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Modelling the effectiveness of artificial oxygenation in the Swan-Canning estuary

The Swan-Canning estuary, like many other urban waterways around the world, is showing signs of stress with algal blooms and fish kills due to low oxygen waters. One source of stress is the way people use land within the catchment, including both urban and agricultural practices. These can contribute large loads of nutrients and organic matter to the estuary, resulting in symptoms of poor health. Less manageable stresses in the system relate to changes in climate. The climate of south-west Western Australia has been consistently drying over the last 40 years and this has altered the dynamics of the estuary. However, the reduced rainfall and lower streamflow have not similarly lowered the concentration of nutrients entering the estuary. In addition, these nutrients and organic matter stay in the estuarine system rather than being flushed out to sea. Low oxygen in the upper Swan and Canning rivers is now a persistent management challenge, with potentially damaging effects on estuarine biodiversity and the overall amenity and health of the estuary.

The Department of Water, in partnership with the Swan River Trust, has been using artificial oxygenation as a remediation strategy for poor water quality in the upper reaches of the Canning River for more than 16 years, and for the past six years in the upper Swan River. Currently there are two oxygenation plants on each of the Swan and Canning rivers (and a third plant currently being built on the Canning).

Key Points

- Numerical (computer-based) models were created to determine how artificial oxygenation improved conditions in the Swan-Canning estuary.
- Dynamics in estuaries are difficult to model but environmental conditions were well captured in these numerical models, giving us confidence to use these models to explore management questions.
- Simulations showed that the oxygenation plants in the upper Swan improved oxygen conditions in 39-92% of the target oxygenation zone (a stretch of river ~7 km long).
- These models were explored to show the most cost-effective way of operating the plants to achieve the greatest improvement in conditions.

These oxygenation plants pump oxygen-depleted water from near the riverbed, supersaturate it with oxygen, and return the newly oxygenated water to the bottom waters of the estuary.

Although weekly monitoring of water quality and intensive operational trials show obvious improvements in oxygen status due to artificial oxygenation, it is hard to definitively assess the effectiveness of these oxygenation plants given the dynamic estuarine environment. Numerical (computer-based) models can evaluate the effectiveness of these oxygenation plants and they can also be used to explore the cost efficiency of operating strategies.



 Oxygenated plumes of water at Guildford in the upper Swan



 One of the oxygenation plants on the Canning River

The strength of a modelling approach is that various scenarios can be tested, for example, with the oxygenation plants either turned on or off under exactly the same environmental conditions. This allows the influence of oxygenation to be directly calculated. This cannot be done in a field situation, where each day has different environmental conditions like temperature, salinity, wind, rain and algal production (aspects which can also influence oxygen conditions in the estuary).

Using substantial amounts of data collected by the Department of Water and Swan River Trust, researchers at the University of Western Australia have built coupled estuarine models (see Box 1) for the oxygenated zones in the Swan and Canning rivers. These models spanned two discrete areas: one in the upper Swan from the Narrows Bridge to the Great Northern Highway (Fig. 1) and the other in the Canning River, upstream of the Kent Street weir (Fig. 2). These models adequately captured the environmental characteristics of the two systems (as explained in Box 2).

1: About the model

Modelling the estuarine environment is difficult as estuaries are very variable and dynamic. To accurately simulate water oxygen concentrations the model needs to be able to move water around tightly curved reaches in response to the tide and wind, resolve steep vertical concentration gradients associated with the salt-wedge, as well as consider biogeochemical transformations of organic matter, nutrients and oxygen. Several potential model platforms were considered before the model TUFLOW-FV was chosen to model at high-resolution the hydrodynamics (water level, velocity, salinity and temperature distribution) coupled with a model for water column biogeochemistry (Framework for Aquatic Biogeochemical Models with Aquatic Ecodynamic modules developed at UWA).

One of the key causes of low oxygen in estuary waters is the use of oxygen by bacteria in the sediment. Sediment oxygen consumption increases as a result of heavier organic loading in the estuary. A separate high-resolution model was created to estimate nutrient and oxygen fluxes across the sediment–water interface and to help understand the interaction with oxygen conditions. This enhanced understanding helped define the appropriate model parameters used in the two estuary models.

2: Testing that the models accurately reflect environmental conditions

The upper Swan model was calibrated against two years of actual data with variable flow conditions: 2008 was a moderately wet year (~182 GL) and 2010 a dry year (~24 GL). The performance of the Swan model was excellent, as it was able to accurately resolve the seasonal and spatial dynamics observed for salinity and temperature (the R^2 values between predicted and observed results are 0.85 – 0.95). Oxygen conditions are generally well captured both spatially and temporally, with an average error of approximately 20 percent (which is considered excellent performance for models of this type). Modelling nutrients is harder as there are so many potential biogeochemical interactions; consequently model estimates of nutrients were less certain. The excellent performance of the model means managers can be confident in its use to evaluate different operational scenarios.

The Canning River model was calibrated against data from December 2008 to May 2009. The performance of this model was not as good as for the Swan model, most likely due to the lack of local weather data to 'force' local conditions accurately. However, the salinity regime, low oxygen conditions and seasonal dynamics were considered adequately captured and this model was also considered appropriate to evaluate different operational scenarios.

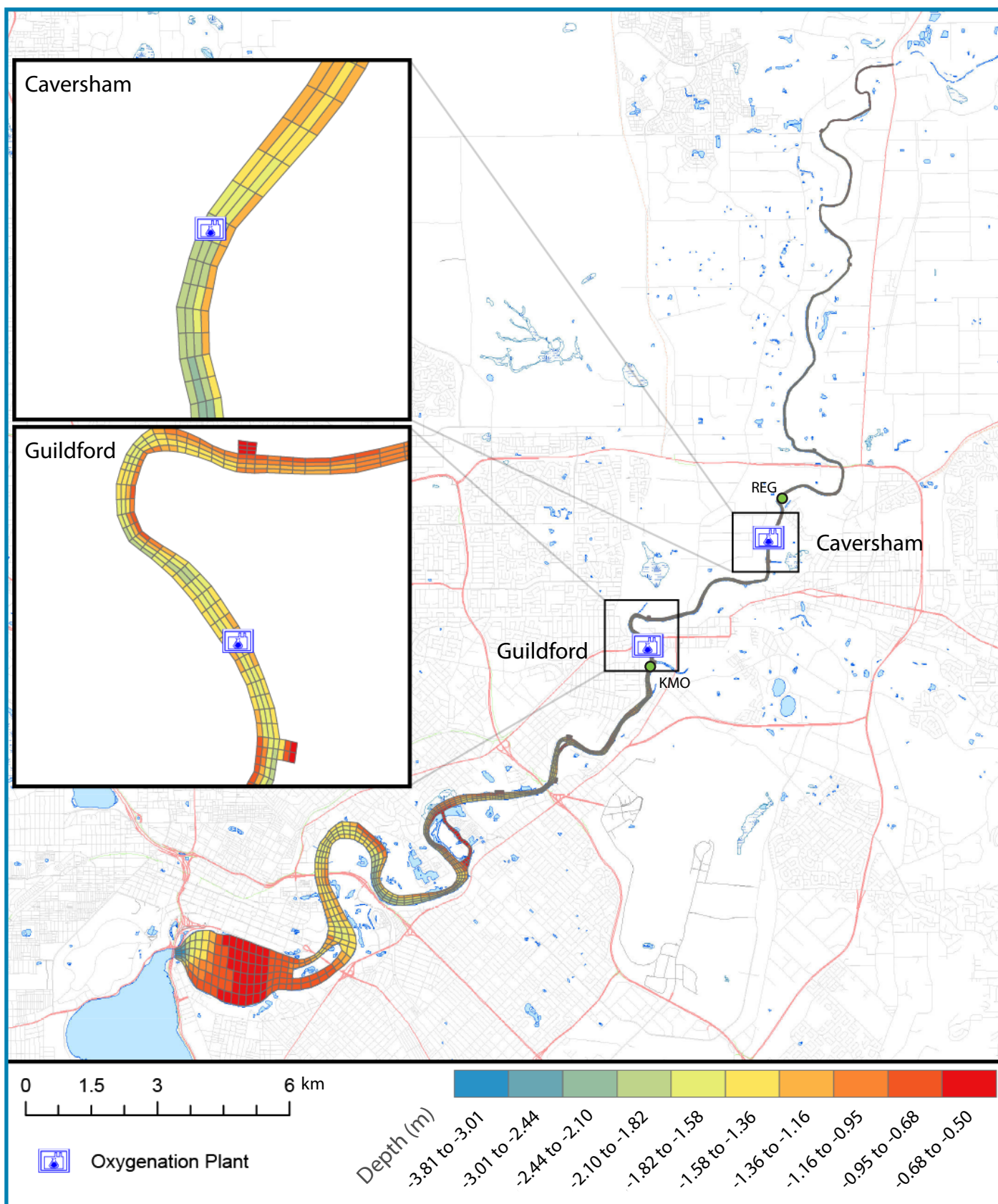


Figure 1. Flexible mesh grid designed for describing model extent and depth for the upper Swan model. The model spans the region between the Narrows Bridge and the Great Northern Highway. The oxygenation target zone is between King's Meadow Oval (KMO) and Reg Bond Park (REG).

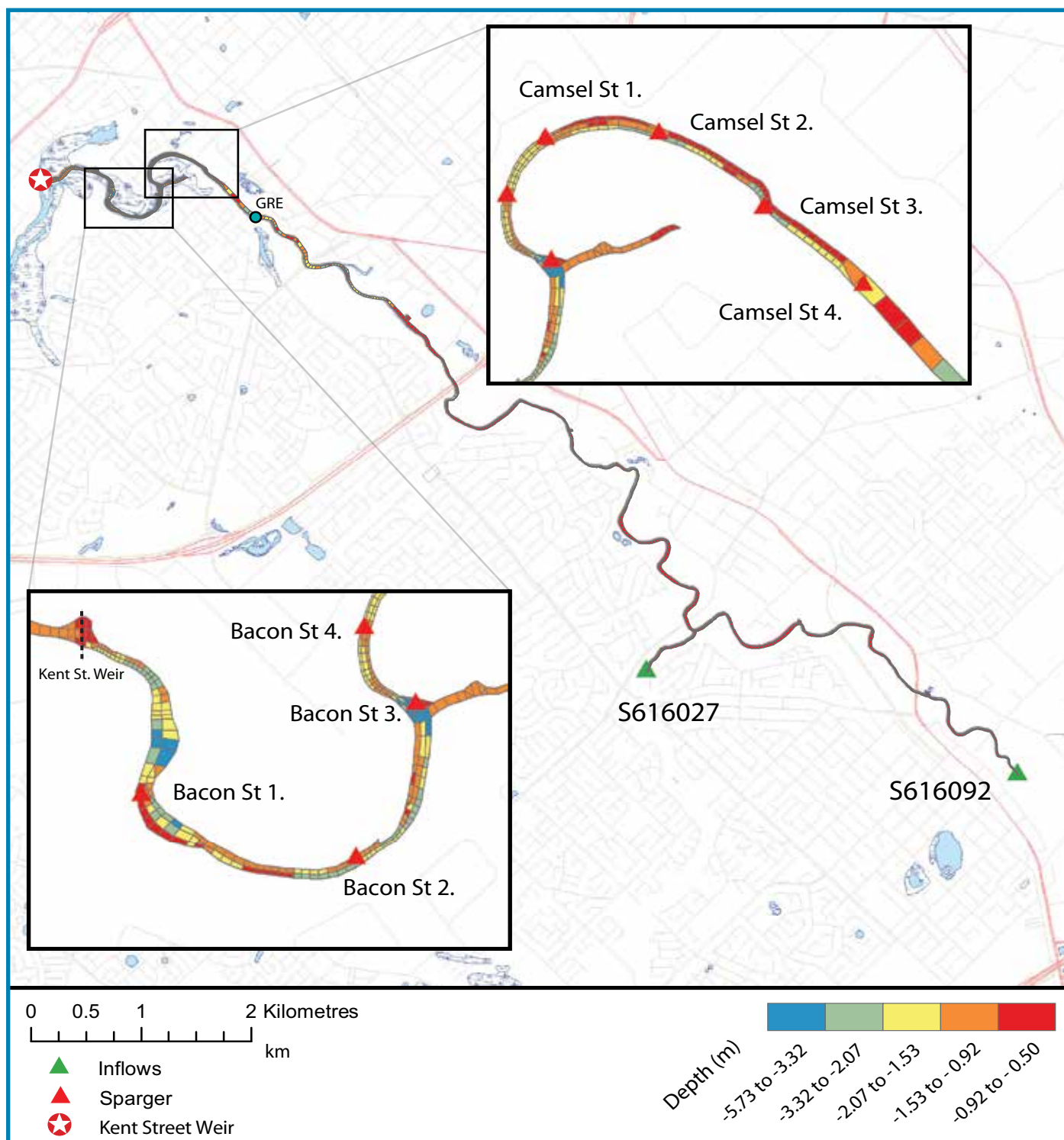


Figure 2. Flexible mesh grid designed for describing model extent and depth for the Canning model. The model spans the region between the Kent Street weir and the Roe Highway. The oxygenation target zone is between the Kent Street weir and the site GRE (50 m upstream of Greenfield bridge). Inflows refer to the inputs of freshwater from the catchment and the spargers (pipes with a series of holes) are where oxygenated water is added by the oxygenation plants.

With the models built and tested, the Swan model was then used to investigate how far oxygen could theoretically move in the estuary from where it was added. With no oxygen consumption, a stretch of river up to 30 km long is potentially influenced by adding oxygen at Guildford and Caversham, depending on the volume of river flow.

In the natural environment, oxygen is continually consumed by biological and chemical processes both in the water column and more significantly by the sediment (see Fig. 3). By modelling the dynamic estuarine environment with and without oxygen intervention and comparing these outputs, we can calculate the actual effects of the artificial oxygenation. We refer to this measure as 'area of benthos saved' and it represents the area of the benthos (riverbed) oxygenated when otherwise it would have been experiencing critically low oxygen concentrations if the oxygenation plants were not operating.

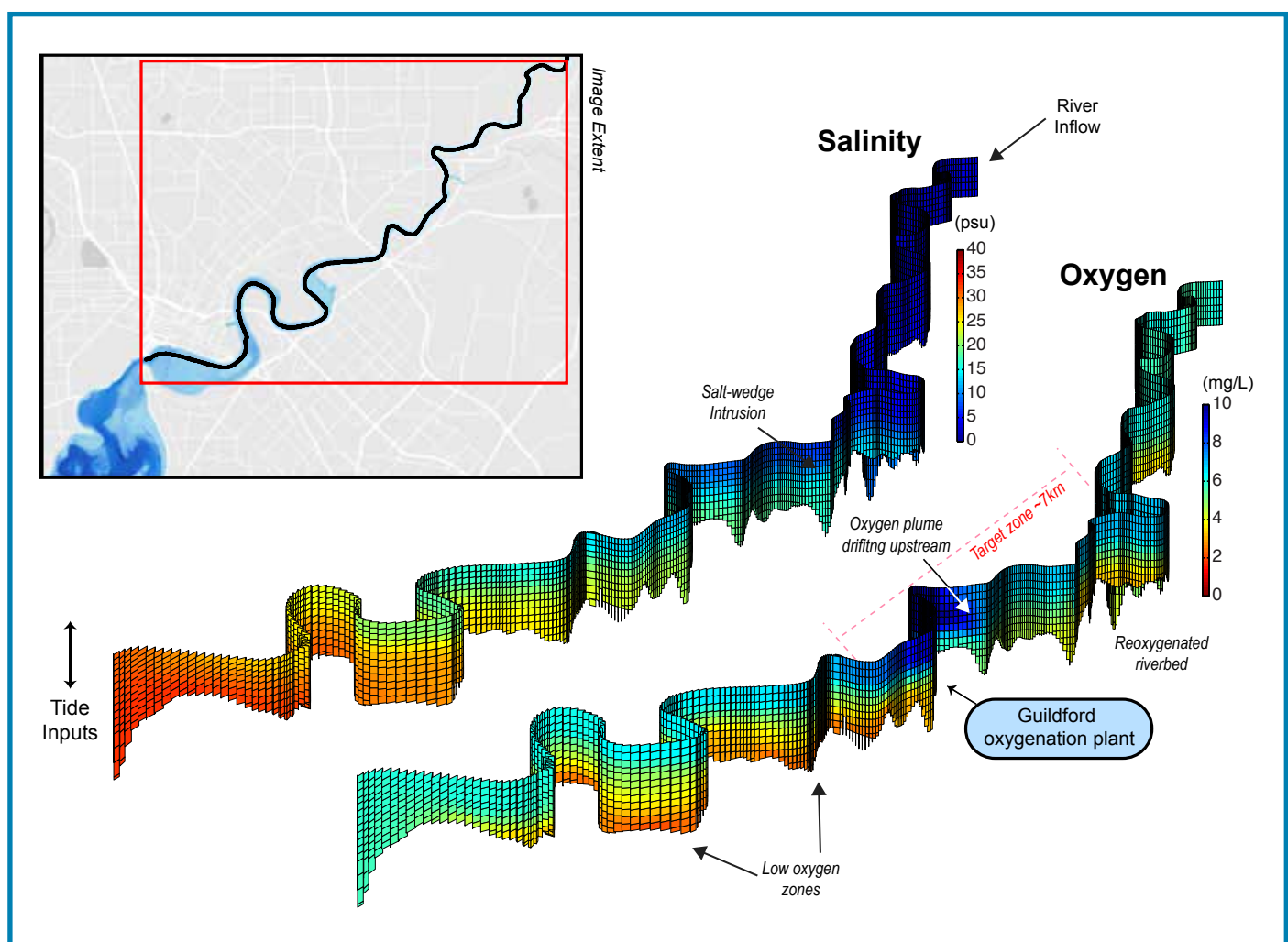


Figure 3. Example of the Swan model output as ribbons showing vertical distributions of salinity and oxygen from the Narrows to the Great Northern Highway. The salt-wedge (where freshwater overlies more salty marine water) is clearly depicted in the top ribbon, and the influence of the Guildford oxygenation plant is shown in the bottom ribbon. Note that bottom waters are generally lower in oxygen due to oxygen consumption by sediment. Caversham oxygenation plant is not shown as its operation was not simulated by the model for this example.

Running the Swan model using the actual operating regime of the Guildford plant in 2010 and comparing it to estuary conditions that would have occurred if the plant was not run at all, we calculated that the area of benthos saved was on average 0.15 km², with a maximum saved area of 0.5 km². Given that the whole oxygenation target zone is 0.38 km² (~7 km long stretch) for both Swan oxygenation plants, this result confirms the oxygenation plant capacity to significantly improve estuary habitat.

The model was used to compare the environmental improvement achieved by a number of simplified operational scenarios and the cost (in terms of oxygen and electricity) of operating these scenarios (Fig. 4). Across all scenarios tested, the average daily area of benthos saved ranged from 0.15 to 0.35 km², while the maximum area saved was 1.2 km² during the peak of plant operations. The cost of these operational scenarios ranged from ~\$200 000 to \$400 000 per annum, and shows that the operations of Guildford and Caversham together achieve a better environmental outcome than either single plant alone. The most cost-effective and environmentally efficient operational scenario was when a moderate concentration of oxygen (30 kg/hr) was added to the river with the flood-tide at Guildford, and the ebb-tide at Caversham.

Simplified operational scenarios were also tested with the Canning model (Fig. 5) and show that the best scenario saved on average ~0.03 km² of riverbed that would otherwise have been experiencing critically low oxygen conditions. The actual operational regime in the 2008 – 2009 operational period was shown to have saved ~0.027 km², 52% of the 0.052 km² target oxygenation zone. There was a clear non-linear relationship to the amount of money spent on operating the plants and the environmental benefit (for example, spending half the money would result in far less than half the benefit). Improvements in environmental benefit were shown to be theoretically achievable with the addition of another oxygenation plant, or improvements in the way the oxygen is delivered by the spargers (a pipe with graduated holes).

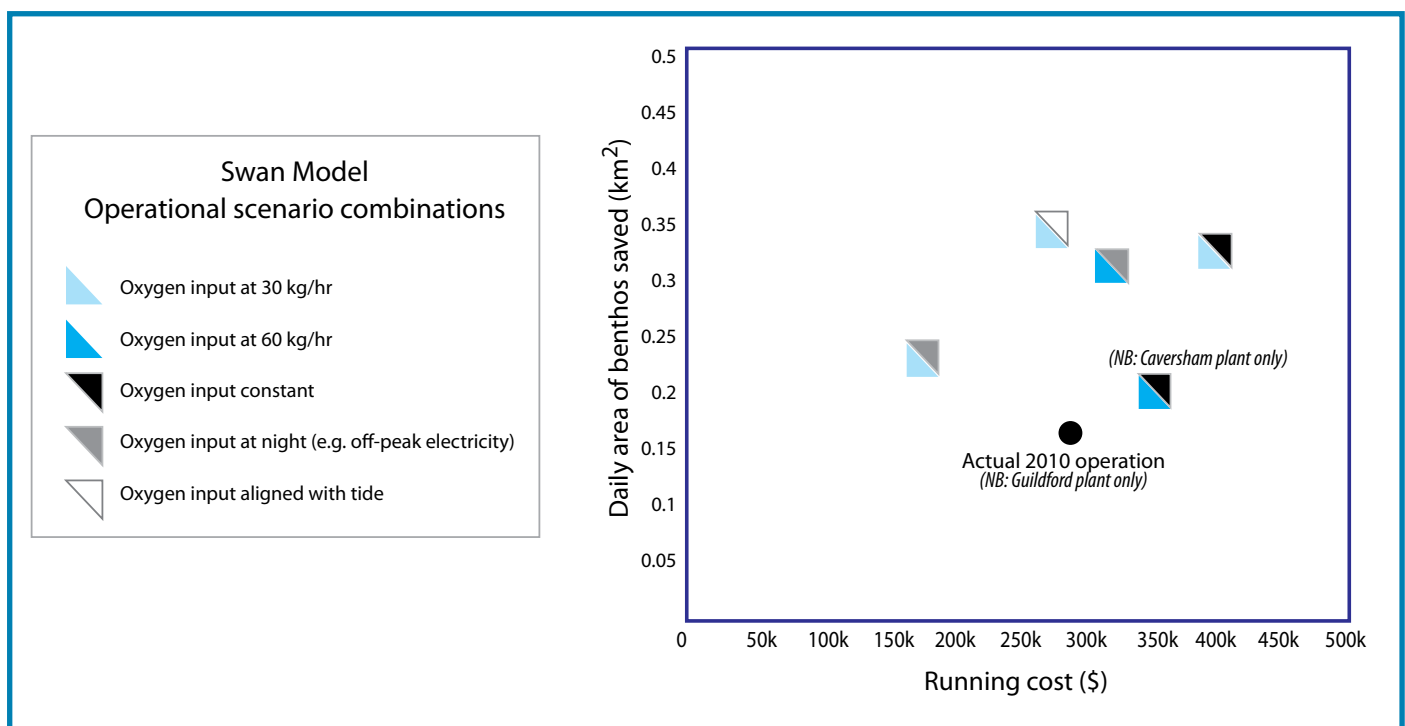


Figure 4. The environmental improvement versus annual running costs for a number of simplified operational scenarios for the Swan model run under low flow conditions. The environmental improvement from the oxygenation plants is reported as the daily average area of benthos (riverbed) saved in the upper Swan from critically low oxygen concentrations.

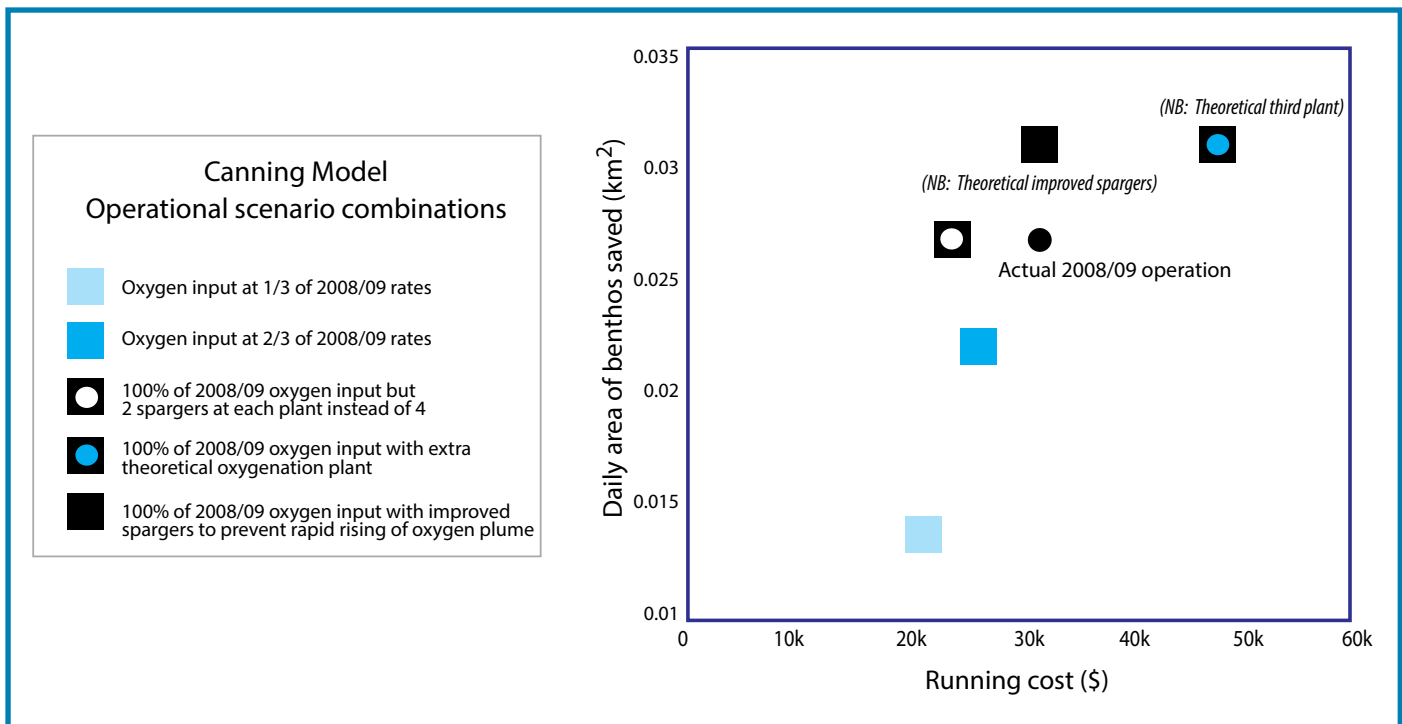


Figure 5. The environmental improvements versus annual running costs for a number of simplified operational scenarios for the Canning model. Environmental improvements of the oxygenation plants are reported as daily average areas of benthos (riverbed) saved in the Canning River estuary from critically low oxygen concentrations.

Overall, modelling the oxygenation zones in the Swan-Canning estuary has provided an excellent tool for management. Model comparisons with operating the plants versus not operating the plants show clear improvement in benthic water quality and oxygen status. The model simulations confirm benefits indicated by monitoring data and have allowed us to more accurately quantify these benefits. While these modelled scenarios are simplifications of actual operational strategies, the outputs can be used to develop more cost-effective operational strategies in the future.

This project was the result of collaborations between the University of Western Australia, the Department of Water, and the Swan River Trust. The full report can be accessed via <http://aed.see.uwa.edu.au/> or available on request.

Department of Water

168 St Georges Terrace
Perth Western Australia 6000
Telephone: Phone: +61 6364 7600
Facismile: +61 6364 7601
National Relay Service 13 36 77
www.water.wa.gov.au

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