Project Plan SP 2022-034

Using Swan Canning Estuarine Response Model to optimise oxygenation plant efficiency

BCS Rivers and Estuaries Science

Project Core Team

X X **Supervising Scientist** Kerry Trayler
Data Custodian Sri Adiyanti

Project status as of May 24, 2023, 9:44 a.m.

X X Approved and active

Document endorsements and approvals as of May 24, 2023, 9:44 a.m.

X X
Project Team granted
Program Leader granted
Directorate granted
Biometrician granted
Herbarium Curator not required
Animal Ethics Committee not required

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Program

BCS Rivers and Estuaries Science

Departmental Service

Service 6: Conserving Habitats, Species and Communities

Project Staff

X X X **Role Person Time allocation (FTE)**

Research Scientist Sri Adiyanti 0.5

Supervising Scientist Kerry Trayler 0.02

Technical Officer Tom Ryan 0.2

Technical Officer Marco Warmt$_{M}urray0.2$

Related Science Projects

None

Proposed period of the project

Sept. 1, 2022 – Sept. 1, 2024

Relevance and Outcomes

Background

The occurrences of anoxia (no oxygen) and hypoxia (very low oxygen) are often observed in the bottom waters of many estuaries (Roberts *et al*., 2012), as a result of environmental conditions associated with the interaction between tides, riverine inflows, meteorological forcing and internal biogeochemical processes. The balance between tide-driven pulsing of oceanic water (saline water) and riverine inflows (fresh water) typically sets up a salt-wedge stratification pattern that restrict vertical mixing between oxygen-depleted bottom waters and oxygen-saturated upper water.

The extent and severity of oxygen depletion can vary across the estuary depending upon the hydrodynamic condition as well as biogeochemical processes such as mineralisation of organic matters, photosynthesis and sediment oxygen demand (Zhu *et al*, 2016). The negative impacts of persistent low oxygen on the estuarine internal nutrient loading and estuarine biota have been well documented (Howarth *et al*., 2011; Testa and Kemp, 2012), however finding long-term solutions remain a challenge in many parts of the world (Zhang *et al*., 2010).

The Swan River estuary is a diurnal, micro-tidal estuary which passes the city of Perth and discharges to the Indian Ocean at Fremantle in Western Australia. The upper estuary is a narrow, shallow and meandering channel, generally well-mixed in winter and partially to highly stratified in other seasons, depending on the salt-wedge and relative intensity of tidal mixing and gravitational circulation (O'Callaghan *et al*., 2007). This morphology and dynamic cause the tide-driven salt wedge to reach the upper estuary.

Eutrophication-related oxygen depletion in the upper reaches of the Swan River estuary has been recorded and has contributed to poor water quality and fish deaths in 2003-2005, 2009 and 2012. As part of a multi-pronged strategy to mitigate the eutrophication in the estuary, side-stream supersaturation oxygenation plants have been installed in the upper reaches of the estuary in Guildford (in 2008) and Caversham (in 2011). Testing over five days of operation showed that these plants can influence oxygen conditions in the upper Swan River estuary over a stretch of 11.5km (Larsen *et al*., 2019).

Key performance indicators (KPI's) are in place to ensure the oxygenation plants achieve the target oxygen concentration. These are applied at the operational level as monitoring guideline and reported to the Minister for Environment as KPI target for the River Protection Strategy requiring that >80% of all individual dissolved oxygen measurements in the oxygenation zone are above 4 mg/L.

Estuarine environments are complex and detailed investigations are required to ensure oxygenated water distribution is responsive to the changes in hydrodynamic and biogeochemical conditions. These are essential to improve the oxygenation in the Swan River estuary.

But these conditions are dynamic at many temporal scales. In addition, climate change needs to be factored into management of the oxygenation plants. Observations on the effect of climate change to freshwater, estuarine water coastal water and marine water have seen higher adverse impacts than predicted (IPCC, 2022). Since surface warming in 1950s, ocean acidification (as a result of increasing CO_2 levels in the atmosphere) and deoxygenation are identified as key threatening factors to the biodiversity of aquatic environment, particularly in estuarine waters. The seventh biennial State of Climate report (bom.gov.au/state-of-climate) reported, since 1910 Australia's climate has warmed by an average of 1.47+0.24°C, and since 1970 in southwest of Australia a decline rainfall approx. 15% in April to October and 19% in May to July, leading to a significant decrease in streamflow.

There are plausible adverse impacts of this climate change on the current oxygenation operation in the upper Swan River estuary and these need to be investigated to proactively define the necessary adaptation approach for oxygenation over the coming decade.

Aims

The project will contribute to improve oxygenation approaches in the Swan River estuary by developing better understandings of variability and drivers of oxygen conditions. This will be achieved through application of the 3D hydrodynamic oxygen predictive model, namely the Swan Canning Estuarine Response Model (SCERM) to address the specific aims:

1. Understanding of the impact of seasonal variations of the estuary conditions on the extent of the oxygenation plant generated plumes.
2. Understanding how salt wedge dynamics influence oxygen distribution.
3. Understanding the influence of the catchment inflow water quantity and quality.
4. Assessment on possible improvement of the oxygenation plants efficiency by changing the current diffuser locations and flow-rate.
5. Assessment on the need to alter the oxygenation plants capacity as a response to climate change scenario 2030, i.e., increase in air temperature, ocean acidification, less rainfall.

Expected outcome

The project will provide key understandings on the Swan River estuary's hydrodynamic (water level, temperature and salinity) and oxygen dynamic based on 5-years (2018-2023) validated oxygen model, which will assist the oxygenation plants managers in optimizing the plants operation and adaptation of climate change impact on the operation.

Knowledge transfer

During the life of the project, reference group meetings are scheduled every 6 weeks. At the meeting, the project leader presents the project progress and discusses any issues that arise with reference/experts, project team members and stakeholders which include the oxygenation team in Rivers and Estuaries Branch (REB). This forms an on-going knowledge transfer process. Additional meetings and discussions will be organized as required.

The project leader will work with managers during the project to enable their input of data supporting model validation. In addition managers will be able to input their expertise in oxygenation management into scenario development (Aims 4 & 5).

The project leader will also provide some additional educational material (in the form of a presentation) to support learnings of managers / junior scientists in model frameworks.

At the end of the project, knowledge gained will be conveyed to the oxygenation team in Rivers and Estuaries Branch of the Conservation and Ecosystem Management Division and other relevant teams in Rivers and Estuaries Science (RES).

Tasks and Milestones

Deliverables and time frames:

Year 1:

- Calibrated and Validated SCERM29 (meshgrids from Upper Swan to Narrows, 2D inflow at Narrows, 29 1D catchment inflows, 2D meteorological forcing) hydrodynamic model for simulation period 2018-2022: 31 May 2023.
- Flow measurements using a boat-mounted Acoustic Doppler Current Profiler (ADCP) performing continuous transects across the estuary around Guilford and Caversham over a tide cycle: June and November 2023 (exact dates TBC).
- Creation of new meshgrids using an updated Swan Canning bathymetry based on the latest hydrographic survey from Ashfield Flat to Belhus (planned in July 2023): 11 August 2023.
- Application of oxygen module, oxygenation spargers hydraulic and operational parameters in SCERM29 hydrodynamic-oxygen model, calibration and validation: 22 September 2023.
- Application of some climate change scenarios (multiple cases of meteorological and rainfall) and impact assessment on oxygenation dynamic: 30 April

Note, WA future climate model by Climate Science Initiative will be accessible from DWER platform in 2024.
Year 2:

- Application of some scenarios of diffuser/spargers locations / operational management to adopt results of climate change scenarios (Year 1 output) and maximise efficiency : 31 May 2024.
- Draft report: 30 September 2024.
- Final report: 31 October 2024.

References

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Study design

Methodology

Detailed steps required to achieve the 5 specific aims are described below.

Aim 1: Understanding of the impact of seasonal variations of the estuary conditions on the extent of the oxygenation plant generated plumes, and **Aim 2: how salt wedge dynamics influence oxygen distribution**.

The Swan Canning Estuarine Response Model (SCERM) developed by the UWA-AED group (Paraska, *et al*. 2022) in collaboration with DBCA will be modified to suit the purpose of this project. Modifications to the original SCERM (with 44 catchment inflows; hence it's called SCERM44) will include a more localised model domain (spanning from the upper reach/Yagan Bridge in Belhus to the Narrows in Perth), 2D meteorological forcing, and 29 inflows from the contributing catchments; herewith is called SCERM29.

The SCERM29 will require calibration and validation processes using data collected by the oxygenation team in Rivers and Estuaries Branch of the Conservation and Ecosystem Management Division and estuarine monitoring by the Rivers and Estuaries Science (RES) team.

Detailed steps required to achieve Aims 1 and 2 include the model setup, calibration and validation described below.

1. The SCERM29 setup

The SCERM29 consists of a 3D flexible-mesh (finite volume) utilizing the TUFLOW-FV (TFV) hydrodynamic driver and TFV Water Quality Oxygen module. TFV accounts for variations in water level, horizontal salinity distribution and vertical density stratification in response to tides, inflows, salt-wedge dynamics and surface thermodynamics. The mesh consists of triangular and quadrilateral elements of different size that are suited to simulating areas of complex estuarine morphometry. The finite volume numerical scheme solves the conservative integral form of the nonlinear shallow water equations in addition to the advection and transport of scalar constituents such as salinity and temperature as well as dissolved oxygen (DO) concentration.

Boundary condition inputs to the model include:

a. 2D (horizontal grids) initial condition, values are extracted from monitoring data.
b. 2D (vertical grids) hourly inflow at Narrows, values are extracted from SCERM44 model output for the same simulation period.
c. 1D daily 29 inflows (flow, temperature, salinity and DO), values are the output of the Swan Canning Catchment Model (SCCM) simulated using eWater Source for the same simulation period.
d. 2D (horizontal grids) hourly meteorological fluxes: air temperature, air humidity, wind components (u component, parallel to x-axis and v component, parallel to y-axis) are calculated from gridded data of wind speed and direction, incoming shortwave and longwave radiation, and rainfall. Data (1.5km grid) are extracted from Bureau of Meteorology Atmospheric high-resolution Regional Reanalysis for Australia (https://dapds00.nci.org.au/thredds/catalog.html).

Parameters input to the model will be applied from the results of calibration process.

2. The SCCM setup

SCCM domain and parameterizations (including runoff parameters) utilized in the SCCM for this project are derived from Paraska, *et al*. (2022). The eWater Source version 5.20 will be used for this project, instead of the older version Source 4.9 utilized in Paraska, et al. (2022). Rainfall and evaporation data inputs for SCCM are from SILO Australian climate data (https://www.longpaddock.qld.gov.au/silo/).

3. Model validations and assessments

Comparisons between simulated and measured state variables (water level, temperature, salinity and DO) will be presented using time-series plots, vertical profiles, 2D horizontal contours, 2D curtain contours, and animation.

To understand the impact of seasonal (summer, autumn, winter and spring) variations of the estuary conditions on the extent of the oxygenation plumes, and salt wedge dynamics influence on oxygen distribution, the following will be presented:

3a. Time-series plots: seasonal comparison of bottom water DO comparison and percentage of bottom area under hypoxia and low DO in the oxygenation target zone.

3b. Contour plots: comparison of the oxygenation distribution in each season for each year simulation.

3c. Calculation of the exceedance of probability of benthic water experiencing hypoxia and low DO for each season.

3d. Time-series overlay plots of DO, salinity stratification, total hypoxia and low DO area, each at surface and bottom layer.

3e. Time-series overlay plots of DO (surface layer-average) and salt-wedge intrusion variation, from Narrows upstream.

3f. Vertical profiles (seasonally averaged) current speeds at same locations around oxygenation diffusers.

Aim 3: Understanding the influence of the catchment inflow water quantity and quality.

The relationship between inflow water quality and estuarine water quality is complex. Hence the assessment will be based on the sensitivity analysis on the 29 inflows water quality on the calibrated and validated models, to gain insights the most critical catchments outflows on the estuarine oxygen dynamics. When applicable, multi-variate statistical analysis will be applied to evaluate different inflow effects.

Aim 4: Assessment on possible improvement of the oxygenation plants efficiency by changing the current diffuser/sparger locations and flowrate.

Assessment methods described in items 3d to 3f will be utilised.

Aim 5: Assessment on the need to alter oxygenation plants capacity as a response to climate change scenario 2030, i.e., increase in air temperature, increase in ocean-driven tide levels, ocean acidification and less rainfall.

2D boundary conditions meteorological inputs derived from Western Australia future climate produced by Climate Science Initiative will be utilised. The 4km grids datasets are expected to be ready in 2024, accessible via DWER Platform.

Assessment methods described in items 3a to 3f will be utilised to inform the resulting changes in oxygen dynamic. When applicable, metrics such as R^2 (coefficient determination), RMSE (root mean square standard error), and NSE (Nash-Sutcliffe Efficiency) will be utilized.

List of softwares utilised:

Technique Programming Software:

Programming and numeric computing MATLAB® and programming languages Python and R are used for the project for data acquisition, processing and extraction throughout the project.

Mapping Software:

Commercial licence and open-source geographic information system ArcMap ArcGIS and QGIS (respectively) are used to process spatial dataset, a community edition SMS (Surface-water Modeling System) is used for the model meshgrids preparation.

Surface Hydrological Model Software:

eWater SOURCE catchment model is used for generating sub-catchment inflow water quantity (daily flow) and water quality (TN and TP concentrations).

Biometrician's Endorsement

granted

Data management

No. specimens

None

Herbarium Curator's Endorsement

not required

Animal Ethics Committee's Endorsement

not required

Data management

Data utilised and resulted from this project are huge. Simulations are run using GPU and need to be run locally (not on OneDrive storage) as otherwise the simulation time will be very slow.

An external hard drive (5TB) is used as a backup storage and updated for every addition of the files. Every month the data will be transferred to the project share point, following DBCA Record Keeping Policy. Model setup and input files will be shared via DBCA Science GitHub:

https://github.com/orgs/dbca-wa/teams/science

Budget

Consolidated Funds

to | X | X | X | X |

Source	Year 1	Year 2	Year 3
FTE Scientist	60,268	60,268	60,268
FTE Technical	47,472	23,736	
Equipment/Software	9,255	3,255	3,900
Vehicle/Hardware	4,810	1,500	
Travel			
Other: Data	1,000	1,000	
Total	122,805	89,759	64,168

External Funds

to | X | X | X | X |

Source	Year 1	Year 2	Year 3
Salaries, Wages, Overtime			
Overheads			
Equipment			
Vehicle			
Travel			
Other			
Total			