Eutrophication Index Methods Port Phillip Bay

May 2023

VICTORIA State Government | Energy, Environment and Climate Action

Author

Rhiannon Holden | Marine Spatial Analyst

Lawrance Ferns | Marine Knowledge Manager

Regan East | Marine Biodiversity Policy Officer

Dr. Tessa Mazor | Marine Spatial Analyst

Laura Town-Hopkinson | Marine Spatial Analyst

Marine Knowledge Unit | Biodiversity Protection and Information | Biodiversity Division | Environment, Climate Action and First Peoples | Department, of Energy, Environment and Climate Action

Citation

DEECA (2023) Eutrophication Index. The State of Victoria Department of Energy, Environment and Climate Action 2023

Photo credit

Merri Creek, VIC © Rhiannon Holden

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it.

We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

DEECA is committed to genuinely partnering with Victorian Traditional Owners and Victoria's Aboriginal community to progress their aspirations.

ISBN 978-1-76136-408-2 (**pdf/online/MS word**)

Accessibility

To receive this document in an alternative format, phone the Customer Service Centre on 136 186, email customer.service@delwp.vic.gov.au, or contact National Relay Service on 133 677. Available at DEECA website (www.deeca.vic.gov.au).

Contents

OFFICIAL

List of acronyms and abbreviations

ANZG	Australian and New Zealand Guidelines
AUSIRVAS	Australian River Assessment System
BGA	Blue Green Algae (event)
Chl- *a*	Chlorophyll *a*
CM	Confidence Metric
CMAs	Catchment Management Authorities
COMP	Common Procedure (OSPAR)
DEECA	Department of Energy, Environment, and Climate Action (Victoria)
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorous
DO	Dissolved Oxygen
EMP	Port Phillip Bay Environmental Management Plan 2017-2027
EPA	Environment Protection Authority (Victoria)
EPT	Ephemeroptera, Plectoptera, and Trichoptera
ER	Eutrophication Ratio
ERS	Environment Reference Standards
EU	European Union
GES	Good Environmental Status
HABs	Harmful Algal Blooms
HEAT+	HELCOM Eutrophication Assessment Tool (pan-European assessment)
HELCOM	Helsinki Commission
HWS	Melbourne Water Healthy Waterways Strategy 2018-28
IEC	Index for Estuarine Condition
ISC	Index of Stream Condition
MACA	*Marine and Coastal Act 2018*
MACKF	Marine and Coastal Knowledge Framework
MBI	Marine Biodiversity Index
MERI	Monitoring, Evaluation, Reporting, and Improvement (plan)
MW	Melbourne Water
NRHP	National River Health Program
OSPAR	Oslo/Paris convention for the Protection of the Marine Environment of the North-East Atlantic

PPB	Port Phillip Bay
SEPP	State Environment Protection Policy (Waters) 2018 (replaced by Environment Reference Standards 2021)
STP	Sewage Treatment Plant
TLI	Trophic Level Index
TN	Total Nitrogen
TP	Total Phosphorous
TRG	Technical Reference Group
TSI	Trophic State Index
UN	United Nations
US EPA	United States Environmental Protection Agency
VFA	Victorian Fisheries Authority
VSQAP	Victorian Shellfish Quality Assurance Program
WIP	Water Intelligence Platform (DEECA)
WQI	Water Quality Index (EPA)
WTP	Western Treatment Plant
WMIS	Water Measurement Information System

Acknowledgements

We acknowledge the contributions of the following people and organisations to development of the Eutrophication Index methodology paper that have provided their feedback, advice, and comments:

Dr Matt Edmunds (Australian Marine Ecology), Dr Adrian Flynn (Fathom Pacific), Giorgia Cecino (Fathom Pacific), Dr Alastair Hirst (EPA), Dr Randall Lee (EPA), Bernard Barbetti (Department of Energy, Environment and Climate Action).

We would also like to acknowledge the provision of data from the following organisations to inform the assessment:

Environment Protection Authority (Victoria), Victorian Fisheries Authority, Victorian Shellfish Quality Assurance Program, WaterWatch Victoria and Melbourne Water.

OFFICIAL

1. Purpose

This document on the Eutrophication Index has been prepared for the Port Phillip Bay Environmental Management Plan 2017-2027 (EMP). It identifies an evaluation methodology for reporting on nutrient inputs and responses to mitigate the potential risk of eutrophication in Port Phillip Bay (PPB) and its catchments. Adopting an integrated ecosystem-based approach, indicators for reporting on the status, trends, and condition of key ecosystem components have been identified and selected for use in an annual report card. The delivery of the report card will support future management decisions, promote adaptive improvements, and ensure that the vision of the EMP is met.

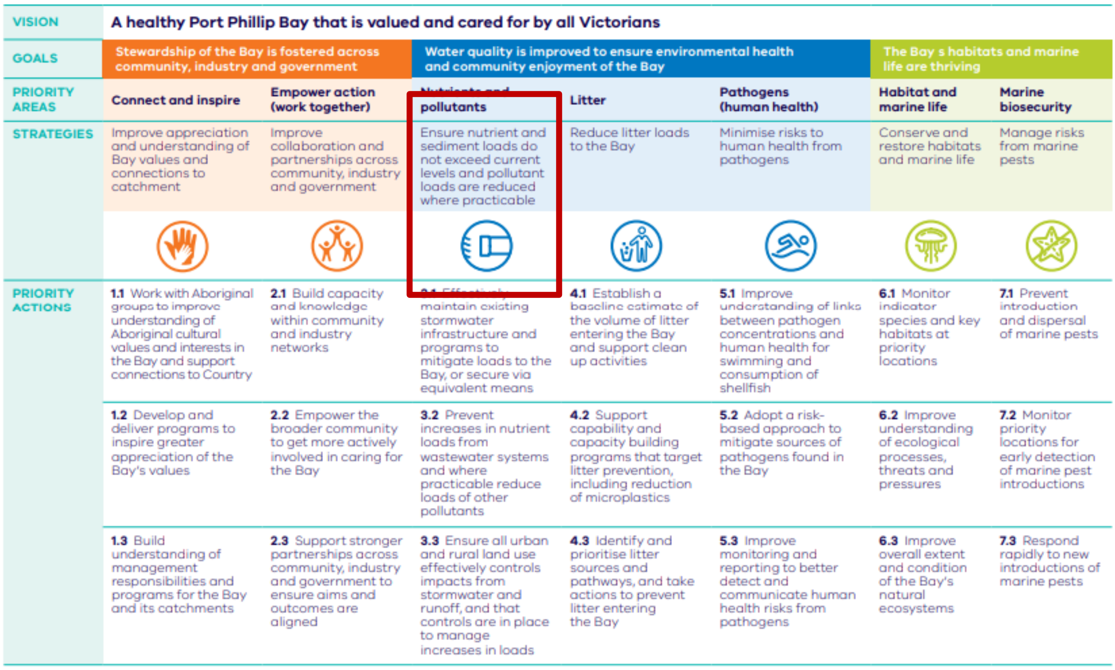
This paper outlines the proposed use of the Eutrophication Index to provide an integrated status assessment to deliver on a set of outcomes. The index will support the delivery of the nutrient and pollutants priority area's strategy to 'Ensure nutrients and sediments loads do not exceed current levels and pollutant loads are reduced where practicable' and is structured under the water quality goal in the EMP.

2. Introduction

2.1 Policy Context

The EMP is authorised under the *Marine and Coastal Act 2018* (MACA). The MACA, section 55 (1) specifies environmental management plans must be reviewed within five years of making the plan.

The EMP's Monitoring, Evaluation, Reporting and Improvement plan (MERI) will guide the five-yearly evaluation through an assessment of the effectiveness and efficiency of the EMP's strategies (Figure 1). As part of this, the EMP MERI will assess the effectiveness of the EMP in delivering on all three overarching goals, of particular relevance in this paper is the second goal of 'Water quality is improved to ensure environmental health and community enjoyment of the Bay'.



VISION	A healthy Port Phillip Bay that is valued and cared for by all Victorians						
GOALS	Stewardship of the Bay is fostered across community, industry and government		Water quality is improved to ensure environmental health and community enjoyment of the Bay			The Bay s habitats and marine life are thriving	
PRIORITY AREAS	Connect and inspire	Empower action (work together)	Nutrients and pollutants	Litter	Pathogens (human health)	Habitat and marine life	Marine biosecurity
STRATEGIES	Improve appreciation and understanding of Bay values and connections to catchment	Improve collaboration and partnerships across community, industry and government	Ensure nutrient and sediment loads do not exceed current levels and pollutant loads are reduced where practicable	Reduce litter loads to the Bay	Minimise risks to human health from pathogens	Conserve and restore habitats and marine life	Manage risks from marine pests
PRIORITY ACTIONS	**1.1** Work with Aboriginal groups to improve understanding of Aboriginal cultural values and interests in the Bay and support connections to Country	**2.1** Build capacity and knowledge within community and industry networks	**3.1** Effectively maintain existing stormwater infrastructure and programs to mitigate loads to the Bay, or secure via equivalent means	**4.1** Establish a baseline estimate of the volume of litter entering the Bay and support clean up activities	**5.1** Improve understanding of links between pathogen concentrations and human health for swimming and consumption of shellfish	**6.1** Monitor indicator species and key habitats at priority locations	**7.1** Prevent introduction and dispersal of marine pests
	1.2 Develop and deliver programs to inspire greater appreciation of the Bay's values	**2.2** Empower the broader community to get more actively involved in caring for the Bay	**3.2** Prevent increases in nutrient loads from wastewater systems and where practicable reduce loads of other pollutants	**4.2** Support capability and capacity building programs that target litter prevention, including reduction of microplastics	**5.2** Adopt a risk-based approach to mitigate sources of pathogens found in the Bay	**6.2** Improve understanding of ecological processes, threats and pressures	**7.2** Monitor priority locations for early detection of marine pest introductions
	1.3 Build understanding of management responsibilities and programs for the Bay and its catchments	**2.3** Support stronger partnerships across community, industry and government to ensure aims and outcomes are aligned	**3.3** Ensure all urban and rural land use effectively controls impacts from stormwater and runoff, and that controls are in place to manage increases in loads	**4.3** Identify and prioritise litter sources and pathways, and take actions to prevent litter entering the Bay	**5.3** Improve monitoring and reporting to better detect and communicate human health risks from pathogens	**6.3** Improve overall extent and condition of the Bay's natural ecosystems	**7.3** Respond rapidly to new introductions of marine pests

Figure 1: The EMP framework and the location of the 'Nutrients and Pollutants' priority area under the overarching goal of 'Water quality is improved to ensure environmental health and community enjoyment of the Bay'.

At end of June 2021, there are 277 activities listed in the EMP's Delivery Plan. Of these there are 68 activities that are contributing to the goal of water quality, with 31 dedicated to the nutrients and pollutants priority area.

To evaluate the effectiveness of this work, the following outcomes for the nutrients and pollutants priority area are proposed:

- No net increase in nutrient and sediment loads ERS load targets are met, and pollutant loads are reduced where practicable.
- No net increase in harmful algal blooms (HABs) due to poor water quality and pollution. Benchmark to be established.
- The level of nutrients and sediments support the maintenance or improvement of the current cover, extent, and condition of seagrasses, within the bounds of natural variation.

The Eutrophication Index provides an overall scoring metric for these outcomes, whereby these outcomes have been determined in consultation with the EMP water quality working group.

2.2 Eutrophication background

Eutrophication in our waterways, coastal seas and oceans poses the most widespread water quality issue globally (UN, 2014). The European Commission defines eutrophication as a process by which excess high-nutrient loads enter the ecosystem from varying point and diffuse sources, leading to increased primary productivity and in turn encouraging algal growth in the form of harmful algal blooms. This can have adverse effects in terms of change shifts in biodiversity, reductions in water quality, public health risks and diminished potential for ecosystem services (Directive 2008/56/EC).

OFFICIAL

The primary pathways of nutrient pollution include non-point sources- agricultural, stormwater and waste runoff, and point sources - sewage outfalls, industrial effluent, in addition to atmospheric inputs from non-renewable burning emissions and bushfires (UN, 2014). The entry of nutrients into systems has been accelerated by multiple practices such as vegetation clearance that enhances the erosion of sediment and retention of nutrients, urbanisation in terms of the creation of impervious surfaces such as driveways and roads which alters flow regimes and correlates with flooding potential, changes in land-use over time and the rise of intensification in the agricultural sector and fertiliser usage on arable land (SOE, 2016).

The Australian State of Environment Report (2016) states that nutrient pollution can lead to a wide range of negative environmental consequence including:

- Eutrophication, harmful algal bloom events and high turbidity
- Low oxygen dead zones or hypoxic events which can eventuate in fish kills
- Disruptions in nutrient and biogeochemical cycling
- Invasive and overabundant species outbreaks such as opportunistic seaweeds and epiphytes
- Macrophyte cover loss and shifts in species distributions.

In the CSIRO 1997 PPB Environmental Study (PPBES) it was concluded that PPB demonstrated a relatively healthy condition showing no evidence for the onset of eutrophication due to the high productivity levels of microphytobenthos in sediments, responsible for recycling nutrients and enhancing oxygen levels. The modelling in the PPBES predicted that if nitrogen loading continues to increase then the sedimentary denitrification potential could be reduced to a point that would lead to the permanent eutrophication of PPB.

Hence nutrient loadings to PPB is of primary concern and management priority to ensure the mitigation of eutrophication. Eutrophication can be used as indicator for the overall condition and state of PPB. The Eutrophication Index has been developed in response to the following recommendations and considerations that indicate the need for a long-term monitoring program:

- The presence of complex linkages between ecosystem compartments, the water column, and benthic processes with the need to determine biological trigger points that could result in irreversible phase shifts (Flynn, 2021).
- Feedback loops associated with the nutrient cycling system are poorly understood in aquatic ecosystems, with relation to the denitrification efficiency, microphytobenthos distributions, and benthic macrofaunal assemblages (CSIRO, 1997).
- The need for a catchment-based approach for reporting to ensure PPB and its catchments as seen as an integrated (CSIRO, 1997). Historically management has been compartmentalised across terrestrial waterways, riverine catchments, and the marine receiving environment. The EMP is driving a multi-stakeholder PPB which aligns with the Victorian Waterway Management Strategy that aims to maintain or improve the condition of rivers, estuaries, and wetlands under a single framework (DELWP, 2013).
- Existing indices for reporting on water quality in Victoria do not currently fully integrate the sequential effects and biological responses resulting from changes in nutrient levels.
- Harmful algal blooms or blue-green algae events are currently responded to on an emergency basis, the Eutrophication Index proposes a dynamic and adaptive reporting framework to move away from diagnostic management strategies. The index will

improve the capacity to detect risks posed by eutrophication through utilising biological first responses to inform and predict the spatial extent, magnitude, and zones of potential influence.

Eutrophication and susceptibility to nutrient pollution in PPB are driven by following factors:

- Population growth of Greater Melbourne with a current population of 5 million people (ABS, 2020).
- The unique geography of PPB means waters are retained in the inlet for up to 400 days (CES, 2016).
- The location of two sewage treatment plants (STP) around PPB with outfall discharges into PPB include: The Western Treatment Plant (WTP) and Altona Treatment Plant.
- The influx of waters entering PPB from eight major rivers and creeks, in addition to multiple stormwaters drain outlets.

2.3 Existing water quality indices and frameworks

There are several existing strategies and programs across the PPB region and statewide that focus on improving the health of bays, rivers, wetlands, and estuaries. For the purposes of this report and relevance to the Eutrophication Index these include the following:

- Healthy Waterways Strategy 2018-28 (HWS) delivered by Melbourne Water (MW).
- Water Quality Index (WQI) developed by the Environment Protection Authority (EPA) and published report cards in the Water Quality Report Card .
- Victoria's Regional Water Monitoring Partnerships' Program managed by Department of Energy, Environment and Climate Action (DEECA).
- Index of Stream Condition (ISC) produced by DEECA and Catchment Management Authorities (CMAs).
- Index of Estuarine Condition (IEC) reported on by DEECA.
- WaterWatch Citizen Science Monitoring Program supported by DEECA and MW.

Implementation of long-term targets and defined performance objectives ensure that the condition of our waterways across Victoria are on a path to recovery. Report cards and data portals are commonly employed to publicly display the annual progression of metrics against specific benchmarks and thresholds. Further detail on Victorian Water Quality Indices and frameworks can be found in Appendix 1: Water quality indices & frameworks.

2.4 Eutrophication Index concept

The establishment of a Eutrophication Index for PPB has been prompted by the EMP MERI's requirement for a data-driven integrated approach for assessing eutrophication impacts. Eutrophication indices or equivalent nutrient enrichment metrics have been implemented globally, however few are applied to both coastal waters and freshwater systems.

The Australian & New Zealand Guidelines (ANZG) for Fresh and Marine Water Quality promote the 'weight of evidence' approach when selecting indicators. This involves the combination of qualitative, semi-quantitative, or quantitative evidence to make an overall assessment of water quality. It is recommended that the indicators measure a cause-and-effect pathway across the pressure–stressor–ecosystem receptor causal pathway, which supports pressure-state-response management models. This model provides a greater certainty to assessment conclusions and allows for management decisions to be made to meet water quality objectives (ANZG, 2018).

OFFICIAL

Victoria's Marine and Coastal Knowledge Framework (MACKF) was developed in 2017 following the recommendation by the Victorian Commissioner for Environmental Sustainability in the State of the Bays 2016 report (COE, 2016) and is a requirement of the Marine and Coastal Policy 2020 (DELWP, 2020). The MACKF employs an outcome-based reporting approach and uses metrics as described by 11 Good Environmental Status (GES) descriptors, whereby eutrophication has been listed and can be defined as 'Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters' (DELWP, 2021b).

The Eutrophication Index will:

- Assist with the prioritisation of management investment to alleviate stresses on the ecosystem as posed by nutrient enrichment.
- Present an aligned approach to reporting on eutrophication across PPB and the catchment.
- Provide a robust and integrated index to capture the effects of nutrient enrichment.
- Analyse long-term trend data to identify areas of concern and highlight necessary improvements or abatement measures.
- Promote collaborate partnerships and approaches to monitoring and reporting on eutrophication.
- Operationalise a decision support tool to spatially inform management decisions.

The development of the methodology for the Eutrophication Index for PPB has been primarily influenced by two European initiatives:

- The thematic assessment of eutrophication status and HEAT+ tool produced by the Baltic Marine Environment Protection Commission or Helsinki Commission (HELCOM).
- The Common Procedure (COMP) approach developed by the Convention for the Protection of the Marine Environment of the North-East Atlantic or Oslo and Paris Convention (OSPAR).

Both integrated approaches utilise a hierarchical nested structure to categorising and weighting indicators which is based on three criteria: 1) Nutrient levels, 2) Direct effects, and 3) Indirect effects. The categories link nutrient loading in-line with budgets or thresholds, encompass eutrophication signals and responses as well as factoring in biological productivity to produce a robust assessment for identifying cause-and-effect pathways. A similar structure for reporting has been adopted in PPB to correspond with the ANZG pressure-stressor-ecosystem receptor management model.

In addition to the HELCOM and OSPAR methods, key aspects of Trophic State Index (TSI) for lakes and reservoirs developed by the United States Environmental Protection Agency (US EPA) and the Trophic Level Index (TLI) for assessing the health of lakes implemented in New Zealand have been integral in informing the eutrophication related variables to adopt, apparent measures and scoring categories. More information can be found on each of the index examples in Appendix 1: Water quality indices & frameworks.

2.5 Eutrophication zone models

Bayesian Network Models have been developed for DEECA in 2023 designed to predict the potential for eutrophication in six marine and coastal receiving habitats specific to PPB (BI, 2023). These zones include:

- Littoral sediment platform
- Littoral rock

- Near shore sediments
- Subtidal rock
- Intermediate sediments
- Mud basin.

The models for each zone are represented by nodes and directed links, capture the anthropogenic and biological input sources of nitrogen, pathways for the cycling and flow of nitrogen in the system, and identification of outputs and eutrophication indicators. Responses regardless of magnitude and the negative or positive directional effect have qualitatively been parameterised to clearly define relationships and describe interactions. Further development in this space could involve stakeholder-led weighting of parameters to produce probabilistic graphical models.

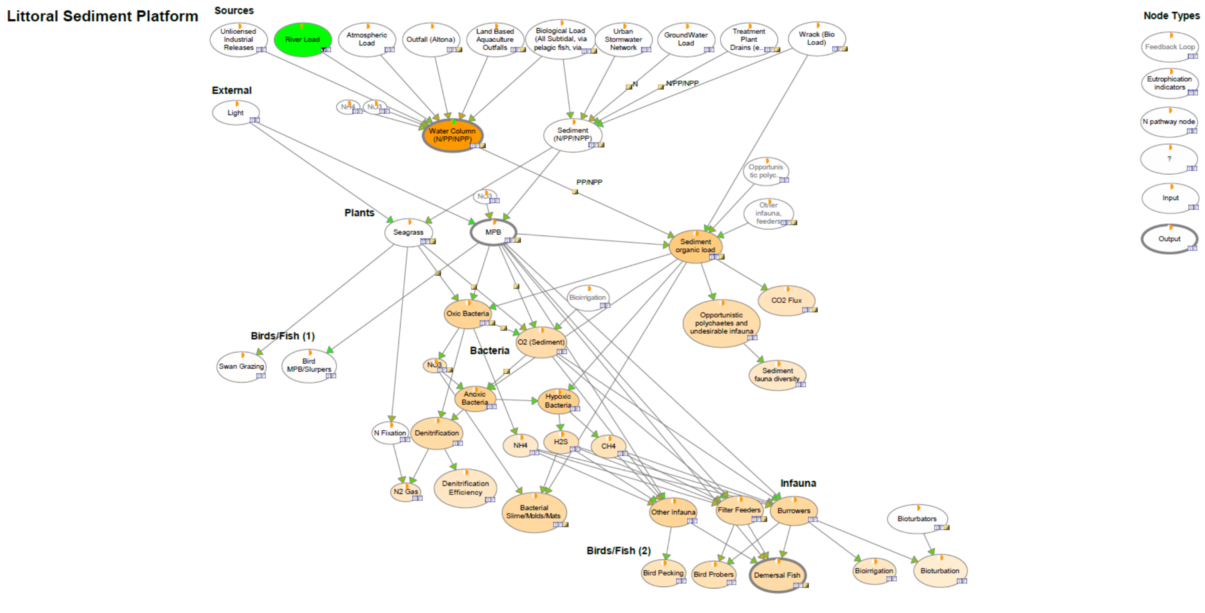


Figure 2: Example Bayesian Network model showing the Littoral Sediment Platform zone interactions with river load inputs. Nodes coloured white indicate no probability of change. Nodes coloured orange indicate a moderate to strong possibility of change and those coloured green a near to certain probability of change (BI, 2023).

Results from these models have informed the selection of metrics for each category grouping in the Eutrophication Index for PPB. In addition to this, the models will assist with understanding how and where to allocate investment to mitigate the effects of nitrogen from various sources. To deliver these models, Bayesian Intelligence ran a series of workshops with Australian Marine Ecology and Fathom Pacific with support provided by DEECA. The results from this exercise can be found in Appendix 4: Eutrophication zone models.

3. Structure of the Eutrophication Index

3.1 Categories, indicators, and metrics

3.1.1 Overview

The Eutrophication Index has been developed to be a multi-parametric index comprising of ten indicators which have been classified into three categories. Category I: Nutrient levels, Category II: Direct effects, and Category III: Indirect effects as represented in the below

OFFICIAL

schematic diagram (Figure 3), which in turn aggregate up to the overall eutrophication status or index. The indicators have been divided into core and secondary criterion, whereby the index calculations should be based on the core indicators as a minimum for assessment.

The ERS outlines environmental values such as water dependant ecosystems and species that apply to surface waters: marine, riverine, and estuarine, as well as noting the degree of modification in the subsegments. For the Eutrophication Index indicators and target values have been selected based on the agreed ERS objectives for each relevant segment, denoting the units for measurement, parameters used for calculations, metrics, percentile targets and the monitoring data available in 4. Eutrophication assessment methodology

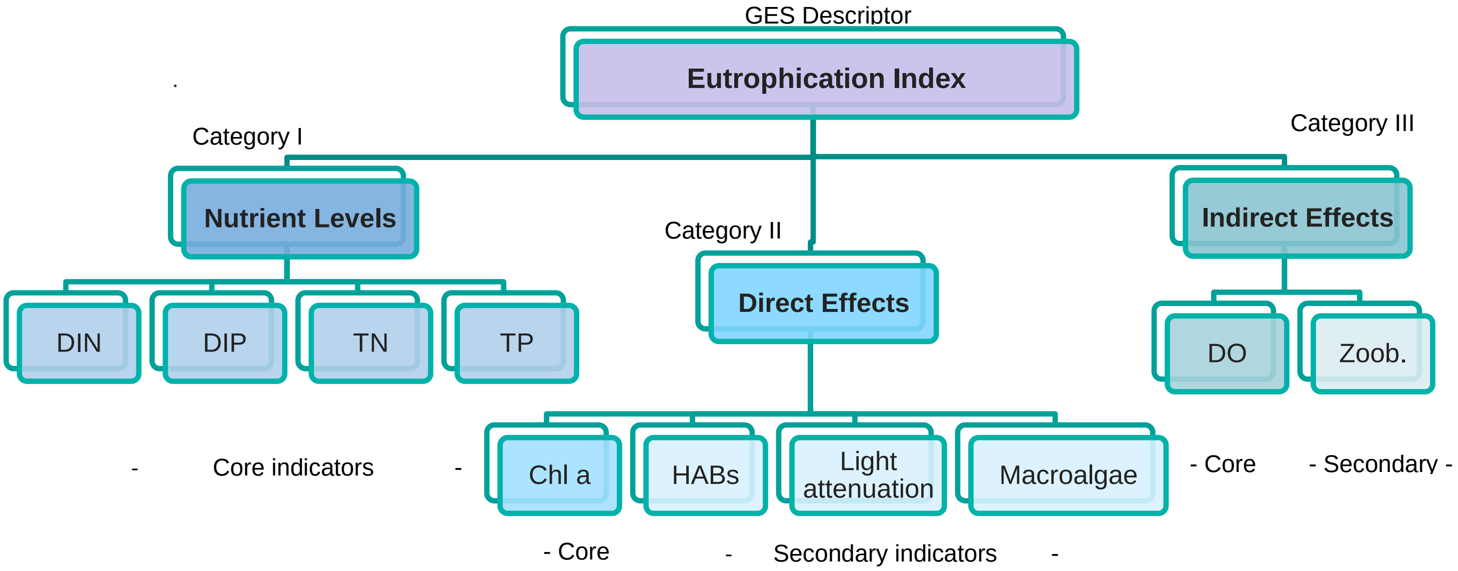


Figure 3: Schematic diagram showing the structure of the Eutrophication Index. GES descriptor at the top of the chart with the categories and ten indicators nested beneath which are used to calculate the overall status assessment. Core indicators (six) are presented are shaded darker and secondary (four) in lighter shade. Abbreviations: DIN = 'Dissolved inorganic nitrogen', DIP = 'Dissolved inorganic phosphorous', TN = 'Total nitrogen', TP = 'Total phosphorous', Chl-a = 'Chlorophyll-a', HABs = 'Harmful Algal Blooms', DO = 'Dissolved oxygen', Zoob = 'Zoobenthos' or benthic quality index.

3.1.2 Nutrient levels

Excess nutrients in the marine and freshwater systems can stimulate growth of plants and algae, and therefore nutrient inputs must be monitored to reduce the possibility of adverse eutrophication effects. Category I: Nutrient levels consist of four indicators, of which all are core indicators in assessing eutrophication status (Table 1). The instruments used for sampling the parameters are flow injection analysis (FIA) and sequential injection analysis (SIA), with an average sample depth of 0.5m and are measured in micrograms per litre (µg/l). Data for the calculations will be acquired through EPA, DEECA and 10-year hydrodynamic modelling using the 'Bubbles' model of TN provided by MW and University of Melbourne.

Table 1: Overview of category I: nutrient levels and indicators that are utilised for assessing the eutrophication status

Category I	Indicators	Parameters
Nutrient Levels	Dissolved Inorganic Nitrogen **(DIN)**	DIN = NH_3 + NO_2 + NO_3 concentration = Ammonia + Nitrite + Nitrate (all filtered/dissolved) (µg/l)
	Dissolved Inorganic Phosphorus **(DIP)**	PO_4 concentration (µg/l) Orthophosphate (filtered)
	Total Nitrogen **(TN)**	Total nitrogen concentration (µg/l)
	Total Phosphorus **(TP)**	Total phosphorous concentration (µg/l)

All the indicators for nutrient levels have a defined set of numerical objectives as outlined in the ERS. The objectives for nutrients are based on a 75th percentile, where data values must be lower than the objective for each sub-segment three quarters of the year. To provide adequate confidence it is suggested by the ERS that a minimum of 11 data values are utilised to monitor on annual basis. The objective values for each surface water sub-segment have been presented in Table 2.

Table 2: Numerical objectives for indicators relating to nutrient levels as defined by ERS, 2021

Category I		**Nutrient Levels**			
Indicators		**DIN**	**DIP**	**TN**	**TP**
Assessment units		µg/L	µg/L	µg/L	µg/L
	Surface waters sub-segments	75^{th} percentile	75^{th} percentile	75^{th} percentile	75^{th} percentile
Marine: PPB	Hobsons Bay	50	70	300	100
	Central-East	10	50	150	70
	Geelong Arm	20	70	300	100
	Exchange	10	30	150	50
Central foothills and coastal plains	Lowlands: Moorabool, Werribee, and Maribyrnong basins	N/A	N/A	≤1,100	≤60
	Lowlands: Yarra and Bunyip basins	N/A	N/A	≤1,100	≤55
	Uplands: Moorabool, Werribee, and Maribyrnong basins	N/A	N/A	≤1,050	≤55
Urban	Tributaries: Werribee and Maribyrnong Rivers	N/A	N/A	≤1,200	≤110
	Tributaries: Yarra River	N/A	N/A	≤1,300	≤110

OFFICIAL

3.1.3 Direct effects

Direct effects of nutrient enrichment can result in an enhancement of primary productivity with increases observed in phytoplankton biomass, plant growth, and shifting of species compositions. To quantify the effects of nutrients across marine, aquatic, and riverine environments, four indicators have been selected as environmental receptors, using a combination of metrics (Table 3) and the objectives as described in Table 4. For the purposes of the inaugural assessment, core indicators from each category will be prioritised for analysis and expanded in future reporting to the secondary indicators. More detail on future reporting options can be found in Section 5.1.

Table 3: Overview of category II: direct effects and indicators, with applicable parameters that will be used to assess the eutrophication status (three secondary indicators are shaded light blue)

Category II	Indicators	Applicable parameters and metrics
Direct Effects	Chlorophyll-*a* **(Chl-*a*)**	Chl-*a* concentration (µg/l)
	Harmful Algal Blooms **(HABs)**	Biovolume of toxin concentrations or cell density i.e. cell counts/litre (mm3/L), Phytoplankton taxa and species HAB event: frequency, duration & extent
	Light Attenuation	Light attenuation coefficient kd (m-1) Turbidity (rivers/streams) Colour (dissolved) Transparency/ Photosynthetically Active Radiation (PAR) attenuation
	Macroalgae	Opportunistic macroalgae: spatial cover, composition, abundance/persistence of blooms and biomass (i.e. drift algae) Condition of perennial, long-lived and sensitive macrophyte species. Denoting evidence of disturbance, smothering, phase shifts or declines.

Table 4: Numerical objectives for indicators relating to Direct effects as defined in the ERS and DEECA, 2019b (macroalgae guidelines to be developed in consultation with a TRG)

Category II		**Direct Effects**			
Indicators		**Chl-*a***	**HABs**	**Light Attenuation**	**Macroalgae**
Assessment units		µg/L	mm^3/L	m^{-1}	
	Surface waters sub-segments	75^{th} percentile	75^{th} percentile	75^{th} percentile	TBD
Marine: PPB	Hobsons Bay	4	0.2	0.5	
	Central-East	1.5	0.2	0.3	
	Geelong Arm	3	0.2	0.4	
	Exchange	1	0.2	0.3	
	Indicators			**Turbidity**	
	Assessment units			NTU	
				75^{th} percentile	
Central foothills and coastal plains	Lowlands: Moorabool, Werribee, and Maribyrnong basins			≤25	
	Lowlands: Yarra and Bunyip basins			≤25	
	Uplands: Moorabool, Werribee, and Maribyrnong basins			≤15	
Urban	Tributaries: Werribee and Maribyrnong Rivers			≤30	
	Tributaries: Yarra River			≤35	

Chlorophyll-a

Chlorophyll-*a* (Chl-*a*) is the most abundant form of chlorophyll pigment and is essential for photosynthesis. High concentrations of Chl-*a* indicate elevated phytoplankton/algal abundance and biomass reflecting a system rich in nutrients. Therefore, understanding and monitoring chl-*a* levels in time-series can indicate if the environment is persistently in poor condition. Annual median concentrations of Chl-*a* are used nationally in the State of Environment reporting (NLWRA, 2008). Data for Chl-*a* will be provided by DEECA and the EPA fixed site water-column monitoring using spectrometry instrumentation.

3.1.4 Indirect effects

Two indicators are employed in the assessment of indirect effects, these include the core indicator dissolved oxygen (DO) or oxygen debt, and secondary indicator Zoobenthos

OFFICIAL

(Table 5). To establish a Zoobenthos Index, this involves assessing the status of soft-bottom macrofaunal communities determining the community composition and diversity, guild abundance and structure and presence of opportunistic or invasive species. Further information on the collection of Zoobenthos data and target objectives can be found in the improvements section 5.1.2 Secondary indicators.

Table 5: Overview of category III: Indirect effects and indicators, with parameters used to assess the eutrophication status

Category III	Indicators	Parameters
Indirect Effects	Dissolved Oxygen **(DO)** or oxygen debt	Percent saturated dissolved oxygen (%)
	Zoobenthos **(Zoob)**	a) Macrofaunal communities (primarily macroinvertebrate) B) Benthic quality index

Dissolved Oxygen

Oxygen depletion, evident in the bottom of the water column is a common response indicator of excess organic materials in water bodies and can lead to eutrophication (HELCOM, 2018). Low DO levels or hypoxia can negatively impact benthic communities and can have widespread effects on mobile species, depending on species-specific DO tolerance ranges, that can sometimes eventuate in fish kill events (US EPA, 2021). DO levels often demonstrate seasonality, daily and periodical fluctuations, in response to temperature changes or the influence of photosynthesis during the day (Edmunds, 2021), where the data is available- Biochemical Oxygen Demand (BOD) should supplement DO measurements.

DEECA, EPA, and WaterWatch measure DO at the surface and bottom of the water column as a percentage saturation (%), which must comply with ERS standards as defined by a min to max range of saturation (Table 6). Hobsons Bay and Central East surface water sub-segments in PPB are susceptible to stratification leading to low DO levels, ERS objectives have been set for bottom waters for these two segments and bottom measurements will be used in the calculations.

With relation to delivering the status assessment for DO, scores have been assigned based on extensive stakeholder engagement in 2022 (see Appendix 3: Dissolved Oxygen status assessment).

Table 6: Numerical objectives for the indicator Dissolved Oxygen (surface) in the PPB assessment areas (ERS, 2021)

Category III		**Indirect Effects**	
Indicators		**DO (surface)**	**DO (bottom)**
Assessment units		% saturation	% saturation
	Surface waters sub-segments	25th percentile – max	25th percentile – max
Marine: PPB	Hobsons Bay	95-130	80-130
	Central-East	95-130	80-130
	Geelong Arm	95-130	N/A

	Exchange	N/A	N/A
Central foothills and coastal plains	Lowlands: Moorabool, Werribee, and Maribyrnong basins	70-130	70-130
	Lowlands: Yarra and Bunyip basins	75-130	75-130
	Uplands: Moorabool, Werribee, and Maribyrnong basins	70-130	70-130
Urban	Tributaries: Werribee and Maribyrnong Rivers	60-130	60-130
	Tributaries: Yarra River	70-130	70-130

3.2 Assessment areas

The Eutrophication Index has been initially developed for the EMP, which applies to PPB and its feed in catchments, encompassing PPB and Greater Melbourne's river and creek basins as shown in Figure 4.

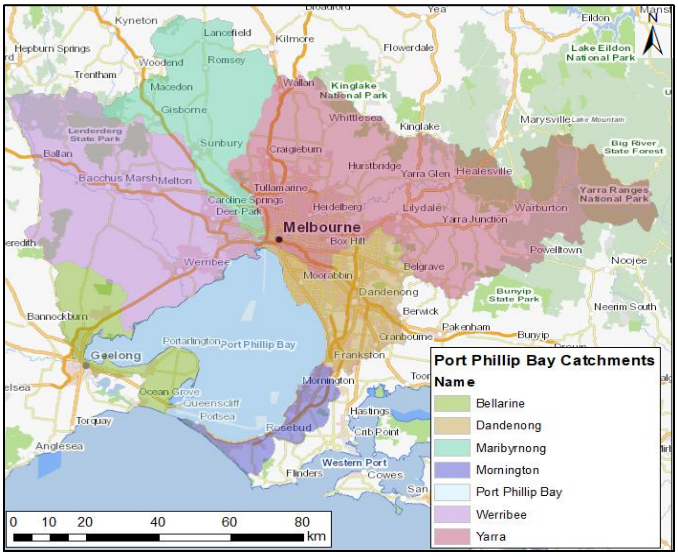


Figure 4: Map showing PPB and its catchments.

Based on the availability of the data, the index could be applied for varying spatial extents, adopting a nested hierarchal structure shifting from broad to local scales (Figure 4):

- Bay-wide, marine biounit and catchment level .
- Surface waters and basin areas e.g. marine sub-segments, inlets, rivers, estuaries, and wetlands.
- Monitoring site level.

OFFICIAL

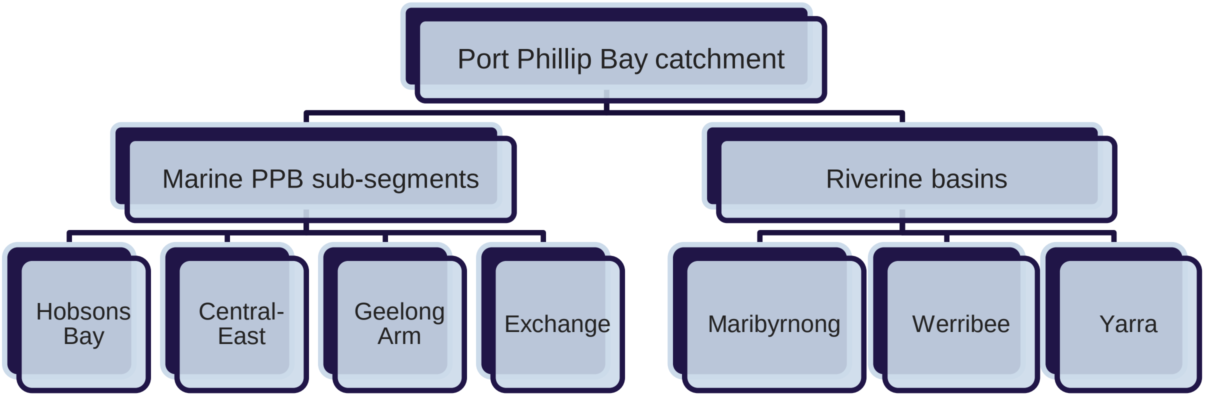


Figure 5: The nested hierarchal structural approach for assessing and reporting on eutrophication for PPB at different spatial scales.

Reporting to smaller area scales is preferred when assessing for eutrophication risk, as the effects are often observed in highly localised area, expanding out from hotspots. This will better inform management responses to identify point source locations for nutrient inputs (Edmunds, 2021). It is recommended that the assessment of eutrophication status should be calculated primarily at monitoring site level and summarised for reporting based on the PPB surface water compartments and the main fluvial catchments or basin areas.

The PPB segment is one of the marine surface waters listed in the ERS. The PPB marine segment comprises of four subsegments:

- Hobsons Bay - the surface waters in the northern section of PPB bounded by Point Cook and Ricketts Point that are directly influenced by outflows from the Yarra River and urban stormwater.
- Central-East - the surface waters of the central section of PPB extending from Point Cook and Ricketts Point in the north, to Mt Martha and Point Richards in the south.
- Geelong Arm - the surface waters of the Werribee coastal zone extending 5 kilometres offshore from Point Cook and south to Point Richards and encompassing the Geelong Arm.
- Exchange - the surface waters of the section of PPB extending south from Point Richards and Mt Martha to Port Phillip Heads.

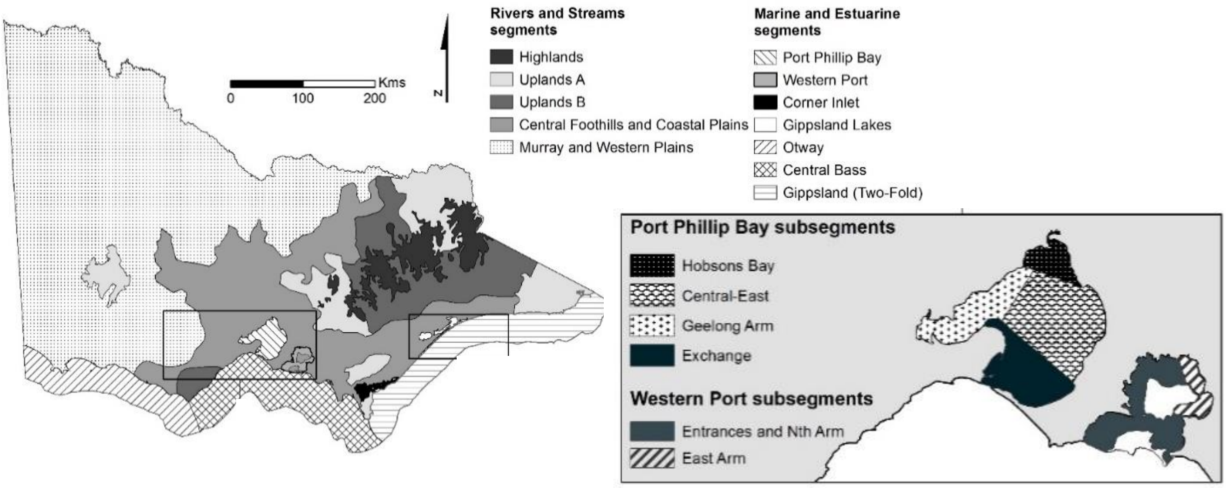


Figure 6: ERS surface water geographic regions across Victoria and focus on the PPB subsegments (ERS, 2021).

Within these four subsegments are six active and consistently sampled sentinel sites and an additional two historic monitoring sites as shown in Figure 6 and detailed in Table 7. Two additional historic sites are shaded grey (source: EPA).

Table 7: EPA's PPB active water quality marine monitoring sites across the four ERS PPB marine sub-segments. Two additional historic sites are shaded grey (source: EPA)

Marine site ID	Monitoring site name	Site description	Latitude	Longitude	ERS subsegment name
369	Long Reef	1.8 km off Werribee Coast	-38.02932358	144.5928192	Geelong Arm
939	Patterson River	0.5 km offshore from Patterson River Entrance to Bay	-38.07698059	145.1150055	Central-East
1229	Central Bay	Central Bay Reference Site	-38.05703354	144.8704071	Central-East
1282	Dromana	Inshore end of Shipping Channel, 8 km east of Hovell Pile	-38.30340576	144.9913177	Exchange
1911	Corio Bay	1.5 km off North Shore docks in Corio Bay	-38.10096741	144.3987274	Geelong Arm
1991	Hobsons Bay	3.5 km from Yarra entrance to the Bay	-37.87018967	144.9338074	Hobsons Bay
2096	Newport	1 km upstream of Yarra Entrance to Bay	-37.84198761	144.8985138	Hobsons Bay
2100	Popes Eye	7 km inshore of Entrance to Bass Strait	-38.27496338	144.6989136	Exchange

For consistent reporting size, the three main riverine catchments flowing into PPB will be scored and reported on for the eutrophication assessment (Table 8). These will include the Yarra, Werribee, and Maribyrnong rivers with data acquired from DEECA, https://data.water.vic.gov.au/, and WaterWatch, www.vic.waterwatch.org.au.

Table 8: Active water quality monitoring sites for the inland riverine catchments around PPB (source: DEECA and WaterWatch)

Surface water ID	River Catchment Name	Number of Active Monitoring Sites	
		Data.Vic	WaterWatch

230	Maribyrnong River Catchment	25	15
231	Werribee River Catchment	16	1
229	Yarra River Catchment	17	29

3.3 Time-series assessment

The range of temporal data available for analysis and time-series assessment differs for each parameter and monitoring site. Water quality monitoring data is collected periodically in most cases monthly, however this is subject to weather, funding, emergency response, and availability of vessel and crew. The frequency of sampling is aligned to the ERS requirements for indicators, whereby percentiles against the objective values must be calculated for a minimum of 11 data points collected from monitoring over one year. This sample number will be reflected in the confidence assessment for each parameter (see section 3.4 Confidence assessment). The data analysis will be conducted by financial year calendar.

The 2022 assessment of eutrophication will analyse historical data to assess the trend of eutrophication and produce a eutrophication status score, 0-100%, for each indicator for each financial year (Figure 7). This will identify changes over time, flagging improvements and declines in water quality. The overall Eutrophication Index will be calculated based on a weighted approach to aggregate the indicators and will be presented for each of the marine PPB sub-segments, riverine basins, and whole PPB catchment. Reporting will be completed on an annual basis so as new data becomes available the time series will be extended.

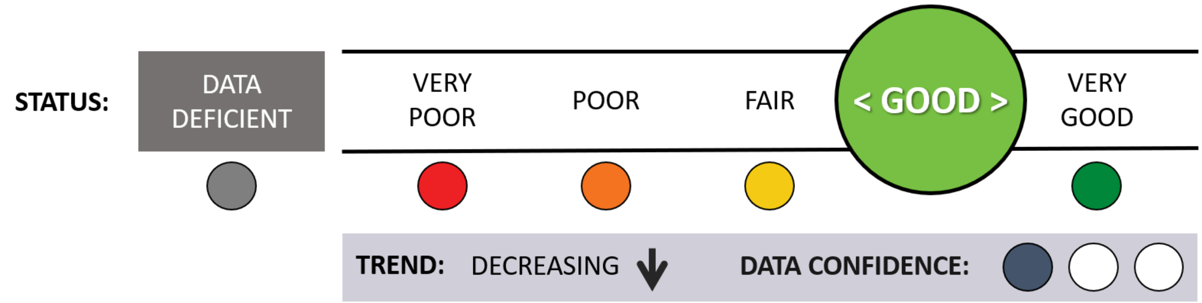


Figure 7: Example of the Eutrophication Index reporting display demonstrating the status, trend, and confidence assessment for each indicator.

3.4 Confidence assessment

A confidence assessment will be integrated into the reporting. The confidence assessment will follow a similar approach as outlined in the Marine Biodiversity Index methodology paper (DELWP, 2021) and adapted for the Eutrophication Index. The confidence of each indicator dependant on the assessment area will be measured in four ways to include accuracy (ConfA), temporal coverage (ConfT), spatial representation (ConfS), and methodological quality (ConfM) as outlined in Table 9. Confidence metrics will be evaluated as high, intermediate, and low by an expert working group.

Table 9: Confidence scoring criteria for data quality as evaluated using four metrics and assigned categorical values

Confidence metrics		High (value = 1)	Intermediate (value= 0.5)	Low (value=0)
ConfA	Accuracy of indicator result based on the frequency of sampling per year.	11 or more samples per year, averaging one per month (aligning with ERS criteria).	At least eight samples, averaging two samples per quarter or season.	Less than eight samples or one sample per quarter or season.
ConfT	Temporal coverage of data available for the indicator across assessment period.	Full temporal coverage or 75% of monitoring data over the assessment period 1984 – 2021, or spanning at least 10 years.	Monitoring data representing 50% of the assessment period, or spanning at least five years.	Data available is less than 50% of the assessment period, or does not span five years consecutively.
ConfS	Spatial coverage across the assessment area, number of monitoring sites.	Data represents ≥ 80% spatial coverage across the assessment area, or greater than five monitoring sites.	60% coverage or two or more monitoring sites across the assessment area.	< 60% or Less than one monitoring site represented per assessment area.
ConfM	Methodological quality of instrumentation, handling, and processing of data.	Methods for data collection are consistent with a high scientific quality or a set industry standard (ISO). Data is collected by regulated body or by personnel who have undergone training. Instrumentation is highly accurate and well calibrated, with a small error rate less than 10%. A data validation procedure is present.	The indicator consists of compiling mixed monitoring methods, sources of data of moderate scientific quality.	Datasets do not have a quality assurance procedure and data collection methods are of low quality.

The four confidence metrics will be combined into an overall Confidence Metric (CM) by applying the below formula. The metrics are equally weighted.

Overall Confidence Status = (0.25*ConfA) + (0.25*ConfT) + (0.25*ConfS) + (0.25*ConfM)

The overall CM for each indicator at each site will be presented as an overall confidence status reflecting high, medium, and low as shown in Table 10.

Table 10: Overall confidence status, class and scoring range

Confidence symbol	Data confidence class	Scoring range
●●●	High	> 75%
●●○	Medium	50 – 75%
●○○	Low	< 50%

4. Eutrophication assessment methodology

4.1 Overview and scoring

The bulk of the analysis will be conducted using RStudio with migration of finalised datasets into ArcGIS online Experience Builder for report carding. Initially the datasets will be cleaned; ensuring that the dataset is formatted by financial year, preservation of site ID, conversion of units i.e. MG/L to µg/L, and blanks removed from calculations.

To determine the eutrophication ratio for each indicator by assessment area, this will consist of dividing the calculated annual percentile value by the ERS objective for each financial year. The number of monitoring samples will be extracted to inform the confidence assessment. The ratio score will then be normalised between 0-1 using the maximum eutrophication ratio score (2.5), inverted, expressed as a percentage and assigned a scoring class (Table 11).

Table 11: Scoring classes for eutrophication assessment based on percentage scoring range (excluding DO scoring- refer to Appendix 3)

Eutrophication ratio score	Normalised percentage scoring range	Scoring class
0 - 0.5	80% - 100%	Very Good
0.51 - 1	60% - 79%	Good
1.01 - 1.5	40% - 59%	Fair
1.51 - 2	20% - 39%	Poor
2.01 – 2.5	0% - 19%	Very Poor
> 2.5	0%	

Following an integrated approach, the Eutrophication Status is based on weighted system for each indicator which is nested up into categories I, II, III. The attributed weightings are equalised depending on the number of indicators that will utilised, whereby the core indicators must be used as a minimum (Figure 8). Therefore, the results for the indicator Eutrophication Ratio scores are averaged across the category (if more than one indicator is used). The overall Eutrophication Status for each assessment area is then guided by a

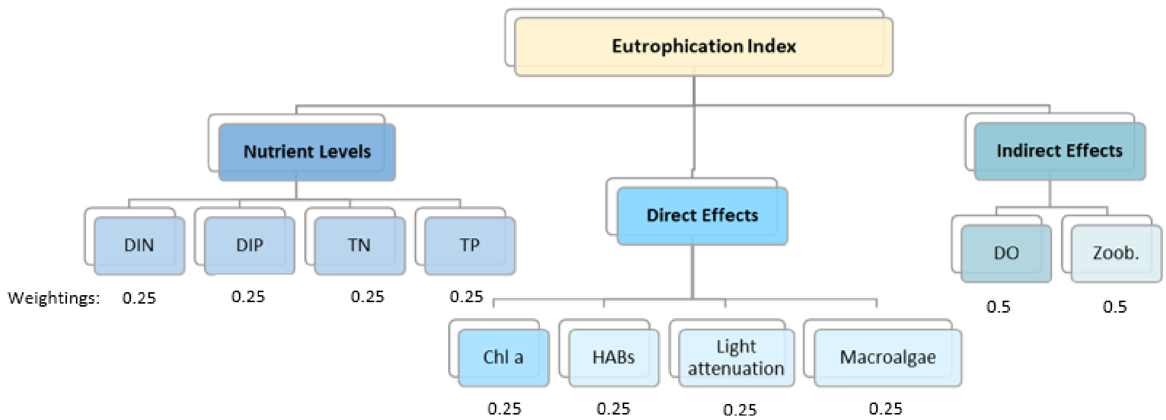


Figure 8: The nested approach of equal weightings for each category, which will be aggregating depending on the number of indicators used in the assessment. The example shows weightings for scenario where all core indicators are utilised.

OFFICIAL

precautionary one-out-all-out principle, which is reliant on the worst score achieved across the three categories.

4.2 Eutrophication ratio

As outlined in the section 3. Structure of the Eutrophication Index**Error! Reference source not found.**, all six core indicators have a defined ERS objective which differ according to the assessment area (

Numerical objectives across the three categories (core indicators)							
		Nutrient Levels				**Direct Effects**	**Indirect Effects**
Indicators		**DIN**	**DIP**	**TN**	**TP**	**Chl-a**	**DO**
Assessment units		**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**% saturation**
	Surface waters sub-segments	75th percentile	75th percentile	75th percentile	75th percentile	75th percentile	25th percentile - Max
Marine: PPB	Hobsons Bay	50	70	300	100	4	95-130
Marine: PPB	Central-East	10	50	150	70	1.5	95-130
Marine: PPB	Geelong-Arm	20	70	300	100	3	95-130
Marine: PPB	Exchange	10	30	150	50	1	N/A
Central foothills and coastal plains	Lowlands: Moorabool, Werribee, and Maribyrnong basins	N/A	N/A	≤1,100	≤60		70-130
Central foothills and coastal plains	Lowlands: Yarra and Bunyip basins	N/A	N/A	≤1,100	≤55		75-130
Central foothills and coastal plains	Uplands: Moorabool, Werribee, and Maribyrnong basins	N/A	N/A	≤1,050	≤55		70-130
Urban	Tributaries: Werribee and Maribyrnong Rivers	N/A	N/A	≤1,200	≤110		60-130

OFFICIAL

	Tributaries: Yarra River	N/A	N/A	≤1,300	≤110		70-130

). For the secondary indicators that are not listed in the ERS, but are relevant to the assessment, objectives are based on expert elicitation and threshold values extracted from Victorian-specific response plans.

Table 12: Compiled numerical objectives for the seven core indicators varying across the assessment areas (ERS, 2021)

Numerical objectives across the three categories (core indicators)							
		Nutrient Levels				**Direct Effects**	**Indirect Effects**
Indicators		**DIN**	**DIP**	**TN**	**TP**	**Chl-a**	**DO**
Assessment units		**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**% saturation**
	Surface waters sub-segments	75th percentile	75th percentile	75th percentile	75th percentile	75th percentile	25th percentile - Max
Marine: PPB	Hobsons Bay	50	70	300	100	4	95-130
	Central-East	10	50	150	70	1.5	95-130
	Geelong-Arm	20	70	300	100	3	95-130
	Exchange	10	30	150	50	1	N/A
Central foothills and coastal plains	Lowlands: Moorabool, Werribee, and Maribyrnong basins	N/A	N/A	≤1,100	≤60		70-130
	Lowlands: Yarra and Bunyip basins	N/A	N/A	≤1,100	≤55		75-130
	Uplands: Moorabool, Werribee, and Maribyrnong basins	N/A	N/A	≤1,050	≤55		70-130
Urba	Tributaries: Werribee and	N/A	N/A	≤1,200	≤110		60-130

	Maribyrnong Rivers						
	Tributaries: Yarra River	N/A	N/A	≤1,300	≤110		70-130

Five of the six core indicators possess a 75th percentile objective as listed in the ERS, where the sampled values need to fall below the objective value 75% of the time. For DO this percentile value is between 25th percentile and maximum. Indicators for each assessment area need to have 11 or more measurements per year, if this number is not met then this will be expressed in the confidence assessment as outlined in section 3.4 Confidence assessment.

The following calculation is applied to the annual dataset to extract the percentile value:

75th = PERCENTILE.INC (ARRAY, 0.75)

25th = PERCENTILE.INC (ARRAY, 0.25)

MAX = PERCENTILE.INC (ARRAY, 1)

To understand whether the target value or objective has been met for the measured percentile value over the 12-month period for each distinct surface water sub-segment or assessment area, the Eutrophication Ratio (ER) is calculated (Figure 9). For each indicator the calculated percentile value is divided by the numerical objective value or target/threshold value as defined for each sub-segment.

$$\text{Eutrophication Ratio} = \frac{\text{Calculated percentile value}}{\text{Objective value}}$$

Figure 9: Eutrophication Ratio calculation formula applied to each indicator according to the assessment area.

The ER score for each indicator by assessment area will be used to establish the overall eutrophication status.

4.3 Integrated eutrophication status

To generate the overall Eutrophication Status score, the ER scores are first aggregated up into their three assigned categories using an evenly distributed weighted average. The weightings depend on the number of indicators that sit under the categories. For instance, when there is only one indicator, the ER value is adopted without the need for averaging (HELCOM, 2018).

The overall eutrophication status will be provided for each assessment area by taking the lowest or worst percentage score across category I, II and III. This follows the 'one-out-all-out' principle that is applied by OSPAR and HELCOM and is in accordance with the EU Water Framework Directive. To calculate the overall Eutrophication Index score by financial year for the EMP catchment area, the score for each category will be averaged across the assessment areas. The results will be presented per financial year for the Eutrophication Ratio score for each assessment area by indicator and associated category.

5. Future improvements

This section outlines proposed methods through which the eutrophication assessment could be improved in terms of data collection and reporting on primary and secondary indicators.

5.1 Indicators

5.1.1 Primary indicators

Nutrient levels

In Europe, DIN and DIP are measured and assessed during the winter when biological activity is seen to be at its lowest (OSPAR, 2008), future reporting in Victoria could align with this. The Eutrophication Index does not currently address low nutrient scenarios characteristic of a prolonged dry or drought period, it is therefore assumed in the index that a reduction in nutrients is good: returning PPB to a former oligotrophic state. In the event of nutrient limiting conditions, the index should be amended to establish a threshold if nutrient levels are too low.

Silicate concentrations could also be factored into future assessments, providing insights into nitrogen and bloom dynamics whereby depletion of silica can limit diatom growth causing shifts in the species composition of the phytoplankton community (CSIRO, 1997). This would require targets to be set for based on biologically trigger values.

Chlorophyll-a

Real-time satellite data collected through the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor by Australia's Integrated Marine Observing System and displayed on the Australian Ocean Data Network could also be used to augment the monitoring of the concentration of chlorophyll-*a*. For processing the multi-spectral imagery using reflectance, the OC3 algorithm developed by NASA Ocean Biology Processing Group has been applied to retrieve estimates for concentrations of Chl-a (Hu et al, 2012). The dataset for Chl-*a* extends from 2014 to 2021, collected daily and has been filtered by a bounding box for PPB. MW moorings in PPB record and collect chl-a data and the EPA Ships of Opportunity (SOOP) program collects autonomous and continuous chl-a data from the Spirit of Tasmania vessel that could be used to augment reporting.

Sediment dredging, bypassing, and disposal either in the form of maintenance or capital works can have an environmental impact on water quality and has the potential to affect algal populations through the mobilisation of nutrients from the resuspension of sediment (EES Minister of Planning, 2007). For the PPB Channel Deepening Project Environmental Management Plan 2012- 22, the Port of Melbourne Corporation as required by the Environmental Effects Statement assessment guidelines, implemented a monitoring program of phytoplankton blooms.

Chl-*a* has been previously utilised in the Channel Deepening Project as a biomass indicator, in addition to surface and bottom florescence, the identification and enumeration of phytoplankton taxa and counts (cells/L) to report on the annual median and annual 90th percentile using quarterly data from across 11 sites around PPB. The 90th percentile was shown to underestimate conditions and has now been replaced by 75th percentile in the ERS

OFFICIAL

2021. The spatial variation in chl-*a* concentrations has also been depicted by interpolating the monthly data across PPB using the Spline method.

Dissolved oxygen

Oxygen profiles could form a more reliable measure of oxygen debt accounting for the full water column and generalising discrete observations, in the Baltic Sea this has been modelled using information from salinity profiles (HELCOM, 2018). Generalised additive models have been applied by HELCOM to describe variability in temporal, seasonal and spatial fluctuations, a similar protocol could be replicated for PPB. The EPA measure Dissolved Oxygen (DO) at the bottom of the water column as a percentage saturation (%) which must comply with ERS standards as defined by a min to max range of saturation (ERS, 2021).

5.1.2 Secondary indicators

Reporting on secondary indicators and inclusion within the Eutrophication Index would allow for a more robust assessment of eutrophication in each assessment area. Category II: Direct effects, could be further informed data on Harmful Algal Blooms, Light Attenuation, and Macroalgae. For Category III: Indirect effects, could be further informed by assessing the status of soft-bottom macrofaunal communities as referred to Zoobenthos.

Harmful algal blooms

Harmful Algal Blooms (HABs) in coastal waters and blue-green algae (BGA) events in the catchment are problematic to human health, have compound effects on aquatic and marine biodiversity with high toxicity levels occasionally leading to mass fish-kills. HABs can consist of toxic phytoplankton, cyanobacteria, benthic algae and macroalgae, and depend on several physical and biological conditions to optimise growth such as sunlight, nutrients, salinity, and hydrodynamics (NOAA, 2016). HABs in PPB are more common between spring and autumn, and generally follow episodic rainfall events mobilising nutrient loads into PPB (DELWP, 2019a).

Data for algal bloom events in the catchment are spatially mapped, logged, and documented on the DEECA water intelligence platform (WIP) or Flood Zoom, which is accessed internally through the algal bloom module. Monitoring is undertaken as part of local and regional Algal Bloom Risk Management Plans to determine the presence and/or concentration (i.e. biovolume) of various species of cyanobacteria and toxicity testing of samples (DELWP, 2019b). The Algal Bloom Risk Management Plan sets thresholds for BGA events outlining the degree of response required at local, regional, and emergency levels, with a mandatory notification required to DEECA for biovolumes at trigger value of 0.2mm^3/L or above in any water body (DELWP, 2019b).

Emergency incidents of an ad-hoc nature in PPB are managed by the Marine Algal Bloom Response Plan led by DEECA's Port Phillip Region and falls within the Victoria Algal Bloom Response Plan (ABRP). The draft 2019 plan (updated from the 2013 version) outlines roles and responsibilities, water sampling procedure, and situation reporting template, which records the algae species, if toxic, extent of bloom along the coast (width out to sea), change in size and weather conditions. Algal samples in PPB are sent to Microalgal Services to identify toxic marine phytoplankton species include *Alexandrium* sp., *Karenia* sp., and *Dinophysis* sp. (Microalgal services, 2019). A recommendation from this report will be to harmonise the collection and storage of this data to be consistent and systematic with the catchment data workflows.

The Victorian Shellfish Quality Assurance Program (VSQAP) has set monitoring requirements for each harvest area identifying harmful bacteria, biotoxins, phytoplankton, and other contaminants. Quantitative testing of the species, cell count per litre (cells/L) and presence of biotoxins, allows for harvesting controls, suspensions, and closures to be implemented following defined trigger levels where algal levels are in exceedance of those specified in the Australian Victorian Marine Biotoxin Management Plan for Shellfish Farming (2001). Monitoring of phytoplankton occurs on a fortnightly average at each harvest area at seven aquaculture reserves, with the PPB dataset spanning from 1999 to present day and is part owned by VFA and industry (VFA & VSQAP, 2019)

In the OSPAR National Common Procedure report for the United Kingdom, the report entails the development of a phytoplankton index. An equivalent metric could be adopted for Victoria, with thresholds developed by an expert working group. The index is dependent on the assessment of several area-specific indicators and areas demonstrating elevated levels of phytoplankton species, changes in composition and/or increased duration of blooms (Painting et al. 2016), these include:

- 90th percentile chlorophyll (March-October).
- Elevated taxa counts (full year) .
    - Count (%) of chlorophyll exceeding threshold (µg/l).
    - Count (%) of individual taxa exceeding cell threshold (cells/L).
- Count (%) of taxa exceeding 10^6 cells/L.
- Seasonal succession of functional groups (full year).
    - Diatoms and dinoflagellates.

In the ERS requirements HABs should not demonstrate an increase in the frequency, duration or spatial extent of phytoplankton or cyanobacterial bloom events.

Light attenuation

Light availability is critical for photoautotrophs and biogeochemical feedback loops associated with eutrophication as they can lead to a photosynthetic growth response in suspended algae and in turn subsequently increase light attenuation (HELCOM, 2018). Light attenuation can be expressed as the decrease in the intensity of propagation of light through the water column either by absorption or scattering by photons (Brito et al., 2013). Due to the shallow depth profile of PPB light attenuation has been chosen over Secchi depth methods and is measured by EPA. (Edmunds, 2021). In the catchments turbidity will be used as a primary measure in the catchment for assessing the photic limit of the water column in rivers and streams as collected by DEECA.

Light attenuation is not only affected by the influx of nutrient inputs but is also enhanced through the advent of suspended solids entering the system from land-based runoff (US EPA, 2021), these processes alter assemblages of phytoplankton, suspended particulate matter, coloured dissolved organic matter (CDOM), and inorganic compounds (HELCOM, 2018). Although there is a strong link associated with light attenuation and eutrophication, the presence of CDOM and particles demonstrates that areas which record a high light attenuation may be due to non-eutrophic related signals (HELCOM, 2018). To account for this, time-series data should be evaluated in accordance with nutrient input data. Future revisions of the index and reporting for light attenuation the following parameters could be incorporated; Photosynthetically Active Radiation (PAR), Total Suspended Solids (TSS) and Colour (dissolved).

Macroalgae

Opportunistic macroalgal blooms have been primarily incorporated into the OSPAR commission eutrophication indicator list with applications to a European context. The macroalgal tool developed by the UK and Ireland, has been applied to both coastal waters and transitional waters i.e. estuaries and intertidal zone, with a distinction between the metrics used to assess the abundance and biomass of macroalgal blooms (Wilkes et al., 2014). Coastal evaluation methods will be considered for PPB to account for mobile accumulations:

- Total percentage cover and extent, in addition to fraction of habitat (%) covered by macroalgae.
- Mapping of drifting algae and duration: based on aerial surveys and remote sensing.
- Composition of the reef and condition of perennial macrophytes and long-lived seagrass beds.

Drift algae is of particular concern in PPB with the growth of mats stimulated by nitrogen loading, and the potential to cause habitat shifts from more perennial species such as seagrass, to these short-lived opportunistic species (Edmunds, 2020). As well as this, enhanced production of drift algae can provide herbivorous sea urchins with more grazing opportunities, that may result in increases in population size and subsequent migration to healthy reefs leading to further declines in condition (COE, 2016). In addition to this, the accumulation of drift algae detritus is also a source of nitrogen in PPB (Wong et al., 2021).

Thresholds and guidelines should be agreed by a steering or technical reference group and open to further discussion on future data collection methods and metrics. Mapping should be conducted, at a minimum, during the growth period of drift algae in the spring months of September, October, and November.

Zoobenthos

A secondary indicator for reporting on indirect effects will be focussed on assessing the status of soft-bottom macrofaunal communities. Encompassing both epifaunal and infaunal organisms, mainly invertebrates, macrofaunal communities play an important functional role in the ecosystem supporting nutrient cycling and ensuring the oxygenation of sediments (HELCOM, 2018). Phyla that favour soft substrate habitats and occur in PPB include Molluscs, Annelids, Arthropods, Porifera and Echinoderms (Port Phillip Taxonomic Toolkit, 2021).

A zoobenthos index would primarily utilise information for assessing the community composition and diversity, guild abundance and structure, and presence of opportunistic or invasive species, where macrofauna are not indicative of a heightened nutrient or organic enrichment regime. In addition to assessing the macrofauna, macroalgae, and other benthic habitats should be considered with regards to understanding growth dynamics and measuring the presence, cover, extent, and condition of endemic species as well as opportunistic macroalgae and epiphytes.

In the absence of sediment grab data for marine benthic fauna, predictive distribution models could be employed to map assemblages based on ecological niches and environmental characteristics. Differences in spatial distributions could be correlated based on sediment grain size, substrate type, salinity, microphytobenthos, and organic carbon content (Beard et al., 2018). Linking this back to the assessment of benthic quality or status, current developments associated with work on marine condition and evaluating seabed integrity in DEECA will be critical in informing this indicator.

For aquatic environments and developed under the National River Health Program (NRHP) a bioassessment of macroinvertebrates involves using a predictive mathematical modelling approach referred to as Australian River Assessment System (AUSIRVAS) which uses a largely undisturbed reference site to compare the similarity of the invertebrate community to the sampled site (ERS, 2021). Biological indicators and objective values have also been set in the ERS for Ephemeroptera, Plectoptera, and Trichoptera (EPT), SIGNAL2 (Stream Invertebrate Grade Number- Average Level) and number of macroinvertebrate families (Table 13).

Table 13: River and streams relevant to PPB assessment area denoting the biological indicators and objectives for Victoria (ERS, 2021)

Segment	Season	Habitat	EPT	SIGNAL2	No. of macroinvertebrate families	AUSRIVAS / Band
Central foothills and coastal plains	Autumn	Riffle	5	4.5	16	A
		Edge	N/A	3.4	17	A
		Edge & riffle	6	4.0	27	N/A
	Spring	Riffle	5	4.5	16	A
		Edge	N/A	3.4	20	A
		Edge & riffle	7	4.2	27	N/A
Urban	Autumn	Riffle	4	3.9	13	B
		Edge	1	3.1	14	B
		Edge & riffle	4	3.7	22	N/A
	Spring	Riffle	3	4.2	13	B
		Edge	3	3.2	16	B
		Edge & riffle	3	3.8	22	B

Watershed

Spatial modelling and mapping the riparian and coastal land use information in the catchments, could assist with informing where to prioritise management action and mitigate potential nutrient enrichment risks as observed in the Eutrophication Index results. More information on the integration of land-use metrics into a eutrophication assessment can be found in examples in Appendix 2: Eutrophication Index concept.

In 2020, DEECA developed a new Victorian land cover time series dataset for 2015-2019 using Landsat satellite imagery to provide an updated version for 19 target land cover classes (Table 14). Each pixel has been classified using machine learning with an overall predication accuracy of greater than 90%. Key land use classes for this purpose could include the distinction between the built environment consisting of a persistent unvegetated areas i.e.

OFFICIAL

industrial developments, the urban area environment reflecting streets, houses and gardens, non-native pasture and grassland, and horticulture/irrigated pasture and crop (White et al., 2020).

Table 14: The 19 Victorian Land Cover Classes used for the land cover time series dataset 2015-2019

Victorian Land Cover Classes	
Water	Wetland perennial (native)
Natural low cover (Bare-ground – Native)	Wetland seasonal (Ephemeral – native)
Disturbed ground (Bare-ground – Not Native)	Treed native vegetation
Built environment	Nature shrub-land
Scattered native trees	Hardwood plantation
Urban area	Conifer plantation
Native pasture/Grassland	Other exotic tree cover
Exotic pasture/Grassland	Horticulture/irrigated pasture and crop
Dryland cropping	Saltmarsh vegetation
	Mangrove vegetation

5.2 Data collection and management

The acquisition of marine environmental data could be augmented by using automated, multi-parameter continuous recording buoys, which could promote more real-time monitoring and validate remote sensing data such as concentration of chlorophyll-*a*. Improved data management systems such as employing databases to store data in applications such as PostgreSQL, would allow for more streamlined updating process, model input and repeatable workflow for producing the annual report cards.

5.3 Future assessments

Data is collected monthly and currently the analysis is completed for financial year timeframes. Moving forward, analysis of individual exceedances of the target could assist prioritisation of management action through identification of any patterns correlating with the time of year and climatic information such as temperature, salinity, and rainfall.

Ideally, the index methodology should be revised to report on a real-time basis, have a built-in response protocol and early warning system and create graphs and visualisations upon data entry. This will require further collaboration amongst the organisations, automation in terms of a streamlined data workflow and data upload procedure and utilisation of database technologies to run calculations on the fly. Similar tools have been embedded in CoastKit (mapshare.vic.gov.au/coastkit/) with the Victorian Coastal Monitoring Program plotting recent wave buoy observation data recording wave height, and peak period and direction.

6. Conclusion

The Eutrophication Index will enable efficient reporting and evaluation of the delivery of the EMP's goal 'Water quality is improved to ensure environmental health and community enjoyment of the Bay'. The method and its outputs are embedded into the MACKF and will help support informed decision-making to ensure a purposeful and systematic approach is taken to assessing the eutrophication status of PPB. In addition, the method will provide a future evidence base for assessing the effectiveness of management interventions with regards to environmental outcomes and/or the impacts of storm events. While the EI has been developed for the EMP, it can be applied in other environmental management settings and applied more widely across Victoria.

It is recommended that the Eutrophication Index be adopted for ongoing use in the evaluation of the EMP.

7 References

Australian and New Zealand Guidelines-ANZG. (2018) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Available at: Water Quality Guidelines Home (Accessed: 31/10/21)

Australian Bureau of Statistics (2021). Regional population- 2019-20 financial year. Available at: Regional population, 2019-20 financial year | Australian Bureau of Statistics (abs.gov.au) (Accessed: 05/09/21)

Bayesian Intelligence Pty Ltd. Mascaro, S., Woodberry, O. (2023). Port Phillip Bay Eutrophication and Seafloor Integrity Models. Developed for DEECA.

Beard, J., Moltschaniwskyj, N., Crawford, C., Gibson, J., Ross, J. (2018). Using macrofaunal communities to inform estuarine classification. M*arine and Freshwater Research* **70**, 371-381. https://doi.org/10.1071/MF17372

Brito AC, Newton A, Fernandes TF, Tett P (2013) Measuring Light Attenuation in Shallow Coastal Systems. J Ecosys Ecograph 3: 122. doi:10.4172/2157-7625.1000122

Clark GF, Johnston EL (2016). Coasts: Coastal waters. In: Australia state of the environment 2016, Australian Government Department of the Environment and Energy, Canberra, Available at: https://soe.environment.gov.au/theme/coasts/topic/2016/coastal-waters, DOI 10.4226/94/58b659bdc758b

Commissioner for Environmental (COE) Sustainability Victoria. (2016) State of the Bays report. ISSN 2207-1067. Available at: State of the Bays Report 2016.pdf (ces.vic.gov.au) (Accessed: 03/07/21).

Department for Environment, Land, Water and Planning (2021). Assessment of Victoria's estuaries using the Index of Estuary Condition: Background and Methods 2021. Department of Environment, Land, Water and Planning, Melbourne, Victoria. Available at: https://www.water.vic.gov.au/__data/assets/pdf_file/0016/541501/IndexEstuaryConditionMethods2021.pdf (Accessed: 09/11/21)

Department for Environment, Land, Water and Planning (2021). Marine and coastal knowledge framework strategic directions 2020-22. Available at: Marine and Coastal Knowledge Framework (marineandcoasts.vic.gov.au) (Accessed on: 31/10/21)

OFFICIAL

Department for Environment, Land, Water and Planning (2021). Marine Biodiversity Index. The State of Victoria Department of Environment, Land, Water and Planning 2021.

The State of Victoria, Department of Environment, Land, Water and Planning. (2020) Marine and Coastal Policy. ISBN 978-1-76077-889-7. Available at: https://www.marineandcoasts.vic.gov.au/__data/assets/pdf_file/0027/456534/Marine-and-Coastal-Policy_Full.pdf (Accessed: 31/10/21)

Department for Environment Land Water and Planning (2019). Marine Algal Bloom Response Plan, Port Phillip Bay. Available at: https://studylib.net/doc/6715934/port-phillip-bay-marine-algal-bloom-response-plan (Accessed on: 05/11/21)

Department for Environment Land Water and Planning (2019). DELWP Algal Bloom Response Plan. Available at https://www.vgls.vic.gov.au/client/en_AU/search/asset/1301591/0 (Accessed on: 05/11/21)

Department for Environment Land Water and Planning. (2013) An overview of the Victorian Waterways Management Strategy. Available at: VWMS-Summary_FINAL_WEB-ready.pdf (water.vic.gov.au) (Accessed: 30/10/21)

Department for Environment, Land, Water and Planning. (2010) Index of Stream Condition- The Third Benchmark of Victoria River Condition ISC3. Available at: ISC_Part1_Introduction.pdf (water.vic.gov.au) (Accessed: 30/10/21)

Edmunds, M. (2020) Submission to the inquiry into Ecosystem Decline in Victoria. Australian Marine Ecology Report No. 568. Available at: https://www.parliament.vic.gov.au/images/stories/committees/SCEP/Ecosystem_Decline/submissions/S815_-_Australian_Marine_Ecology_Redacted.pdf (Accessed: 09/11/21)

Environment Protection Authority Victoria. (2020) Report Card 2019-20. Publication number 1923. ISBN 978-1-74287-894-2. Available at: https://www.epa.vic.gov.au/about-epa/publications/1923

Environment Protection Authority, Victoria (2010). Baywide Water Quality Monitoring Program. Milestone Report No. 5. Available at: https://imos.org.au/fileadmin/user_upload/shared/SOOP/100331_EPA_WQ_Milestone_Rep._5_31Mar10_Final.pdf (Accessed on: 05/11/21)

European Commission (2018) The first phase of implementation of the Marine Strategy Framework Directive (2008/56/EC). Available at: https://ec.europa.eu/environment/marine/good-environmental-status/descriptor-5/index_en.htm (Accessed: 01/09/21)

Environment Reference Standards 2021 (Vic)

HELCOM. (2018) HELCOM Thematic assessment of eutrophication 2011-2016. Available at: http://www.helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2018/reports-and-materials/ (Accessed: 01/09/21)

HELCOM (2018). Water clarity: HELCOM core indicator report. Online. ISSN 2343-2543 Available at: https://helcom.fi/media/core%20indicators/Water-clarity-HELCOM-core-indicator-2018.pdf (Accessed: 15/09/21)

HELCOM (2018) Oxygen debt. HELCOM core indicator report. Online. Available at: https://helcom.fi/wp-content/uploads/2019/08/Oxygen-debt-HELCOM-core-indicator-2018.pdf (Accessed: 08/11/21). ISSN 2343-2543

HELCOM (2018) State of soft-bottom macrofauna community. HELCOM core indicator report. Available at: https://helcom.fi/wp-content/uploads/2019/08/State-of-the-soft-bottom-macrofauna-community-HELCOM-core-indicator-2018.pdf (Accessed: 08/11/21)

HELCOM (2009) Eutrophication in the Baltic Sea – An integrated thematic assessment of the effects of nutrient enrichment and eutrophication in the Baltic Sea region. Balt. Sea Environ. Proc. No. 115B. Available at: https://helcom.fi/wp-content/uploads/2019/08/BSEP115B-1.pdf (Accessed: 01/11/21)

Hu, C., Lee, Z., & Franz, B. (2012). Chlorophyll a algorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference. Journal of Geophysical Research, 117(C1). doi: 10.1029/2011jc007395

Land Air Water Aotearoa (LAWA). (2020). Factsheet: Lake Trophic Level Index. Available via: https://www.lawa.org.nz/learn/factsheets/lake-trophic-level-index/ (Accessed: 31/10/21)

Macroalgal Services (2021). List of harmful phytoplankton. Available at: https://microalgal.com.au/harmful-phytoplankton/ (Accessed on: 05/11/21)

Melbourne Water Corporation. (2018) Healthy Waterways Strategy. Available at: https://www.melbournewater.com.au/about/strategies-and-reports/healthy-waterways-strategy (Accessed: 30/10/21)

Minister for Planning, Victoria (2007). Assessment: Port Phillip Bay Channel Deepening Project, Environmental Effects Act 1978. SBN 978-1-74208-165-6

Murray, A., Parslow, J. (1997) CSIRO Port Phillip Bay Environmental Study- Technical Report No.44. Commonwealth Scientific and Industrial Research Organization (Australia). ISDN 1039-3218

Museum of Victoria (2011) Taxonomic Toolkit for Marine Life of Port Phillip Bay V1.0. Available at: https://portphillipmarinelife.net.au/. (Accessed: 08/11/21)

National Oceanic Atmospheric Administration, U.S.A (2016) What is a harmful algal bloom. Available at: https://www.noaa.gov/what-is-harmful-algal-bloom (Accessed on: 20/09/21)

NLWRA (2008). Estuarine, coastal, and marine habitat condition, indicator guideline. OzCoasts, Australian Online Coastal Information. Available at: https://ozcoasts.org.au/indicators/biophysical-indicators/chlorophyll_a/ (Accessed: 16/09/21)

Nygård, H., Murray, C., Andersen, J.H., Martin, G., Torn, K. and Korpinen, S., (2018). BEAT 3.0 – a Tool for Integrated Biodiversity Assessments. *Journal of Open Research Software*, 6(1), p.19. DOI: http://doi.org/10.5334/jors.226

OSPAR Commission. (2008) Second Integrated Report on the Eutrophication Status of the OSPAR Maritime Area. Available at: https://www.ospar.org/documents?v=7107 (Accessed: 31/10/21)

OSPAR Commission. (2016). Third OSPAR Integrated Report on the Eutrophication Status of the OSPAR Maritime Area, 2006-2014. Available via: Third OSPAR Integrated Report on the Eutrophication Status of the OSPAR Maritime Area, 2006-2014. (Accessed: 31/10/21)

Painting, S., Garcia, L., Collingridge, K. (2016) Common Procedure for Identifying the Eutrophication Status of the OSPAR Maritime Areas UK National Report 2016. Available at: https://www.ospar.org/site/assets/files/37302/national_common_procedure_report_2016_united_kingdom_and_annexes.zip (Accessed: 01/11/21)

Planning and Environment Act 1987 (Vic)

Riverness Pty Ltd. (2015) The plan for Waterwatch Victoria. Available at: www.vic.waterwatch.org.au/resources/15 0417 The Plan for WW Victoria.pdf (Accessed: 30/10/21)

State Government Victoria. (2019) Water Quality Monitoring Data- Explanatory Notes V1.0. Available at: Microsoft Word - WQExplanatoryNotesv1 (water.vic.gov.au) (Accessed: 30/10/21)

OFFICIAL

United States Environmental Protection Agency (2021). Indicators: Water Clarity. Available at: https://www.epa.gov/national-aquatic-resource-surveys/indicators-water-clarity (Accessed: 05/11/21)

United States Environmental Protection Agency (2021). Indicators: Dissolved Oxygen. Available at: https://www.epa.gov/national-aquatic-resource-surveys/indicators-dissolved-oxygen (Accessed: 08/11/21)

United States Environmental Protection Agency- U.S. EPA. (2012) National Coastal Condition Report IV. Available at: https://www.epa.gov/sites/default/files/2014-10/documents/0_nccr_4_report_508_bookmarks.pdf (Accessed: 31/10/21)

United States Environmental Protection Agency- U.S. EPA (2000). Nutrient Criteria Technical Guidance Manual: Lakes and Reservoirs. Available at: https://www.epa.gov/sites/default/files/2018-10/documents/nutrient-criteria-manual-lakes-reservoirs.pdf (Accessed: 31/10/21)

United Nations (2014). Water for Life Decade- Water Quality. Available at: Water quality | International Decade for Action 'Water for Life' 2005-2015 (un.org) (Accessed: 01/09/21)

Victorian Fisheries Authority and VSQAP (2019). Victorian Shellfish Quality Assurance Program. Available at: https://vfa.vic.gov.au/__data/assets/pdf_file/0006/479697/VSQAP-V1.6.pdf (Accessed on: 05/11/21)

Water Act 1989 (Victoria). Available at: Water Act 1989 (legislation.vic.gov.au)

White, M., Griffioen, P. and Newell, G. (2020). Multi-temporal Native Vegetation Extent for Victoria. Arthur Rylah Institute for Environmental Research Technical Report No 311. Department of Environment, Land, Water and Planning

Wilkes, R., Best, M., Kolbe, K., Neto, J., Rossi, N., Scanlan, C. (2014). Using Opportunistic Macroalgal Blooms as a tool for assessing ecological status for the EU Water Framework Directive. Presented at conference: 2014 Joint Aquatic Sciences Meeting in Oregon. Prepared by the Environmental Protection Agency, Ireland.

Wong, W. W., Greening, C., Shelly, G., Lappan, R., Leung, P.M. (2021). Effects of Effects of drift algae accumulation and nitrate loading on nitrogen cycling in a eutrophic coastal sediment. Science of The Total Environment, Volume 790, 2021, 147749, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2021.147749

Appendix 1: Water quality indices & frameworks

Existing strategies across the PPB region and the rest of Victoria focus on improving the health of the rivers, wetlands and estuaries.

MW's HWS 2018-28 has set long-term targets to improve the condition of waterways in PPB and Westernport regions. The strategy primarily aims to sustain the diverse and thriving biodiversity, protection of ecosystem services, and preservation of amenity to local communities (MW, 2018). The implementation is supported by five co-designed catchment programs, where each of the riverine catchments have been evaluated and scored on the current state, the current trajectory, and target trajectory against the nine key values and eleven waterway conditions (Figure 10).

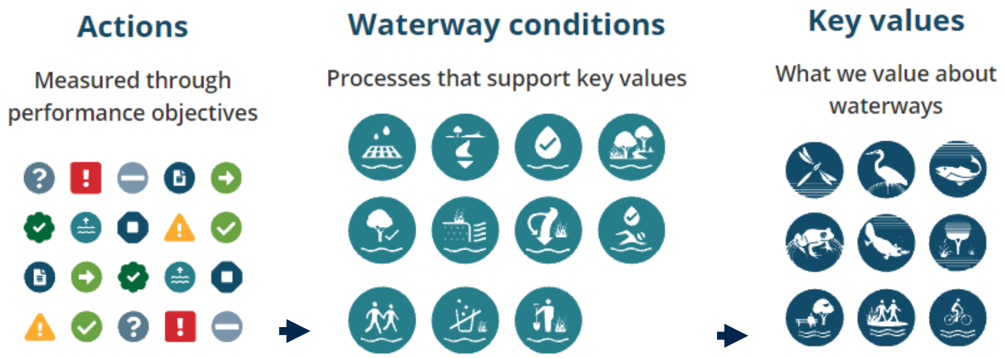


Figure 10: Core components of the Melbourne Water Healthy Waterways Strategy 2018-28 (MW, 2018).

Actions relevant to the Eutrophication Index currently being undertaken as part of the MW strategy to improve water quality include reducing agricultural run-off, STP loads, community septic tank inputs, industrial run-off, and construction run-off. Other waterway conditions that could mitigate nutrient loads or prevent the incidence of algal blooms include establishing vegetation buffers, infiltrating stormwater, and improving flow regimes. The short-term progression of these performance objectives is reported annually on the

Figure 11: Report Carding example from the Melbourne Water Healthy Waterways Strategy 2018-28 for three PPB catchments. Tracking the performance objectives up to 2020 for reducing agricultural run-off to improve water quality (MW, 2018).

OFFICIAL

interactive online report carding system available at healthywaterways.com.au/report-card (Figure 11).

EPA produces an annual report card summary for environmental water quality in PPB, Western Port, Gippsland lakes, and their catchments. Scores are calculated against environmental quality objectives for relevant indicators in the ERS and combined to produce an overall Water Quality Index score (WQI) corresponding to ratings from Very Poor to Very Good (EPA, 2020). The indicators used for the catchment waterway sites, and bays and lakes are algae (chlorophyll *a*), dissolved oxygen, metals, nutrients (total nitrogen), pH, salinity, and water clarity.

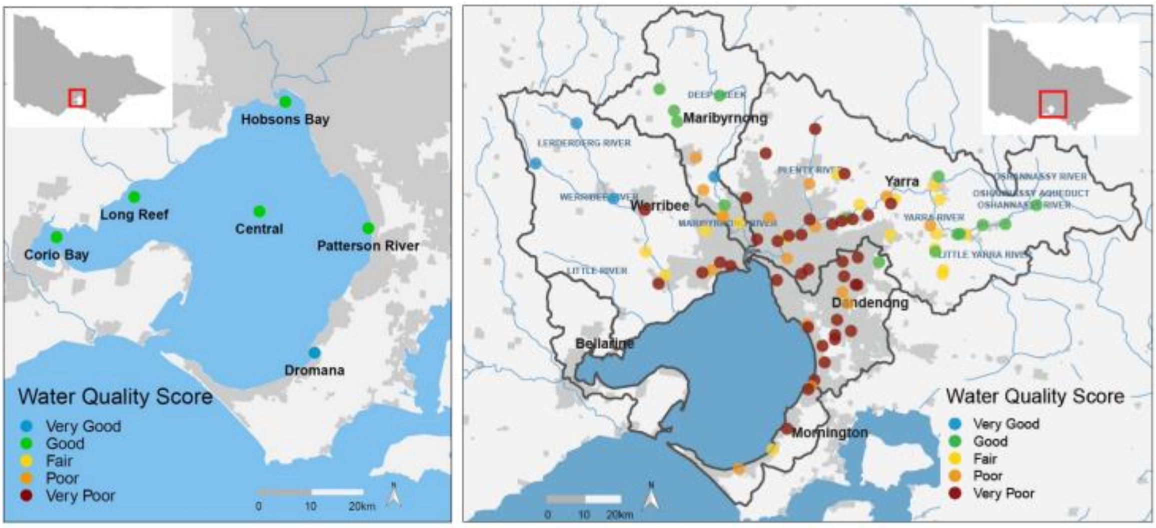


Figure 12: 2019-2020 WQI report card results across the PPB catchment and marine sites (EPA, 2020).

The report card for the PPB and the catchment is calculated using data acquired from over 100 MW monitoring sites and the six marine EPA sites in PPB (Figure 12). Only sites that have a minimum of six samples within 12-months receive a WQI score. Since 2018, EPA has transitioned away from the interactive Yarra and Bay site which published results for embayments, catchments, and individual sites to publishing brief annual PDF versions of the report cards which only display results for embayments and catchments.

At DEECA, surface water monitoring occurs across the state under Victoria's Regional Water Monitoring Partnership's program and involves 51 organisations. This is aligned to the *Water Act 1989*, which states water resource assessment programs must provide for the collection, collation, analysis, and publication of information about water quality (*Water Act 1989*). Data collected in the catchment waters for each of the regions is stored on the Water Measurement Information System (WMIS) and accessed via data.water.vic.gov.au. Relevant parameters measured include, but are not limited to turbidity, dissolved oxygen, and nutrients.

In 2010, the Victorian government, in conjunction with the Catchment Management Authorities (CMAs), undertook the third statewide assessment of river condition and reported on the Index of Stream Condition (ISC). The benchmarking process incorporates information on five aspects of river condition; hydrology, streamside zone, physical form, water quality and aquatic life to produce an overall measure of environmental condition (Figure 13).

Hydrology	Physical Form	Streamside zone	Water Quality	Aquatic Life
Hydrology refers to the amount of water that is within the river channel at a particular point in time at a particular 15 years of monthly flow data is used.	Physical form takes into account the river bank condition as well as instream habitat (logs or 'snags') and major such as dams and artificial weirs.	Streamside zone measures characteristics of the woody vegetation within 40 metres of the river's edge. • Width • Fragmentation • Overhang • Cover of trees and shrubs • Structure • Large Trees • Weeds	Water quality is the quality of water in the river.	Aquatic life is based on the number and type of aquatic macroinvertebrates found within the river.
• Low flows • High flows • Zero flows • Seasonality • Variability	• Bank condition • Artificial barriers • Instream woody habitat		• Total Phosphorus • Turbidity • Salinity (EC) • pH	• AUSRIVAS • SIGNAL • EPT • Number of Families

Figure 13: 2010 statewide assessment of river condition, featuring sub-indices and metrics for calculating the ISC (DELWP, 2010).

Each river is given an overall score between 0-50 and categorised into five condition ratings, very poor to excellent (Figure 14). The ISC is based on a referential approach, where each section of river is compared to a minimally disturbed or altered site, which has been established through using historical data, modelling or expert opinion (DELWP, 2010). The ISC report informs strategic planning for CMA's regional waterways strategies and assists with prioritising work programs.

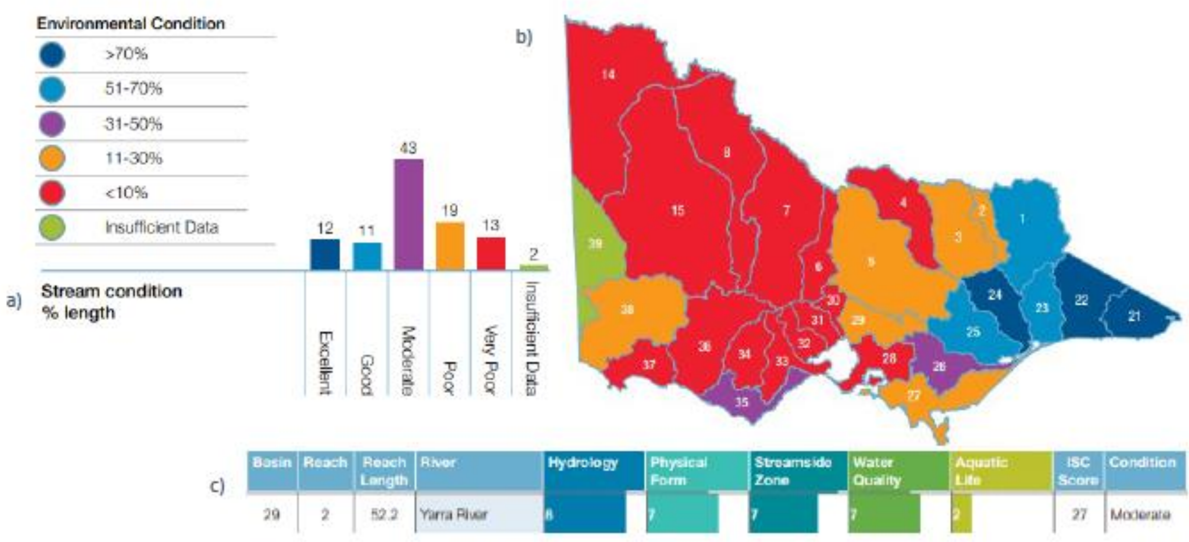


Figure 14: State-wide results from the 2010 ISC report and legend for environmental condition. a) Histogram showing overall state-wide stream condition by percentage length for the state, b) Map of percentage basins demonstrating good or excellent condition (numbers denoting basin names), c) Snapshot result from one section of the Yarra River in the Yarra Ranges scored against each of the five ISC criteria (DELWP, 2010).

DEECA has developed a consistent method for assessing the environmental condition of estuaries, the Index for Estuarine Condition (IEC). The first statewide report was published in 2021 and assessed 101 Victorian estuaries (DELWP, 2021a). The IEC integrates information based on five sub-indices, complementing the ISC, and are scored from one (poorest condition) to 10 (best condition). Measures are proportionally weighted and combined based on their contribution to the sub-index, with several metrics in some cases to calculate one

OFFICIAL

measure (Table 15). The metric is also classified on type determining whether it is a threat or condition, in addition to the metric response to the threat (e.g. decrease or increase).

Table 15: Adapted from Index of Estuarine Condition (IEC) background and methods document 2021, showing sub-indices, measures, response to threats and metrics (DELWP, 2021a)

Sub-index	Measure	Metrics	Response to threat	Scoring range	Metric type
Physical Form	Artificial Barriers	% natural length affected	Increase	1 - 5	Threat
	Artificial Shorelines	Proportion of perimeter bounded by built structures	Increase	1 - 5	Threat
Hydrology (Modification)	Marine exchange	% artificial openings	Increase	1 - 5	Threat
	Freshwater inflows	% winter and summer runoff intercepted	Increase	1 - 5	Threat
Water Quality	Turbidity	Turbidity	Increase	1 - 5	Condition
	Chlorophyll *a*	Chl *a* concentration	Increase	1 - 5	Condition
Flora (Vegetation)	Fringing	%, nativeness, structural complexity	Decrease	0 - 100	Condition
	Submerged	Ratio of macroalgae to total submerged	Increase	1 - 5	Condition
Fish	Fish assemblages	Richness, species, relative abundance	Decrease	1, 3, 5	Condition
	Non-native	Presence/absence of introduced species	Present	1 - 5	Condition

Community-led water monitoring programs also occur across Victoria, these include WaterWatch and EstuaryWatch, which have been active organisations for over 25 years. In addition to collecting important data on the quality of Victoria's waterways and basins, the program encourages stewardship, fosters participation, and raises awareness. Groups follow best-practice procedures and adopt Quality Assurance/Quality Control to reflect data confidence. Key water physical chemical parameters that are recorded by groups are turbidity, ammonia, nitrate, dissolved oxygen, and reactive phosphate, as well as surveying for macroinvertebrates and occasionally scoring habitat condition (Riverness Pty Ltd, 2015).

Appendix 2: Eutrophication Index concept

The development of a Eutrophication Index for PPB was prompted by the need for a data-driven integrated approach for assessing eutrophication impacts as required by the EMP MERI. Eutrophication indices or equivalent nutrient metrics have been implemented globally, however few are applied to both coastal waters and the catchment. New Zealand have adopted a Trophic Level Index (TLI) for assessing the health of lakes using four separate water quality parameters: total nitrogen, total phosphorous, water clarity, and chlorophyll-a (LAWA, 2020). The lake body is then assigned a category and status as per Figure 15.

VERY GOOD — **Microtrophic**: The lake is very clean with very low levels of nutrients and algae. The lake can have snow or glacial sources.

GOOD — **Oligotrophic:** The lake is clear and blue, with low levels of nutrients and algae

FAIR — **Mesotrophic:** The lake has moderate levels of nutrients and alga

POOR — **Eutrophic:** The lake is murky, with high amounts of nutrients and algae

VERY POOR — **Supertrophic:** The lake has very high amounts of phosphorus and nitrogen and can be overly fertile and often associated with poor water clarity. Excessive algae growth can occur. Suitability for recreational purposes is often poor.

Figure 15: TLI status and category.

A similar index is also used by the United States Environmental Protection Agency (US EPA) called the Trophic State Index (TSI) intended for estimating the state of lakes and reservoirs based on the biological productivity they sustain (US EPA, 2000). Criteria variables for estimating enrichment include measures of nutrient concentrations, plant biomass, and watershed attributes, as shown in Table 16.

Table 16: Selection of criteria indicators used for determining TSI for lakes and reservoirs (US EPA, 2000)

Criteria theme	Eutrophication-related variables	Apparent measure
Nutrient concentrations	Total phosphorous	Nutrient concentration, biomass
	Total nitrogen	Nutrient concentration, biomass
Macroalgal/algal biomass	Total organic carbon	Biomass
	Chlorophyll pigments	Algal biomass, photosynthetic capacity
	Suspended solids	Suspended biomass
	Transparency	Suspended algal biomass
	Turbidity	Suspended algal biomass
	Direct algal counts/ Biovolume	Algal biomass
	Biological oxygen demand (BOD)	Algal biomass

OFFICIAL

	Macrophytes	Total macrophyte biomass (kg) TSMB= surface water area (SA) x % cover (C) x average biomass (B)
Other	Dissolved oxygen	DO concentrations near bottom of water body
	Biological community structure	Bioassessment aquatic species and groups
Watershed	Land use	Compositional percentage using GIS

Land use information in the watershed has been delineated through mapping using remote sensing and geographic information systems to establish a compositional percentage range using the following categories: forest, water, wetlands, and marsh, cultivated, pastured, and developed land (U.S. EPA, 2000).

Following the US EPA National Nutrient Assessment Workshop in 1996, it was decided that the most robust TSI variables for indicating early signs of eutrophication are total phosphorous, total nitrogen, chlorophyll *a,* Secchi transparency, and dissolved oxygen, in addition to one watershed metric – land use and associated phosphorous loading. Therefore, these variables above are required as a minimum for calculating the TSI and can be augmented further using the other candidate variables listed (US EPA, 2000). There has been some effort in the National Coastal Condition Report IV in applying the index to assessing the potential downstream effects of nutrient inputs in the watershed, leading to expressions of eutrophication on the open coast (U.S. EPA, 2012). The five component indicators used in the report were dissolved inorganic nitrogen, dissolved inorganic phosphorous, chlorophyll *a*, water clarity, and dissolved oxygen.

Marine eutrophication has been thematically assessed in the Baltic Sea, through the development of a Eutrophication Index by the Helsinki Commission (HELCOM). The intergovernmental organisation, made up of ten contracting parties, established the index based on expert elicitation in response to requirements listed in the Baltic Sea Action Plan (HELCOM, 2009), with later refinement of indicators for State of the Baltic Sea Assessment (HOLAS II, 2011-2016).

The index uses a multi-metric method referred to as the HELCOM Eutrophication Assessment Tool (HEAT 3.0), which compares the indicator parameters to threshold values or nutrient allocated reduction targets and aggregates each indicator result into a quantitative estimate of overall eutrophication status (HELCOM, 2018a). The HEAT tool aligns with an equivalent tool which evaluates the status of marine biodiversity (Nygård et al, 2018) and follows a similar nested integrated structure (Figure 16).

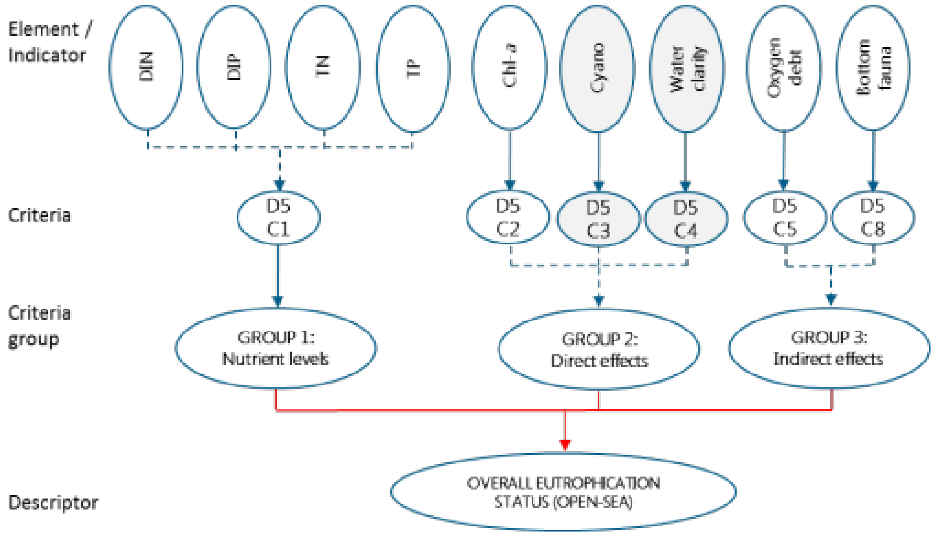


Figure 16: The HELCOM structure of conducting the eutrophication assessment in open-sea areas in the Baltic Sea. Showing the aggregation of indicators into criteria groups (HELCOM, 2018a).

OFFICIAL

The OSPAR commission, consisting of 15 governments and the European Union, has also developed a eutrophication assessment framework for maritime areas. The areas included in the framework are Artic Waters, the Greater North Sea, Celtic Seas, and the Bay of Biscay. This is referred to as the Common Procedure and fosters a shared approach across the jurisdictions to periodically assess the status of eutrophication (OSPAR, 2016). The program is augmented by long-term data acquired through dedicated monitoring of:

- Atmospheric inputs.
- Riverine inputs and direct discharges.
- Concentrations and effects in the marine environment.

Nutrient abatement activities are modelled alongside monitoring data to understand nutrient reduction scenarios and areas are assigned under three categories: problem areas, potential problem areas, and non-problem areas. The OSPAR eutrophication framework follows a comprehensive diagnostic procedure with harmonised assessment parameters across the contracting parties, these are divided into four categories (Table 17) identifying the causal links between disturbances and nutrient enrichment (OSPAR Commission, 2008).

Table 17: Parameters required for estimating eutrophication status in the OSPAR integrated common procedure (COMP). Harmonised parameters (shaded) and additional voluntary parameters (*) (OSPAR commission, 2008)

Category #	Category	Parameter
I	Degree of nutrient enrichment	Riverine inputs and direct discharges
		Winter DIN and DIP concentrations
		N/P ratio
		*Total nitrogen, total phosphorous
		*Transboundary nutrient transport
		*Atmospheric nitrogen deposition
		*Silicate (and SI ratios)
II	Direct effects	Chlorophyll *a*
		Phytoplankton indicator species
		Macrophytes including macroalgae (shifts in species)
III	Indirect effects	Oxygen deficiency and lowered % saturation
		Kills in fish and zoobenthos
		Long-term changes in zoobenthos biomass and species composition
		*Organic carbon
		*Secchi depth
IV	Other possible effects	Algal toxins

Succeeding the initial broad-brush identification of areas of concern by OSPAR, the Common Procedure method is then applied nationally in each of the country's maritime areas to establish the eutrophication status (Figure 17). The assessment utilises a nested approach characterising 'estuarine or transitional' within one nautical mile, 'coastal' with a salinity range between 30 to ≤ 34.5, and 'offshore' salinity of ≥ 34.5.

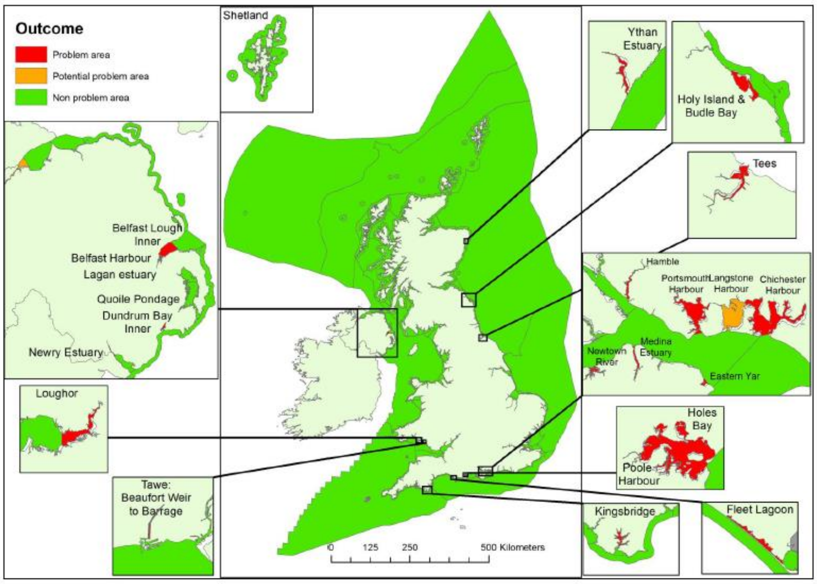


Figure 17: Example of the National Common Procedure approach three (COMP3) applied in UK to assess the level of eutrophication. It can be observed that most marine areas are 'non-problem areas' with a small proportion of 'problem areas' in transitional (estuarine) and coastal waters, typically with restricted water circulation (Painting et al, 2016).

Appendix 3: Dissolved Oxygen status assessment

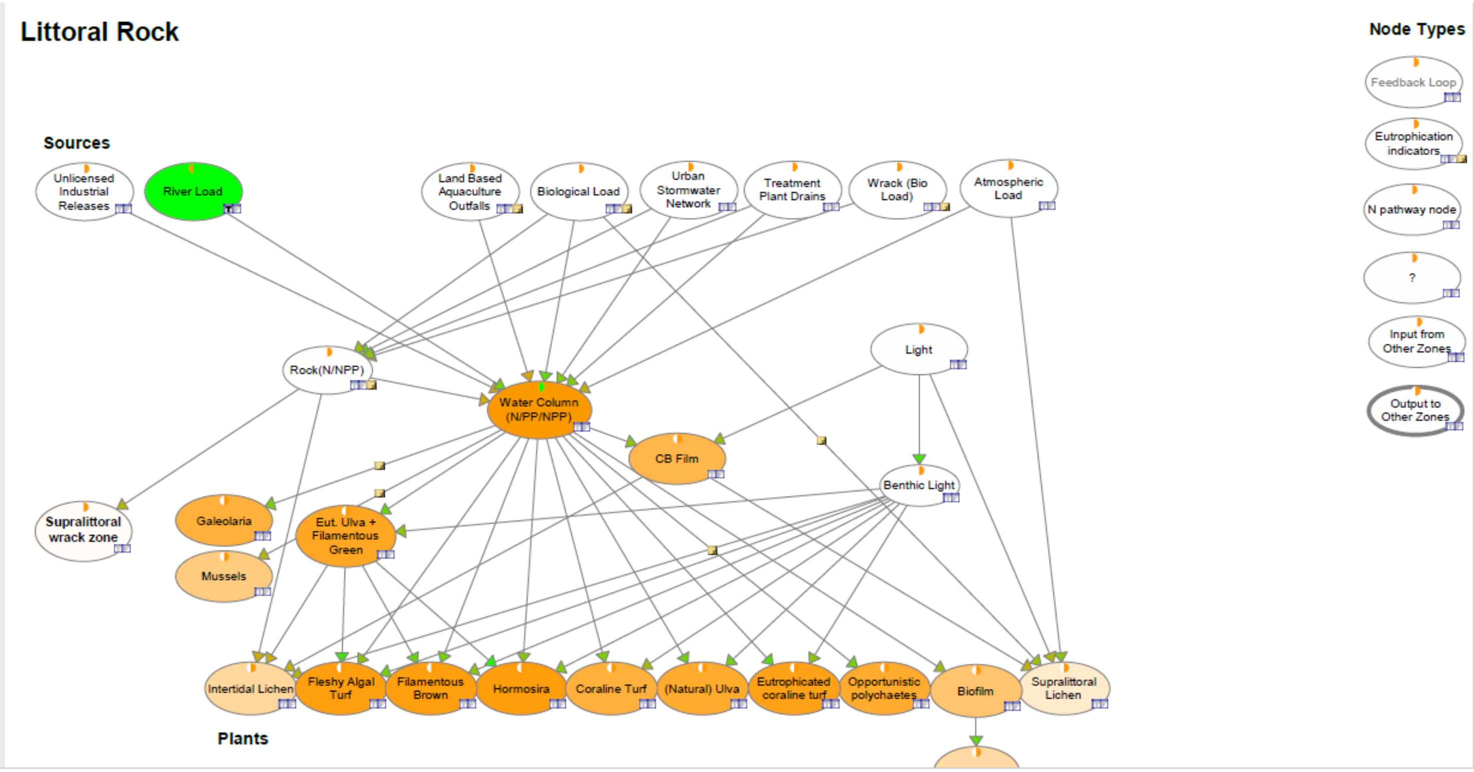
To determine the status assessment for dissolved oxygen (DO), scores have been assigned based on extensive stakeholder engagement in 2022, with the results found below in (Table 18).

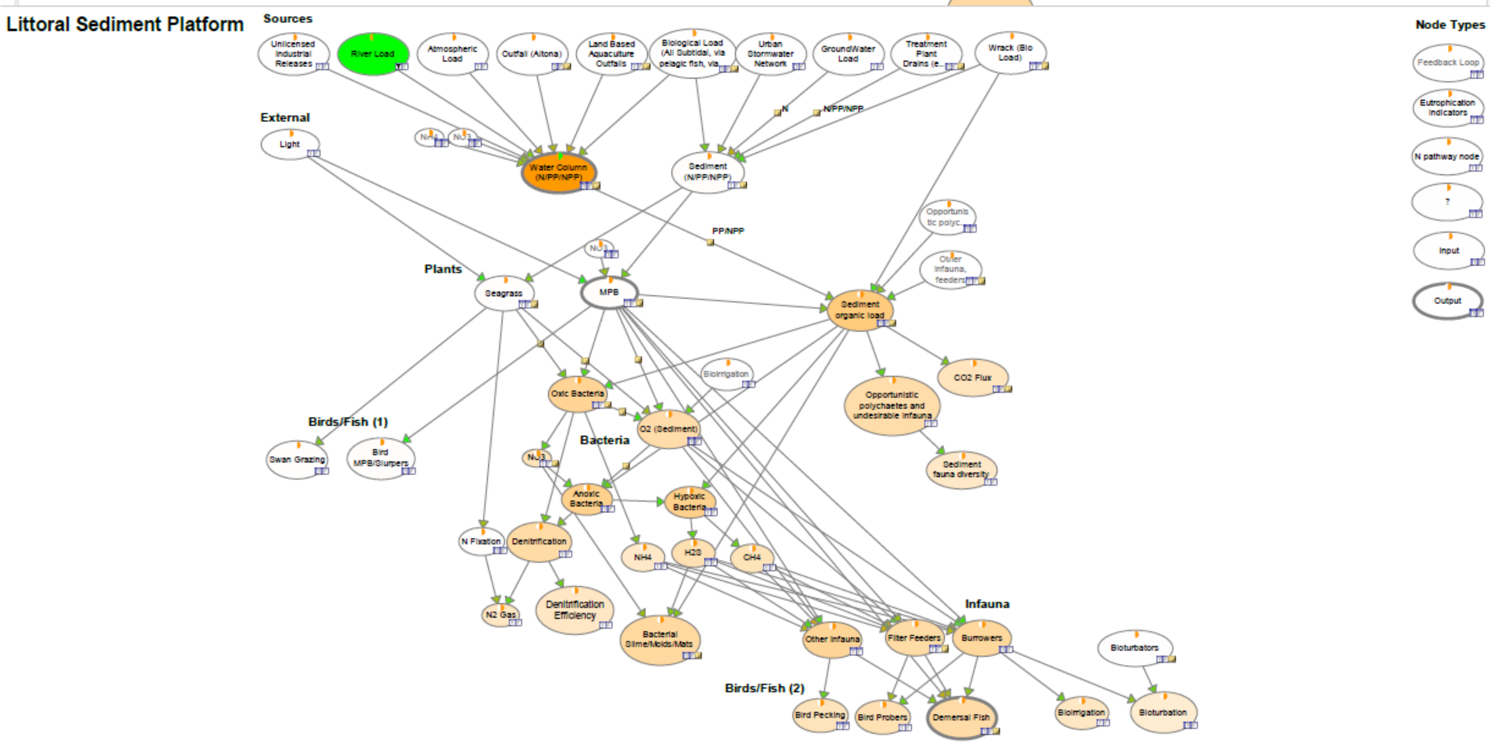
Table 18: DO status assessment scoring thresholds

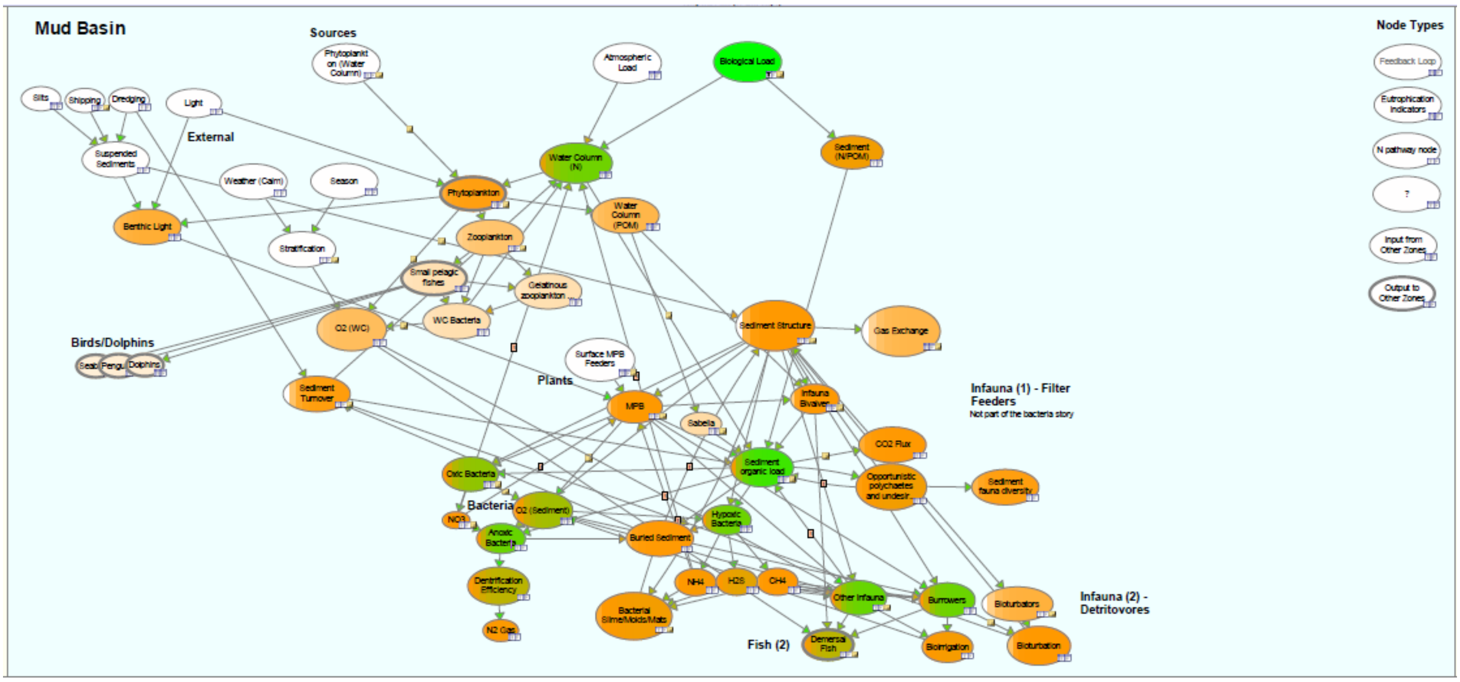
		ERS 25th percentile - max	VERY POOR	POOR	FAIR	GOOD	VERY GOOD
Marine: PPB	Hobsons Bay	*80-130*	<60 or >130	60- 70	70- 80	80- 100	100 - 130
	Central-East	*80-130*	<60	60- 70	70- 80	80- 100	100 - 130
	Geelong Arm	*N/A*					
	Exchange	*N/A*					
Central foothills and coastal plains	Lowlands: Moorabool, Werribee, and Maribyrnong basins	*70-130*	<60	60-65	65-70	70-100	100- 130
	Lowlands: Yarra and Bunyip basins	*75-130*	<60	60-65	65-75	75-100	100- 130
	Uplands: Moorabool, Werribee, and Maribyrnong basins	*70-130*	<60	60-65	65-70	70-100	100- 130
Urban	Tributaries: Werribee and Maribyrnong Rivers	*60-130*	<50	50-55	55-60	60-100	100-130
	Tributaries: Yarra River	*70-130*	<60	60-65	65-70	70-100	100- 130

Appendix 4: Eutrophication zone models

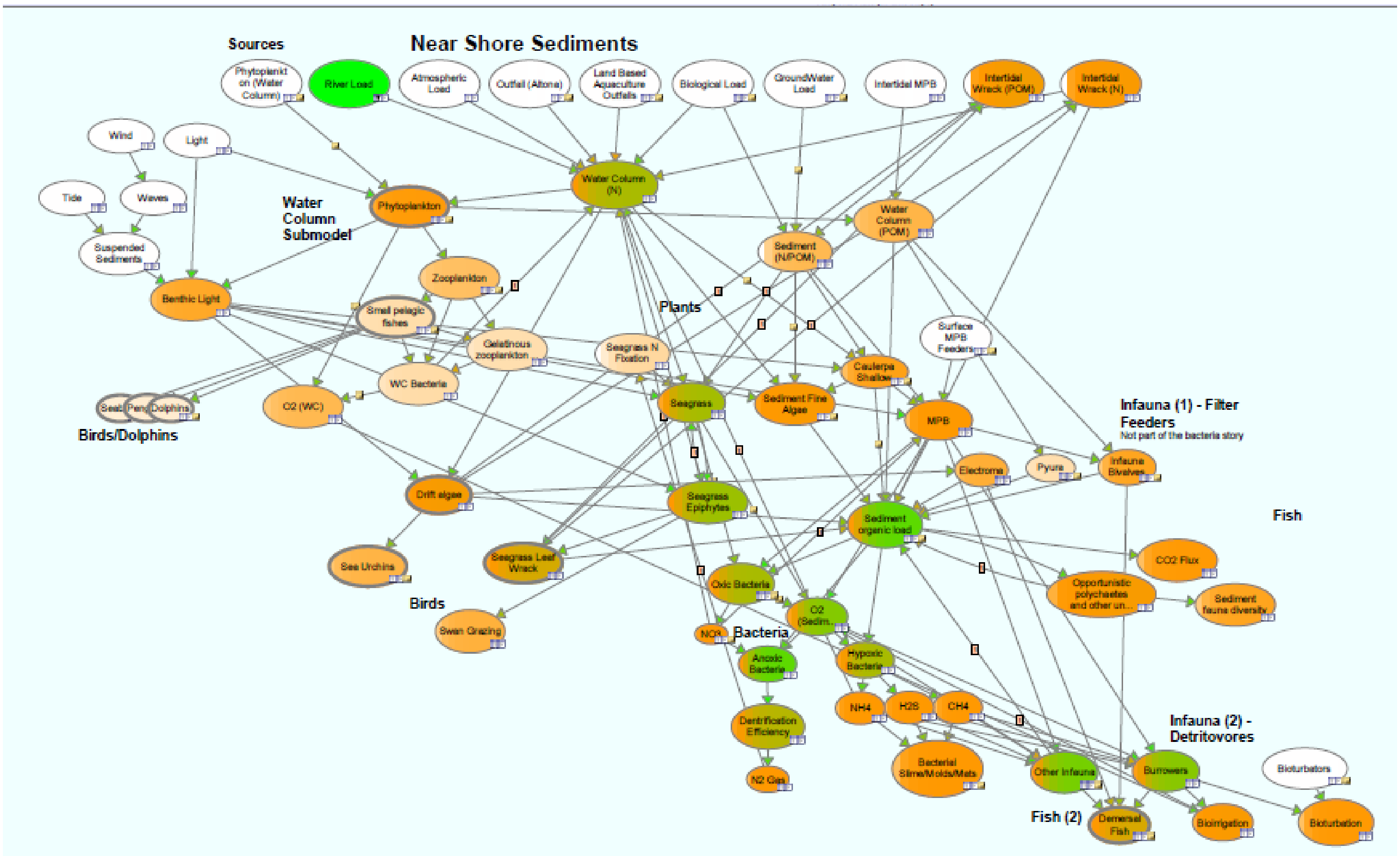
Over 60 eutrophication models have been created for DEECA by Bayesian Intelligence for the six zones in PPB. Included in this appendix are only the riverine source interactions and biological loading for mud basin zones. The darker orange indicates a moderate to strong probability of change, and green a near certain probability of change.



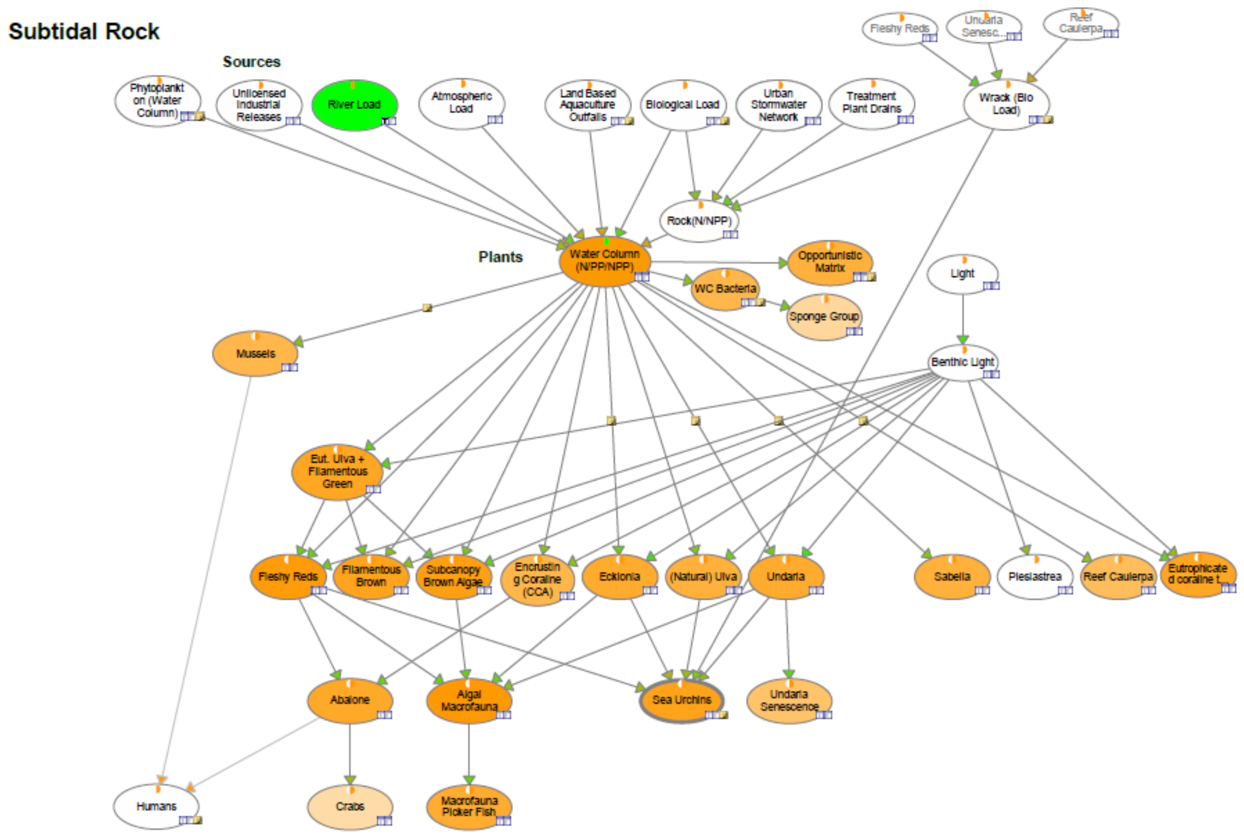




Mud Basin
Sources
External
Birds/Dolphins
Plants
Bacteria
Infauna (1) - Filter Feeders
Not part of the bacteria story
Infauna (2) - Detritovores
Fish (2)
Node Types
Feedback Loop
Eutrophication Indicators
N pathway node
?
Input from Other Zones
Output to Other Zones



Near Shore Sediments
Sources
Water Column Submodel
Plants
Birds/Dolphins
Birds
Bacteria
Infauna (1) - Filter Feeders
Not part of the bacteria story
Fish
Infauna (2) - Detritovores
Fish (2)
River Load
Atmospheric Load
Outfall (Altona)
Land Based Aquaculture Outfalls
Biological Load
GroundWater Load
Intertidal MPB
Intertidal Wreck (POM)
Intertidal Wreck (N)
Wind
Light
Tide
Waves
Suspended Sediments
Phytoplankton
Water Column (N)
Water Column (POM)
Sediment (N/POM)
Benthic Light
Zooplankton
Small pelagic fishes
Gelatinous zooplankton
Seagrass N Fixation
Caulerpa Shallow
WC Bacteria
O2 (WC)
Seagrass
Sediment Fine Algae
MPB
Drift algae
Seagrass Epiphytes
Electroma
Pyura
Infauna Bivalves
Sediment organic load
Sea Urchins
Seagrass Leaf Wrack
CO2 Flux
Oxic Bacteria
Opportunistic polychaetes
Sediment fauna diversity
Swan Grazing
NO3
Anoxic Bacteria
Hypoxic Bacteria
NH4
H2S
CH4
Denitrification Efficiency
N2 Gas
Bacterial Slime/Molds/Mats
Other Infauna
Burrowers
Bioturbators
Demersal Fish
Bioirrigation
Bioturbation


Subtidal Rock
Sources
Phytoplankton (Water Column)
Unlicensed Industrial Releases
River Load
Atmospheric Load
Land Based Aquaculture Outfalls
Biological Load
Urban Stormwater Network
Treatment Plant Drains
Fleshy Reds
Undaria Senesc...
Reef Caulerpa
Wrack (Bio Load)
Rock(N/NPP)
Plants
Water Column (N/PP/NPP)
Opportunistic Matrix
WC Bacteria
Sponge Group
Light
Mussels
Benthic Light
Eut. Ulva + Filamentous Green
Fleshy Reds
Filamentous Brown
Subcanopy Brown Algae
Encrusting Coraline (CCA)
Ecklonia
(Natural) Ulva
Undaria
Sabella
Plesiastrea
Reef Caulerpa
Eutrophicated coraline t...
Abalone
Algal Macrofauna
Sea Urchins
Undaria Senescence
Humans
Crabs
Macrofauna Picker Fish

OFFICIAL