Innovation in improving estuarine water quality

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ABSTRACT

Allconnex Water is responsible for the management of water distribution and wastewater assets servicing the cities of Gold Coast, Logan and Redlands in south east Queensland. Treated recycled water is released on either side of the Gold Coast Seaway, a channel connecting The Broadwater estuary with the Pacific Ocean. This release occurs on an outgoing tide to allow dispersion of the recycled water plume before the tide changes and re-enters the Broadwater.

Rapid population growth on the Gold Coast has placed increasing demands on the existing recycled water system, requiring additional volumes of recycled water to be released to the Seaway. The Gold Coast Seaway *Smart*Release Project was implemented in order to optimise the release of the excess recycled water in such a way as to improve receiving water quality while meeting operational requirements at the wastewater treatment plant (WWTP) and reducing energy consumption.

A partnership was developed between Allconnex Water, Griffith University and DHI to define and scope the issue, plan an extensive study and deliver a world class solution.

An intensive monitoring campaign provided information on water levels, currents, winds, waves, nutrients and faecal indicator bacteria within the Broadwater. These data were then used to calibrate and verify hydrodynamic and advection dispersion models using the MIKE by DHI suite of software. A decision support system then continually collects data such as winds and waves, interacts with the SCADA system and runs the numerical models to forecast the optimal time window to release the required amount of recycled water from the WWTP while improving water quality.

This innovative tool provides the operators of the WWTP with information regarding the potential impact of the recycled water on the natural coastal environment while still accommodating the expected growth of the Gold Coast City without the need for new infrastructure investments.

INTRODUCTION

As one of the fastest growing regions in Australia, the Gold Coast's population is projected to double to 1.2 Million by 2056. This rapid growth is already placing stress on the City's infrastructure and environments. Allconnex Water holds the primary responsibility for the collection, treatment and release of wastewater within the city.

Around 108 million litres per day of excess recycled water is released to the Gold Coast Seaway – a man-made channel that connects The Broadwater to the Pacific Ocean. The Broadwater is a semi-enclosed coastal lagoon system (Mirfenderesk & Tomlinson, 2007) located adjacent to the northern regions of the Gold Coast to the southern end of the Moreton Bay Marine Park.

The Coombabah wastewater treatment plant (WWTP) releases excess recycled water from the northern Seaway wall through a diffuser system, which receives approximately 60 million litres per day. The Elanora and Merrimac WWTPs release system is located on the southern seaway wall, and receives approximately 48 million litres of recycled water per day.

The Seaway release system only releases recycled water on the outgoing tide, allowing the recycled water to be dispersed to the Pacific Ocean while limiting the amount of excess recycled water returning into the Seaway and The Broadwater on the next incoming tide. Because of the difference in flow patterns between the ebb and flood tides, a portion of the ebb tide is not returned with the following flood tide, but is replaced by nearshore coastal waters (Tomlinson 1990; Braddock et. al., 2000).

The release of recycled water to the Seaway is controlled by a Development Approval (DA) from the Queensland Department of Environment and Resource Management (DERM) under the *Environmental Protection Act 1994*; which specifies the timing, location, volume and quality of water which can be released.

The ebb-staged release system (and the existing DA conditions) effectively limits the volume of water that can be discharged to the Gold Coast Seaway. The key issue of concern in this study was determining a way to accommodate the needs of a growing city to release more water without having negative consequences for water quality within The Broadwater.

Literature dealing with ebb-staged releases at an entrance is sparse. Webb and Tomlinson (1992) provide a description of the processes impacting the effectiveness of this type of release system.

The Seaway *Smart*Release Project was initiated by Allconnex Water to optimise the release of the recycled water from the City's largest WWTP at Coombabah in order to minimise the impact on the receiving waters and maximise the cost efficiency of the pumping system within the approved DA conditions. Following the successful installation of the *Smart*Release DSS at the Coombabah WWTP, Allconnex Water instigated a similar study with the same project team to investigate the optimisation potential of the release system on the southern side of the Seaway, which is currently underway.

METHODOLOGY

Overview

This project was conducted in three phases as described below with internal and external peer review within each phase.

1. Monitoring
2. Modelling
3. Decision Support System (DSS)

This project combines scientific and engineering disciplines to assess the complex hydrodynamics and unique mixing characteristics of the Seaway. The project launched an extensive water quality monitoring program coupled with flow fields measurement and real-time tide monitoring to collect scientific data which will be utilised to calibrate and validate the hydrodynamic and advection-dispersion models. The objective here was to provide a powerful and calibrated modelling tool capable of real-time simulation of the recycled water release. In addition, the intensive monitoring program is designed to provide vital water quality data to supplement the monthly Ecosystem Health Monitoring Program that is collected and compiled by Healthy Waterways.

A project team comprising specialists from DHI, Griffith University and Allconnex Water was established to scope, design and deliver the various project components. As the client, Allconnex Water provided the goals, defined the desired outcomes for the project and peer review as well as WWTP and release system technical expertise. Griffith University provided detailed knowledge of the local area, monitoring coordination and a long term history of research into ebb-staged releases. DHI provided project management, data analysis, numerical modelling and DSS skills.

The key success factor of this project was the collaborative approach that all team members took to scoping and delivering this innovative project.

At each significant hold point within the project, reports and/or presentations were prepared for review by both the project team and by Healthy Waterways. This detailed level of peer review ensured the project remained on track to meet its goals and that the study was undertaken with the appropriate level of scientific rigour.

The underlying principle of minimising the impact of the release system on water quality within The Broadwater is to ensure the maximum amount of mixing occurs in the Pacific Ocean before the tide turns and re-enters The Broadwater. The existing DA conditions tied the release window to specific times in relation to the predicted local high and low waters. Previous studies however, showed a significant lag between the water level and current direction (Mirfenderesk & Tomlinson, 2008). A release window based on the flow conditions was expected to provide a better opportunity to maximise water quality than one based on water levels.

Monitoring

An intensive, short-term monitoring campaign was designed to describe the hydrodynamic processes likely to affect the dispersion of recycled water at the Gold Coast Seaway. This was achieved by measuring flows, water levels, waves and water quality in receiving waters and discharged water as well as water quality within the recycled water trunk mains just upstream of the release locations.

Pilot Monitoring Campaign

The initial pilot study for the monitoring occurred on 12 December 2008. The primary aim of this pilot campaign was to test the monitoring techniques and procedures and verify a preliminary understanding of the physical characteristics of the Gold Coast Seaway.

A boat mounted acoustic Doppler current profiler (ADCP) was used to measure the discharge across a transect within the Seaway entrance. A vertical ADCP was also located east of Wave Break Island. Water samples were taken at three locations across this transect and at three depths (surface, mid and bottom). These samples were then analysed for NO_x, NH_3^+, PO_4^{3-}, TN, TP and caffeine. Conductivity, Temperature and Depth (CTD) casts were also taken at the water quality sampling points.

This pilot monitoring campaign verified the appropriateness of the techniques and provided valuable insights into the logistical planning for the detailed monitoring campaigns. Improvements included increased monitoring frequency and better definition of control sites.

Northern Monitoring Campaign

The first intensive monitoring campaign included water quality measurements within the entire Seaway focusing on the release from the northern and southern walls. The hydrodynamic measurements focussed on the northern wall as the original DSS was designed to only optimise the release from the Coombabah WWTP.

The objectives of this campaign were to:

- Measure the dispersion of the recycled water release within the Seaway under a range of tidal conditions;
- Define the relationship between tidal level and current direction in the Seaway; and
- Provide data to calibrate hydrodynamic and advection-dispersion models in the Seaway.

A full description of the conceptual models for flow within the Broadwater and the Gold Coast Seaway are provided in the final modelling report for the Broadwater Assimilative Capacity Study (BACS) (DHI, 2007) and the review of this study undertaken by Griffith University (Tomlinson, 2007).

Three ADCPs (two vertical and one horizontal) were deployed over a three month period from February to June 2009 as shown in Figure 1. These measurements provided a detailed data set that identified the current patterns affecting the recycled water upon release at the northern wall.

Boat mounted ADCP transects were also used to measure the discharges in the Seaway and to the north and south of Wave Break Island as shown in Figure 1. These measurements were taken hourly on over a 12 hour period; -1 hr to +10 hrs relative to the start of the release of recycled water from Coombabah WWTP. Measurements were made on three separate days (12/02/09, 23/03/09, and 22/04/09).

Figure 1: Locations of northern ADCPs

Approximately three quarters of the flow through the Seaway goes past the northern end of Wave Break Island with only one quarter going to the south. This distribution of flow, along with the bathymetry and geometry of the Seaway results in complex flow phenomena. An eddy in the vicinity of the horizontal and seabed ADCPs was identified and simulated in the hydrodynamic model. Further detailed boat mounted ADCP transects were measured in order to accurately describe this important flow feature in the model.

Detailed water quality samples were taken on the same three days as the original boat mounted transects, at the locations shown in Figure 2 below. The sampling times and parameters measured are outlined in Table 1.

Table 1: Water quality sampling times and parameters

Sampling Day	Date	Sample times (relative to start of recycled water release)	Parameters measured
DAY 1	10/02/09	-1, +1, +2, +3, +5, +7	TN, TP, NO_x, F. coliforms, Enterococci, Caffeine, CTD
DAY 2	23/03/09	-1, +1, +2, +3, +5, +7, +9, +10	TN, TP, NO_x, NH_3, F. coliforms, Enterococci, CTD
DAY 3	22/04/09	-1, +1, +2, +3, +5, +7, +9, +10	TN, TP, NO_x, NH_3, F. coliforms, Enterococci, CTD

Figure 2: Locations of water quality samples

Six teams of field staff (a total of 17 team members) were required for each monitoring day. In excess of 800 individual samples were collected and 228 CTD casts. Five percent of the samples were sent to a NATA accredited lab for comparison with the results from the Griffith University laboratory.

Southern Monitoring Campaign
Following the success of the optimisation of releases from Coombabah, Allconnnex Water commissioned the same team to undertake a similar study for the release from the southern Seaway. This required additional monitoring to refine and calibrate the models along the southern Seaway wall.

The existing data set of water quality measurements was still valid for the southern release however a more detailed measurement of the currents along the southern wall was required. In addition to this, the interactions between waves and currents at the Seaway entrance was also measured.

An initial pilot campaign was undertaken that included boat mounted ADCP transects to assess the shape and extent of the eddy structure in the vicinity of the southern wall diffusers and to determine the most appropriate locations for stationary ADCP deployment.

Four ADCPs (1 horizontal and 3 vertical) were placed along the southern wall and entrance of the Seaway as shown in Figure 3, to measure detailed tidal flow and wave characteristics. The ADCPs were deployed in the week beginning 19 April 2010 with a maintenance dive on 18 May 2010 and retrieved on 11 June 2010.

Figure 3: Locations of stationary ADCPs

Modelling
The numerical modelling program was focused on simulating the dispersion of the plume of recycled water released into the Seaway and identification of the optimal release window. The modelling was divided into three broad stages, which were:

- Establishing the numerical models, which involved first identifying the appropriate modelling methodology;
- Calibrating and verifying the models against data collected in the monitoring campaigns; and
- Undertaking a range of scenarios to represent different met-ocean conditions and varying release strategies.

Three different detailed, three dimensional numerical models were used, which were a hydrodynamic (HD) model to simulate currents and water levels, a spectral wave (SW) model to simulate the wave conditions at the Seaway which were input to the hydrodynamic model and an advection dispersion (AD) model to simulate the plume of recycled water using the results from the HD and SW models. The overall modelling approach is summarised in Figure 2Figure 4 below.

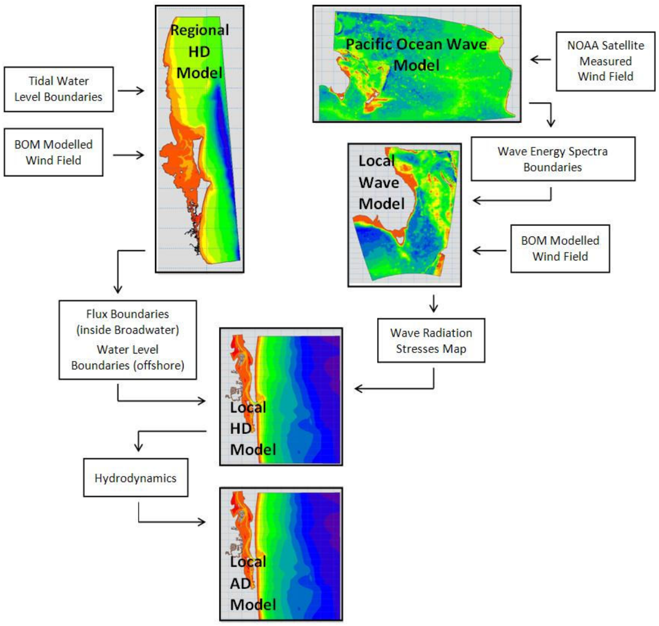

Figure 4: Summary of modelling methodology

The results from the modelling were analysed to investigate the impacts of typical tide, wind and wave conditions on the dispersion of recycled water. The numerical models form a significant component of the DSS.

The hydrodynamic modelling approach consisted of using a detailed three dimensional (3D) model, nested within a large scale regional 2D model. The large scale model, which was developed for the Gold Coast Estuarine Modelling Study (GEMS), covered South East Queensland from Tweed Heads in the south to Double Island Point in the north. The model represents tidal variations and the affects of wind on currents. Output from this model is used as the input to the local model. The local model was developed from the previous 2D model of The Broadwater and the Seaway used in the BACS (DHI, 2007). The model was updated to provide a finer resolution of 25 m – 35 m in the Seaway and to include three vertical layers to represent any vertical variation in currents and in the behaviour of the recycled water plume. The 3D model also represents the effects of winds, which are input from Bureau of Meteorology (BoM) data, and waves, which are derived from the wave model. Output from the HD model provides the input to the AD model that simulates the dispersion of the recycled water plume.

The wave models have been developed specifically for this project and consist of a local model nested within a large scale Pacific Ocean model. The local model focuses on the east coast of Australia out to Noumea and New Zealand, while the Pacific Ocean Wave Model covers the area of the South Pacific Ocean between Australia and South America. The models are driven by winds fields derived data provided by the BoM's atmospheric model and from U.S. Department of Commerce's National Climatic Data Center. The wave conditions output from the local wave model are input into the HD model to enable simulation of wave driven currents.

The AD (or transport) model uses the flow field calculated by the HD model together with a dispersive contribution, which together define the transport of the recycled water plume. The AD model covers the same area as the local HD model, which provides the input data on currents speeds and directions. The recycled water is input into the model based on the release rate and the concentrations of the constituents of the release. The recycled water is entered into the model at the diffuser locations; for the Coombabah WWTP these locations are a series of pipes along the northern seawall near the water surface and on the southern side these are a seabed diffuser system. The results from the AD model show concentrations of water quality parameters in both time and space.

The HD model was calibrated and verified against current data from the three fixed ADCPs and the three ADCP transects taken to define the extent of the eddy along the northern Seaway wall. The model was found to be well calibrated against the observed data.

The SW model was calibrated and validated against measured wave data from the Gold Coast directional wave recording buoy maintained by Gold Coast City Council and DERM. The buoy is located in 18m of water to the south of the Seaway entrance. The calibration was undertaken during a period of easterly swell waves, while the validation was performed on wave data corresponding to the three intensive water quality monitoring field days. It was considered that the wave model accurately represented the actual wave conditions during the calibration and validation periods.

The AD model was calibrated and validated against the water quality monitoring data from the intensive water quality monitoring program. A review of the data determined that the strongest signal of the recycled water release was provided by the NO_x samples taken on Day 1 and these data were used for calibration of the AD model.

It was concluded that the model provides results that allow an appropriate level of certainty for calculating the relative change in water quality resulting from various recycled water release scenarios.

Decision Support System

The optimisation of the release of recycled water from the Coombabah WWTP is based on the following constraints:

- Water levels and tidal currents in the Gold Coast Seaway;
- Water quality in The Broadwater;
- Water levels in the recycled water storage lagoons at the WWTP; and
- Power usage and energy tariff costs.

The tidal conditions in The Broadwater are not a variable that can be influenced by the WWTP operators, which means there are then three variables available for optimisation.

1. Water level in the WWTP lagoons - it is preferable that the lagoons are brought to minimum levels at the end of each release to avoid overflows to Coombabah Lake (a protected green zone of Moreton Bay Marine Park).
2. Water quality in The Broadwater - minimising water quality impacts involves maximising the flushing of the plume from The Broadwater and minimising the return when the tide turns, which is achieved by varying the start and end times of the release.
3. Power usage and energy costs - varying the use of one and two pumps over different release periods can have significant impacts on electricity cost.

It is important to note that there trade-offs to be made between the optimising water quality effects and minimising power usage. Providing data to allow operators to make decisions to balance these two potentially competing factors is a key feature of the DSS.

The core of the DSS is based upon determining the optimum pumping schedule, considering both water quality and energy usage. The operation of the DSS is based upon determining the allowable impact on the receiving waters from a Base Case, which is defined by the current DA release window. The DSS then finds the optimum improvements to water quality and pumping costs compared to this Base Case by varying the start and finish times of the release and the use of one pump versus two. The optimisation is based upon results from the numerical models outlined above. Significant improvements in water quality can be gained by shifting the start of the release period to coincide with the maximum discharge into The Broadwater and by finishing the release earlier to allow for greater flushing of The Broadwater by the ebb tides. This procedure allows a single pump to be run for a longer period than in the Base Case optimising energy usage and still provide for improvements to water quality.

The processes followed by the DSS in this determination are summarised as follows:

- Boundary conditions for running the HD and SW models are extracted from the database, which includes wind data retrieved from a BOM ftp, tide data developed from tidal constituents and wave boundary conditions retrieved from the DHI global wave model.
- The volume of water needed to be discharged from the lagoons before the end of the next permitted release period can be calculated using a forecasted inflow, current water level in the lagoon, a relationship between the volume and water level in the lagoon and period until the end of the next end of permitted release period.
- A Base Case scenario is then run using the AD model assuming the maximum allowable discharge for that release, which is, two pumps operating at full speed over the entire release window (10 minutes after local high tide until 50 minutes after local low tide) or until the minimum water level at the lagoons is reached.
- A series of iterations of the AD model is performed in order to determine the most appropriate start time based on two pumps running over the same duration as the Base Case, which provides the best outcome for water quality (Optimum Water Quality Case) within the Broadwater but may not provide the optimum results for pumping costs.
- A weighting factor is then applied to the optimum water quality results; for example if the optimum water quality results show decrease in nutrient concentrations by 25% it may be acceptable to aim for a 15% decrease in nutrient concentrations to save 20% in pumping costs.
- Total pumping costs over a release period are determined by the number of pumps used (1 or 2), the length of time they operate and the time of day (high/low tariff).
- In order to maintain an improvement in water quality compared to the Base Case the DSS provides an optimised pumping schedule that uses a combination of 1 and 2 pumps operating over a period longer than the current release window to find the optimal release window.
- The database in the DSS then stores the results from the Base Case, Optimum Water Quality Case and the Optimum Pumping Cost Case and provides the operator with animations of the resulting plumes and a pumping schedule.

This sequence of processes is executed so that the processes will be completed approximately 30-60 minutes before the start of the permitted release period begins. This ensures that the suggested pump table is as up-to-date as possible for the upcoming pumping period. This means that the tasks will be performed twice a day.

TAKE HOME MESSAGES

The key outcomes from the project were:

- Monitoring of currents and water levels found that there was a phase lag was found between high tide and the commencement of ebb flows. During flood flows an eddy was observed along the northern Seaway wall.
- The monitoring program collected a comprehensive and high quality dataset suitable for calibration of the numerical models and so the primary purpose of the monitoring program was fulfilled.
- The model establishment and calibration stages provided a robust suite numerical models that could be used with confidence to simulation the dispersion of the recycled water releases from the Coombabah WWTP and could be used to optimise the release.
- The modelling showed that significant reductions in water quality effects could be made by starting the release earlier than the currently DA release window at the time of maximum incoming flows and then finishing pumping earlier than the currently DA release window.
- The modelling also found that significant cost savings for pump operating costs by initially running two pumps at the earlier release and then a single pump for a longer period, whilst maintaining improvements in water quality effects compared to the DA release window.

- The project has resulted in the development of a DSS that guides the release of recycled water to minimise water quality impacts to The Broadwater and reduce operational costs at the WWTP.

The project has resulted in the delivery of a DSS that enables the operators at the Coombabah WWTP to achieve a balance between the objectives of optimising the release of recycled water from Coombabah WWTP to minimise impacts to water quality and of reducing the energy consumption at the plant and thereby reducing costs.

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