PD
2	E	E or PD	PD or TBD
3	PD	E or PD	E or PD
4	PD	PD or TBD*	PD or TBD*
5	TBD	TBD	TBD

* If both baseline condition and condition description PD then score as 3

Operational costs will be influenced by aspects of data collection such as frequency of collection and the required skill level of those involved in collection (Table 6).

For the purpose of comparing the relative operational cost of each measure, skill level was scored from 1 to 3 based on the approximate annual cost of staff required for data collection. For example, Low skill level (1) requires the equivalent of community volunteers with some technical support; Medium skill level (2) requires approximately two technical staff; and High skill level (3) equates to a scientist plus technical staff.

The number of collections required during the reporting cycle of 5 years was used to weight the frequency score e.g. 1- off equals 5 and monthly equals 60.

It is assumed that the data required is only collected for the IEC program. Operational costs will be less if the data is also collected as part of other programs. For example water quality data is scored as high but may already be collected routinely as part of existing water quality monitoring programs.

Table 6. Criteria for assigning operational costs. Low cost (1-5) Medium cost (10-40) High cost (60-180)

	Skill Level (score)		
Frequency (Score)	Low (1)	Medium (2)	High (3)
1-off (1)	L	L	L
Annual (5)	L	M	M
Quarterly (20)	M	M	H
Monthly (60)	H	H	H

Table 7. Summary of recommended IEC themes and measures including requirements for data collection and interpretation. Type of measure shown as surrogate (S) or condition (C). See Section 5 for further explanation of the following scores and abbreviations E established; PD partially developed; TBD to be developed. Frequency: Q quarterly; A annual, M- monthly. Skill level:. H High; M Medium; L Low. Baseline type: H Historical, M modeled C1 Current data from specific estuary C2 Current data from range of estuaries See section 2.3.2 for further details of baseline condition. Cost Development 1 low – 5 very high (These scores are used as proxies for the feasibility of immediate implementation see Table 5) and Operational; High (H) Medium (M) Low (Low)

Theme	Content	Measure	Type	Data collection			Data interpretation			Cost	
				Sampling protocol	Frequency	Skill level	Baseline type	Baseline condition	Scoring description	Development	Operational
PHYSICAL FORM											
1	Changed Bathymetry	Changed bathymetry at sites of likely sediment deposition	S	PD	1-off	H	C1	TBD	PD	4	L
2	Sediment load	Current vs modelled natural	S	PD	1-off	H	M	PD	PD	3	L
3	Upstream barriers	Presence/absence, type and location	S	E	1-off	M	H	PD	E	1	L
4	Lateral Connectivity	No. & type of artificial structures on foreshore (% of estuary perimeter affected)	S	E	1-off	M	H	TBD	E	2	L
HYDROLOGY											
5	Marine exchange-Intermittently open Estuaries	a1 Artificial openings (% of total)	S	E	A	L	H	TBD	E	2	L
		a2. Height (AHD) of opening	S	E	A	M	H	PD	PD	2	M
	Permanently open estuaries	b1. Dredging	S	E	A	L	H	PD	E	1	L
		b2. No. of training walls	S	E	1-off	L	H	PD	E	1	L
6	Freshwater Flow – ISC reach upstream:	a. ISC hydrology score	S	E	1-off	H		PD	E	1	L
	No ISC reach:	b1. no. of structures (dams) standardised by catchment area	S	PD	1-off	M	H	PD	E	3	L
		b2. No. of licences (extraction)-volume relative to MAF	S	PD	1-off	H		PD	TBD	4	L

Theme	Content	Measure	Type	Data collection			Data interpretation			Cost	
				Sampling protocol	Frequency	Skill level	Baseline type	Baseline condition	Scoring description	Develop ment	Operational
7	Salinity Regime	Depth profiles at fixed sites (axial salinity distribution)	S	PD	Q	M		PD	PD	3	M
WATER QUALITY											
8	Water clarity	a. Turbidity	S	E	M	M	C2	PD	PD	2	H
9	Dissolved Oxygen	a. DO concentration (mg/L) & % saturation	S	E	M	M	C2	PD	PD	2	H
SEDIMENT											
10	Sediment particle size	a. % of sediment as fines (< 125 µm)	S	PD	1-off	H		TBD	PD	4	L
11	Bank erosion	ISC visual	S	E	1-off	M		PD	E	1	L
12	Sediment Respiration Rate	a. Incubated core tubes (net daily metabolism µmole O2/m2/day)	C	PD	A	H	C2	PD	PD	3	M
FLORA											
13	a. Aquatic Macrophyte	% change from historical/present	C	PD	TBD	H	H & C2	PD	TBD	4	TBD
	b. Aquatic Macroalgae	a. % cover	C	PD	Q	M	C2	PD	TBD	4	M
		b. no. of blooms	C	PD	M	M	C2	E	E	4	H
14	Fringing Macrophyte-	Extent & condition	C	PD	1-off	H	H & C2	PD	PD	3	L
15	Microphytobenthos	Phaeophytin (&/or Chl a) biomass	C	PD	A	H	C2	TBD	PD	4	M
16	Phytoplankton	a. Chlorophyll *a*	C	E	Q	H	C2	PD	PD	2	H

Theme	Content	Measure	Type	Data collection			Data interpretation			Cost	
				Sampling protocol	Frequency	Skill level	Baseline type	Baseline condition	Scoring description	Develop ment	Operational
		b. Cell counts of dominant spp.	C	E	Only if Chl a levels high	H	C2	E	E	2	H
FAUNA											
17	Naturalness of Fish – estuarine use	Observed/expected species	C	PD	TBD	H	C2	TBD	TBD	4	TBD
	Naturalness of Fish - trophic levels	a. Observed/expected representatives of trophic guilds	C	TBD	TBD	H	C2	TBD	TBD	5	TBD
18	Naturalness of Birds	a. Observed/expected estuarine bird guilds	C	TBD	TBD	M	C2	TBD	TBD	5	TBD

Table 8. Feasibility of immediate implementation of recommended measures. Numbers assigned to measures are consistent with those used throughout the report. For some measures there are several components. Scores rate the feasibility of *immediate* implementation from 1 most feasible to 5 least feasible, given the current stage of development of sampling protocols, baseline condition and condition descriptions (see Table 5).

SCORE	PHYSICAL FORM	HYDROLOGY	WATER QUALITY	SEDIMENT	FLORA	FAUNA
1	3. Upstream Barriers (presence, type & location)	5. Marine Exchange- b) structures and behaviours (dredging & training walls)		11. Bank Erosion (ISC method)		
1		6. Freshwater Flow (a.ISC Hydrology mod index)				
2	4. Lateral Connectivity (No. & type of artificial structures on foreshore)	5. Marine Exchange- a) mouth openings (AHD & number)	8. Water Clarity (turbidity)		16. Phytoplankton (Chlorophyll a)	
2			9. Dissolved Oxygen (mg/L & %)		15. Fringing Macrophyte (extent & condition)	
3	2. Sediment load (current vs natural)	7. Salinity Regime		12. Sediment Respiration Rate (incubated core tubes)		
3		6. Freshwater Flow: (b1.no. of structures (dams) standardised by catchment area)				
4	1. Changed Bathymetry	6. Freshwater Flow:b2. No. of licences (extraction)- volume relative to MAF		10. Sediment Particle size	13. Aquatic Macrophyte (% change from historical/present)	17. Naturalness of Fish - estuary use
4					13. Aquatic Macroalgae (% cover)	
4					14. Microphytobenthos (Phaeophytin (&/or Chl a) biomass)	
5						17. Naturalness of Fish - trophic level
5						18. Naturalness of Birds

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5.2 Next steps

The scores assigned to development costs are also useful for comparing the feasibility of immediately implementing each measure (Table 8). With the exception of fauna, some measures in each theme could be implemented immediately while others require further development.

The next steps required prior to a measure being adopted into the IEC will vary depending on the particular measure and its current stage of development. Relevant references and programs to assist with selection of data collection methods and data interpretation are provided for each recommended measure in Section 4. For most measures, condition descriptions for good and poor are provided, however assigning intermediate scores in most cases will require further data collection and analysis. For some measures, where information is available, it is important to ensure that data are collected using protocols that allow valid and accurate comparisons through time and between estuaries and reaches. Scores, and estimates of their distributions will be required for all measures before it is possible to combine measures within sub-indices, or to combine sub-indices into overall condition categories.

A trial of the recommended IEC measures in a selection of estuaries is recommended as it would provide an opportunity to:

- Establish/confirm baseline conditions
- Assess the suggested sampling methodologies, including the delineation and assessment of reaches, for practicality/ efficiency of collection
- Assign and/or refine scores from 0-4 to reflect condition of the measure
- Ensure measures provide a spread of values to allow adequate discrimination between estuaries and also reflect the potential range of estuary condition
- Determine if there are ambiguities in interpreting data
- Investigate options for combining scores (if multiple measures are recommended) in a way that best reflects the condition of the theme content.
- Investigate aggregation and integration methods which best reflect overall estuary condition.

To ensure the measures and condition scores are applicable to all Victorian estuaries it is recommended that trials be conducted on estuaries that represent the range of possible responses to particular threats. In the absence of extensive ecological data for Victorian estuaries, Barton et al (2008) classified estuaries into four groups based on their physical characteristics (Figure 3 & 4;Table 9). These broad physical attributes of estuaries and their estuarine and fluvial (freshwater) catchments were used as proxies for the major drivers (e.g. catchment size and steepness and orientation with regard to wind and current direction) that are likely to influence their ecological functioning. Within each group, estuaries exposed to a range of human threats such as land use, population density, modification to the freshwater flow regime as measured by the hydrology component of ISC levels and freshwater catchment condition, as measured by the ISC score were identified. A trial of the recommended IEC measures should include estuaries from each of the four groups (see Appendix 4) exposed to different levels of threat.

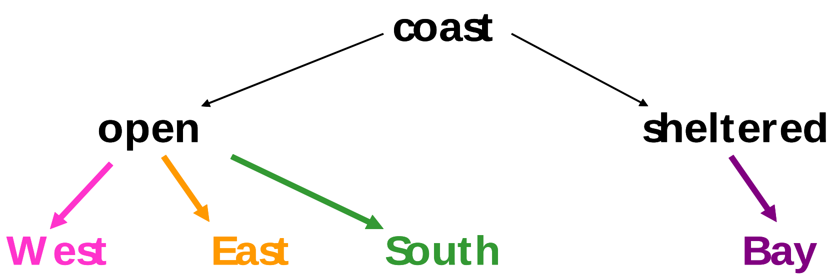

Figure 3 Classification of Victoria's estuaries modified from Barton (2006), based on physical characteristics (source (Barton *et al.*, 2008).

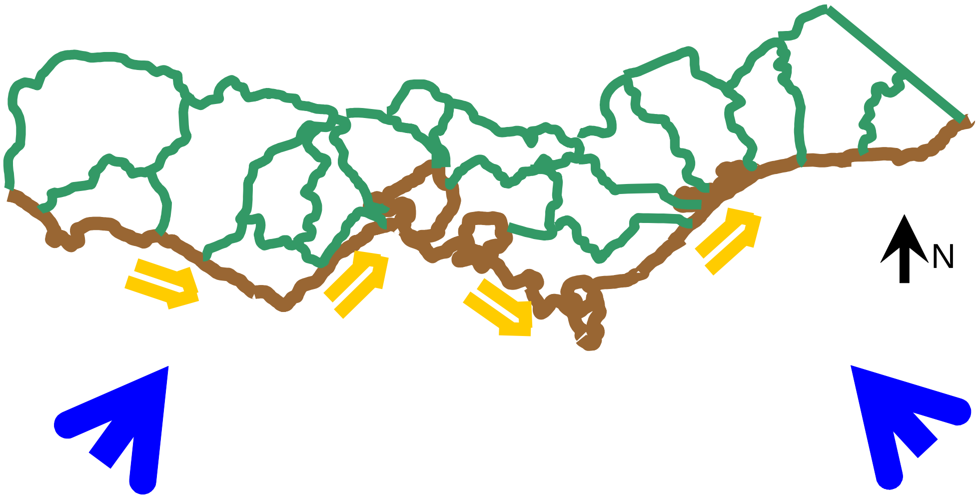

Figure 4. The major physical drivers of catchment size, steepness and orientation (green), wind direction (blue arrows) and long-shore current and sand movement (yellow arrows) that are likely to influence the classification in Figure3 (Source Barton 2008).

Table 9. Descriptions of groups of Victorian estuaries Source Barton et al. 2008

Group	Description
West	W = open, west facing coast. Large to moderate size estuaries & catchments. Intermittent mouth often with lagoon. Sandy, high energy coast facing major weather patterns.
East	E = open, east facing coast. Small, intermittent estuaries with steep catchments. Rocky, moderate energy coast at angle to major weather patterns.
Bay	B = embayment, sheltered coast. Small to moderate, generally permanently open estuaries without lagoons. Flat small to moderate catchments. Muddy, low energy coast with large tides.
South	S = open coast, south facing. Large to moderate size estuaries & catchments. Intermittent mouth often with lagoon. Limited seasonal difference in rainfall. Sandy, moderate energy coast facing major weather patterns.

Acknowledgements

A large number of people contributed to the development of these recommended themes and measures. The time and input of these people is very much appreciated. A list of steering committee members and workshop participants is provided in Appendix 2

Acronyms

CMA	Catchment Management Authority
EEFAM	Estuary Environmental Flows Assessment Methodology
FARWH	Framework for assessment of River and Wetland Health
IEC	Index of Estuary Condition
ISC	Index of Stream Condition
IRC	Index of River Condition
RiVERS	River Values and Environmental Risk System

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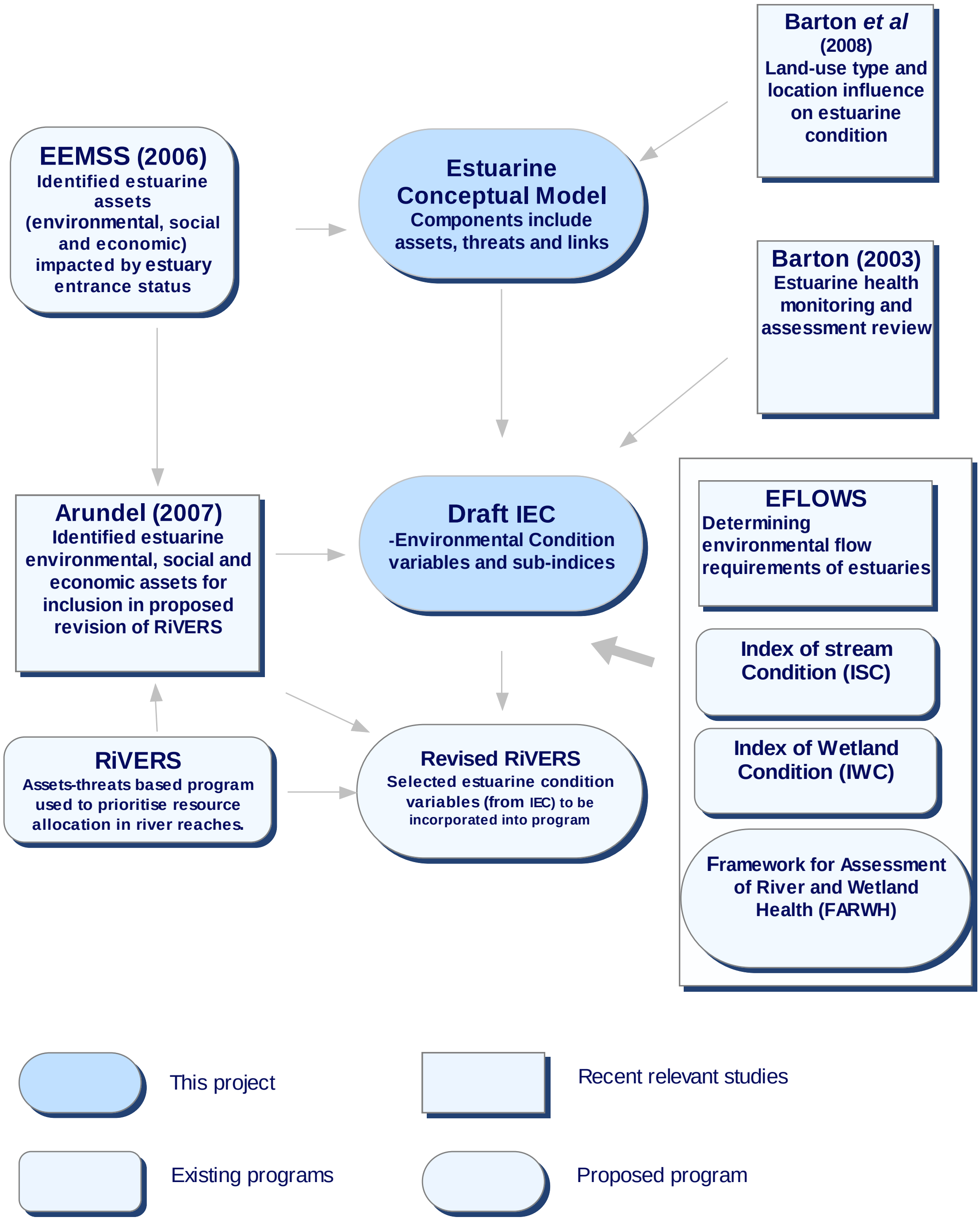
6 Appendices

Appendix 1 Summary of relevant studies and existing or proposed programs and their relationship to an Index of Estuary Condition



Appendix 2. Contributors to the IEC Project

The IEC project was guided by a steering committee with representatives from various agencies.

Steering Committee Members

Name	Agency /Institution
Paul Wilson (project manager)	Department of Sustainability and Environment
Penny Gillespie	Department of Sustainability and Environment
Jeremy Hindell	Department of Sustainability and Environment
Sarina Loo	Department of Sustainability and Environment
Lisa Dixon	Environment Protection Authority Victoria
Anne Casey	Melbourne Water

Participants Workshop 1

Date: June 27, 2008

Venue: Deakin University, Warrnambool

Name	Agency /Institution
Gerry Quinn	Deakin University
Adam Pope	Deakin University
Helen Arundel	Deakin University
Ty Matthews	Deakin University
Alistair Becker	Deakin University
Michael Coates	Deakin University

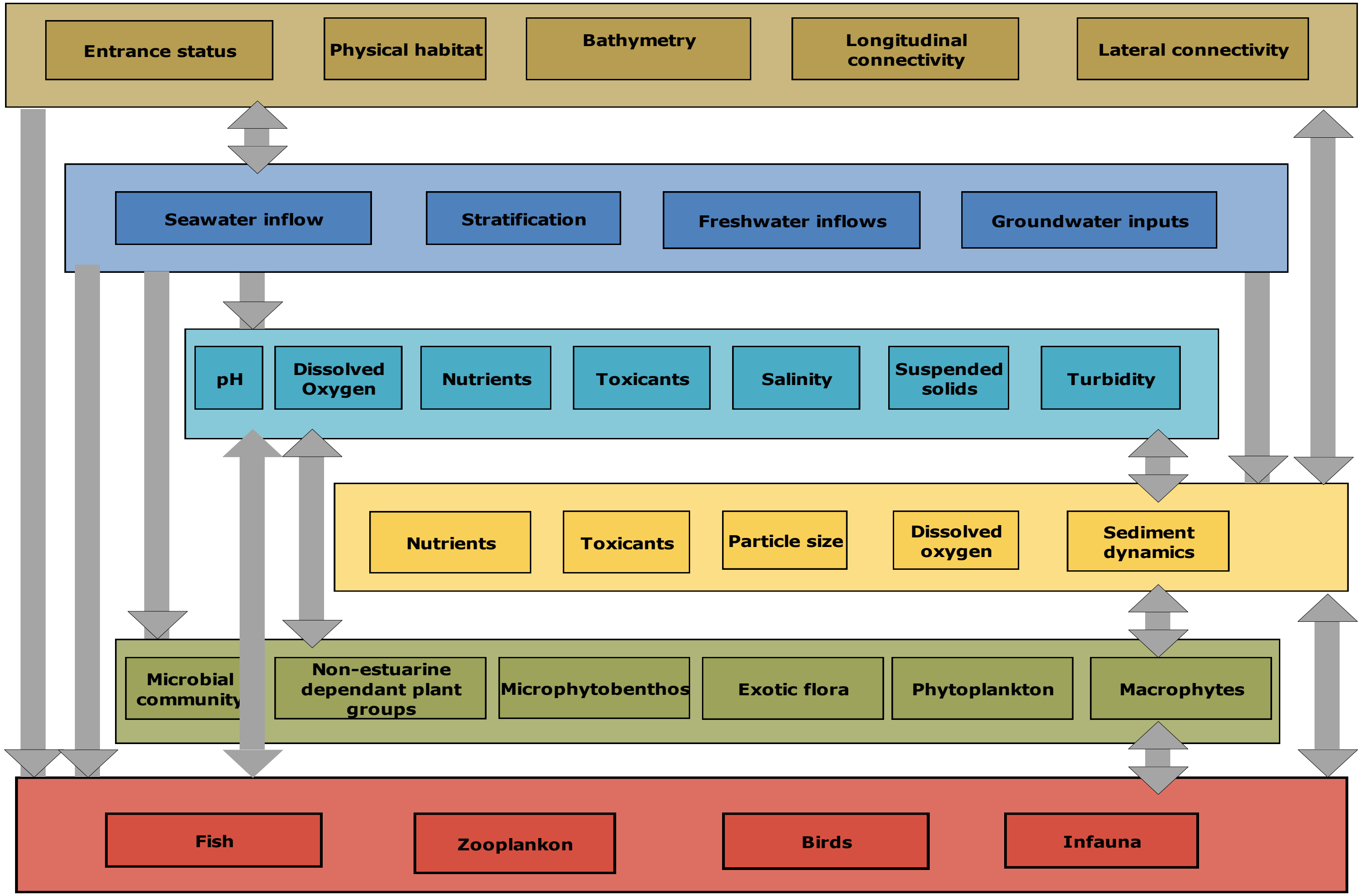
Participants Workshop 2

Date August 21 & 22, 2008

Venue: University College, Melbourne

Name	Agency/Institution
Janine Adams	Nelson Mandela Metropolitan University
Peter Scanes	NSW Department of Environment and Climate Change
Jeremy Hindell	Department of Sustainability and Environment
Vanessa Forbes	WA Department of Water
Mike Weston	Deakin University
Paul Wilson	Department of Sustainability and Environment
Sam Lake	Monash University
Nicole Barbee	University of Melbourne
Tony Roper	NSW Department of Environment and Climate Change
Dave Rissik	EPA QLD
Nina Bate	EPA Vic
David Tiller	Karoo consulting/EPA Vic
Lisa Dixon	EPA Vic
Paul Boon	Victoria University
John Gibson	University of Tasmania
John Sherwood	Deakin University
Jan Barton	Deakin University
Adam Pope	Deakin University
Helen Arundel	Deakin University
Gerry Quinn	Deakin University

Appendix 3. Output from Workshop 1. Conceptual model showing main themes (from top physical form, hydrology, water quality, sediment flora and fauna), content and direction of influence



Appendix 4. Suggested estuaries to be assessed with the IEC. [1]: Gippsland Lakes not included in Barton et. al (2008). *(Region codes: SA – South Australia, CO – Cape Otway, PPB – Port Phillip Bay, WPT – Western Port, WPR – Wilsons Promontory, CI-Corner Inlet/Nooramunga, GL – Gippsland Lakes, NSW – New South Wales.)*

Estuary	Sub-estuaries	Region	Coast type (as per Barton *et al.*, 2008)	ISC/IRC site upstream?
Glenelg R		SA to CO	West-facing	Y
Wattle Hill Ck		SA to CO	West-facing	Y
Surrey R		SA to CO	West-facing	Y
Fitzroy R		SA to CO	West-facing	Y
Eumeralla R		SA to CO	West-facing	Y
Moyne R		SA to CO	West-facing	Y
Merri R		SA to CO	West-facing	Y
Hopkins R		SA to CO	West-facing	Y
Curdies R		SA to CO	West-facing	Y
Campbells Ck		SA to CO	West-facing	Y
Sherbrook R		SA to CO	West-facing	N
Gellibrand R		SA to CO	West-facing	Y
Johanna R		SA to CO	West-facing	N
Aire R		SA to CO	West-facing	Y
Barham R		CO to PPB	East-facing	Y
Wild Dog Ck		CO to PPB	East-facing	N
Kennett R		CO to PPB	East-facing	Y
Wye R		CO to PPB	East-facing	Y
Saint George R		CO to PPB	East-facing	Y
Erskine R		CO to PPB	East-facing	Y
Painkalac Ck		CO to PPB	East-facing	Y
Anglesea R		CO to PPB	East-facing	Y
Spring Ck		CO to PPB	East-facing	Y
Thompson Ck		CO to PPB	East-facing	Y
Barwon R		CO to PPB	East-facing	Y
Swan Bay		PPB	Bay	N
Hovell Ck		PPB	Bay	Y
Little R		PPB	Bay	Y
Werribee R		PPB	Bay	Y
Skeleton Ck		PPB	Bay	Y
Laverton Ck		PPB	Bay	Y
Kororoit Ck		PPB	Bay	Y
Yarra R	Stony Ck, Maribyrnong R, Moonee Ponds Ck	PPB	Bay	Y
Elwood Canal		PPB	Bay	N
Mordialloc Ck		PPB	Bay	Y
Patterson R		PPB	Bay	Y
Kananook Ck		PPB	Bay	Y
Balcombe Ck		PPB	Bay	Y
Merricks Ck		PPB to WPT	East-facing	Y
Cardinia Ck		WPT	Bay	Y

Estuary	Sub-estuaries	Region	Coast type (as per Barton *et al.*, 2008)	ISC/IRC site upstream?
Deep Ck		WPT	Bay	Y
Bunyip R		WPT	Bay	Y
Yallock Ck		WPT	Bay	Y
Yallock drain		WPT	Bay	Y
Lang Lang R		WPT	Bay	Y
Bass R		WPT	Bay	Y
Powlett R		WPT to WPR	West-facing	Y
Anderson Inlet	Screw Ck, Pound Ck, Tarwin R	WPT to WPR	West-facing	Y
Shallow Inlet		WPT to WPR	West-facing	N
Darby R		WPT to WPR	West-facing	N
Tidal R		WPT to WPR	West-facing	Y
Growlers Ck		WPT to WPR	West-facing	N
Sealers Ck		WPR to CIN	East-facing	N
Chinaman Ck		CIN	Bay	N
Old Hat Ck	Poor Fellow Me Ck	CIN	Bay	N
Stockyard Ck		CIN	Bay	N
Bennison Ck		CIN	Bay	Y
Franklin R		CIN	Bay	Y
Agnes R		CIN	Bay	Y
Shady Ck		CIN	Bay	N
Nine Mile Ck		CIN	Bay	Y
Albert R	Muddy Ck	CIN	Bay	Y
Tarra R		CIN	Bay	Y
Neil's Ck		CIN	Bay	N
Bruthen Ck		CIN	Bay	Y
Jack Smith Lake		CIN to GL	East-facing	N
Lake Dennison		CIN to GL	East-facing	N
Merriman Ck		CIN to GL	East-facing	Y
Latrobe R	Thomson R?	GL	Bay[1]	Y
Lake Wellington Main Drain		GL	Bay[1]	N
Diamond Ck		GL	Bay[1]	N
Avon R	Perry R	GL	Bay[1]	Y
Toms Ck		GL	Bay[1]	Y
Forge Ck/Newlands Arm		GL	Bay[1]	Y
Mitchell R	Clifton Ck	GL	Bay[1]	Y
Nicholson R		GL	Bay[1]	Y
Slaughterhouse Ck		GL	Bay[1]	N
Tambo R		GL	Bay[1]	Y
Stock Ck		GL	Bay[1]	N
Mississippi Ck		GL	Bay[1]	N
Bunga R		GL to NSW	South-facing	N
Lake Tyers		GL to NSW	South-facing	Y
Snowy R		GL to NSW	South-facing	Y

Estuary	Sub-estuaries	Region	Coast type (as per Barton *et al.*, 2008)	ISC/IRC site upstream?
Yeerung R		GL to NSW	South-facing	Y
Sydenham Inlet		GL to NSW	South-facing	Y
Tamboon Inlet		GL to NSW	South-facing	Y
Thurra R		GL to NSW	South-facing	Y
Mueller R		GL to NSW	South-facing	N
Wingan Inlet		GL to NSW	South-facing	Y
Easby Ck		GL to NSW	South-facing	N
Red R		GL to NSW	South-facing	N
Benadore R		GL to NSW	South-facing	N
Seal Ck		GL to NSW	South-facing	N
Shipwreck Ck		GL to NSW	South-facing	N
Betka R		GL to NSW	South-facing	Y
Davis Ck		GL to NSW	South-facing	N
Mallacoota Inlet	Double Ck, Genoa R, Wallagaraugh R, Teal Ck Dowell Ck, Harrison Ck	GL to NSW	South-facing	Y

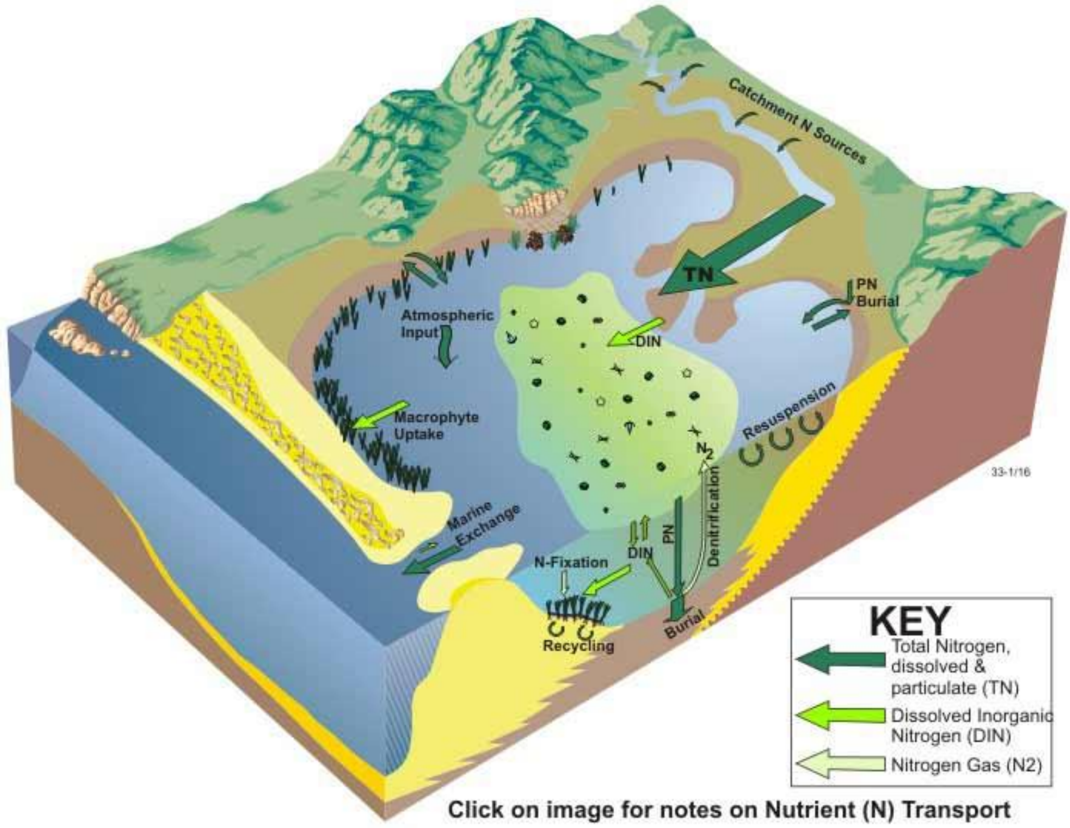
Appendix 5. Comparison of Draft IEC Sub-indices and indicators with other assessment programs and projects

Index of Stream Condition ISC (Victoria)	**Draft IEC**	**Framework for assessment of river and wetland health (FARWH). (National).** **Themes in italic were recommended for inclusion if framework was to be used for estuary assessment**	**Index of Wetland Condition IWC (Victoria)**	**Streams & Estuaries Assessment Program. (VIPSIRR) (Queensland)**	**Estuarine threats (Barton *et al* 2008) (Victoria)**
Physical form	**Physical Form**	**Physical form and processes.**	**Physical Form**	**Sediment load**	**Entrance Modification**
Large Wood; Fish Barriers	Sediment load Changed bathymetry Upstream barriers Lateral connectivity	Bedload condition, (compared with pre-1750 condition, and connectivity (comparison with no dam, levee diversion or pumping regime)	% reduction in wetland area. % of wetland where activities have resulted in a change in bathymetry	Total sediment load (kg/yr/m3) cleared surface (%) Erodibility of catchment soils (%) Estuary flushing time days Tidal range m	Training walls, dredging, artificial opening
	Sediment		**Soils**		
	Sediment respiration rate Sediment particle size % fine fraction Bank erosion (as per ISC)		% & severity of wetland soil disturbance		
Water quality	**Water quality**	**Water (and sediment) quality**	**Water properties**	**Nutrients**	
Phosphorus; Turbidity; Salinity; pH;	Clarity (turbidity, Secchi depth, vertical variation in PAR) Dissolved oxygen	Basin scale - four indices; SS, TP, TN and salinity. Reach scale- three indices; SS, TN and TP.	Activities leading to input of nutrients (N & P). Factors likely to lead to wetland salinisation or wetland occurs in salinity risk area	Total P load Total N load Estuary flushing time (days) Event based rainfall runoff /estuary volume	

				Chlorophyll a (µg/L) Macroalgal extent %-	
		Marine connectivity			
Hydrology	**Hydrology**	**Hydrological change**	**Hydrology**	**Hydrodynamics**	**Hydrological change**
Low Flows: High Flows; Zero Flows; Seasonality; Variability	Flow-ISC hydrology score Flow-presence of modifying structures (dams) or extraction Marine exchange-a. height and b. number of artificial openings Marine exchange- presence of structures and behaviours Salinity regime?	Deviation from mean annual flow, Change to the flow duration curve, Change to seasonal amplitude and periodicity; Changes to water regime timing, frequency, extent & depth and variability, including groundwater contribution	Severity of activity that changes the water regime	% of estuary modified (channels, walls etc); Presence of structures/behaviours that modify flow Change to tidal extent/velocity (1-3) Change to sedimentation/deposition (1-3)	Dams, weirs, extraction, ISC Hydrology score
Streamside zone	**Flora**	**Fringing zone**	**Wetland Catchment**	**Habitat removal**	
Width; Longitudinal Continuity; Understorey; Recruitment; Large Trees; Tree Canopy cover; leaf litter; Logs; Weeds	Aquatic extent –seagrass Aquatic extent-macroalgae Habitat quality intactness Microphytobenthos Phytoplankton-Chla & cell counts of dominant groups	(i.e. Includes 100m beyond riparian). Includes riparian biota condition and riparian vegetation condition	Average width of buffer % of wetland perimeter with a buffer % of land in different intensity land use classes adjacent to the wetland.	% habitat modified (includes intertidal, subtidal and floodplain) Dispersal range compared with patch distance (1-5) Abundance of expected species (1-5)	
Aquatic life	**Fauna**	**Biota**	**Biota**		
AUSRIVAS; SIGNAL	Naturalness of Fish –a. trophic levels b. species Naturalness of birds- no. of species in expected guilds.	Comparison with biota in near pristine environments. Ideally several would be used e.g. invertebrates, but also	Wetland vegetation quality based on : Critical life forms Presence of weeds Indicators of altered	See 'Habitat removal' condition measure – 'abundance of expected species'	

		fish water plants algae and riparian vegetation	processes Vegetation structure and health		
		Catchment disturbance			**Catchment land-use**
		Land use, land cover change and infrastructure.			Fluvial & estuarine catchment land use
					Coastal development
					Built infra structure; estuarine catchment land use, population density, habitat occurrence
		Waterway activities			**Recreational & commercial use**
					Fishing, ports; boating

Appendix 6. Nitrogen dynamics in wave-dominated estuaries



Nitrogen dynamic processes in embayments and drowned river valleys

1. Catchment nitrogen sources

Nitrogen, both particulate and dissolved or total nitrogen, enters the embayment system from point- and non-point sources from within the catchment. River flow and nutrient input varies regionally, depending on local catchment and climatic conditions (Harris, 2001).

2. Processing of nitrogen by phytoplankton

The catchment-derived dissolved inorganic nitrogen is transported into the embayment, where it is rapidly processed and assimilated by phytoplankton and benthic micro-algae, if temperature and light levels are suitable (Elosegui et al., 1987, Nicholson et al., 1999, Longmore et al., 1999).

3. Deposition and burial of particulate nitrogen

Some deposition and burial of particulate nitrogen occurs on flanking environments, due to wave-induced landward sediment transport, depending on exposure to oceanic swells, and tidal deposition aided by the baffling effects of saltmarsh and/or mangrove vegetation, depending on latitude. Burial and resuspension of particulate nitrogen and dissolved inorganic nitrogen can also occur within intertidal flats.

4. Uptake of nitrogen by marine algae

Seagrasses and macrophytes take up dissolved inorganic nitrogen from the water column. Nitrogen-fixation occurring in the root-zone of seagrasses contributes additional dissolved inorganic nitrogen to this pool. Denitrification is also an important process in seagrass meadows (Pollard et al., 1991). Sandy sediment is permeable, hence can be ventilated by oxygen-rich overlying waters resulting in efficient remineralisation of organic debris (mostly by denitrification) with little preservation of organic matter.

5. Upwelling of nutrient-rich waters

Upwelling of nutrient-rich waters can introduce nitrogen to the embayment system, however typically in low quantities (Cresswell, 1994).

6. Atmospheric inputs

Input of particulate nitrogen from atmospheric sources such as smoke and ash are typically of low significance.

7. Large tidal **prism and exchange of marine waters**

A large tidal prism results in much of the dissolved and particulate nitrogen, including phytoplankton debris, being transported offshore (Bulthuis et al., 1984), and diluted by seawater.

Appendix 7. Estuarine and adjacent freshwater EVCs - current and previous classification (Source EEMSS (2006))

Current estuarine EVC	EVC No.	Previous EVC (may appear in DSE mapping)	EVC No.
Coastal Saltmarsh	009	Same	
Estuarine Wetland	010	Same (but see below)	
Brackish Sedgeland	013	Estuarine Wetland	010
Mangrove Shrubland	014	Same	
Seasonally Inundated Sub-saline Herbland	196	Same	
Brackish Herbland	538	Brackish Wetland	656
Saline Aquatic Meadow	842	Same	
Seagrass Meadow	845	Same	
Estuarine Flats Grassland	914	Coastal Tussock Grassland	163
Brackish Grassland	934	Coastal Tussock Grassland	163
Estuarine Reedbed	952	Estuarine Wetland	010
Estuarine Scrub	953	Estuarine Wetland (Gippsland) Swamp Scrub	010 053
Littoral Rainforest	new	N/A	
Non-vegetated	990	Same	
Freshwater EVCs			
Coastal Lagoon Wetland	011	Same	
Swamp Scrub	053	Same	
Tall Marsh	821	Reed swamp	
Blocked Coastal Stream Swamp	875	Same	
Warm Temperate Rainforest	032	Same	
Damp Sands Herb-rich Woodland	003	Same	