Review of the Broadwater Assimilative Capacity Study

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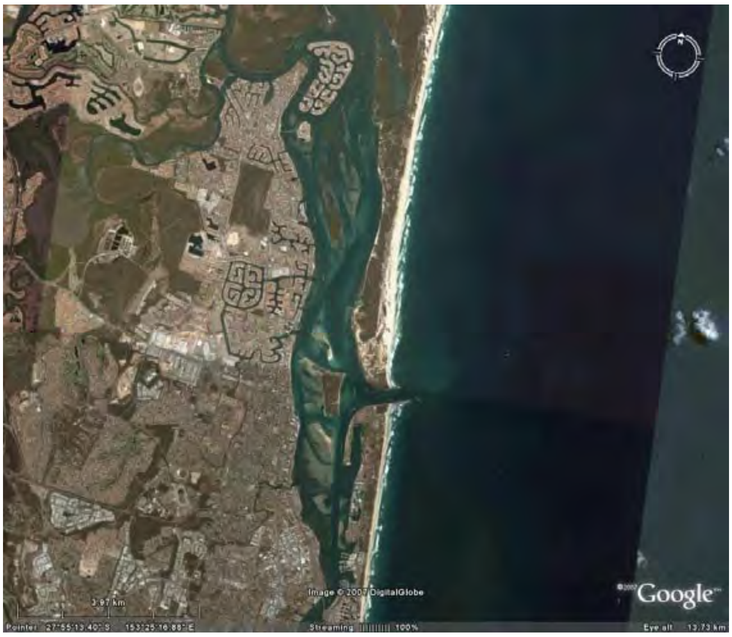
REVIEW OF THE BROADWATER ASSIMILATIVE CAPACITY STUDY



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1. INTRODUCTION

As part of Gold Coast Water's Coombabah Release Options Assessment a Broadwater Assimilative Capacity Study is being undertaken to assess the impact of a range of options to modify the current recycled water release strategy at the Gold Coast Seaway.

A review has been called for the whole process and outcomes of the Broadwater Assimilative Capacity Study in relation to EPA's licensing requirements and best engineering practices. The review will broadly address the appropriateness of the ebb-staged release scheme, adoption of the Gold Coast Estuarine Modelling Study (GEMS) model, dye test program, AD model calibration and the release scenario simulations.

Especially, the review will critically appraise the adopted process for release scenario simulation and review the report prepared on the model simulations. In particular, the review will address details such as grid sizes, time step, model parameters, and simulation periods in relation to the proposed release windows. In this regard the scope of the review includes comment on the initial mixing zone model setup, tidal exchange ratio, transient flow characteristics of the ebb tide and role of coastal currents, wind and other parameters on dispersion.

2. BACKGROUND

The recycled water release into the Seaway was first proposed in the 1970s as an innovative alternative to ocean outfalls and other expensive disposal technologies (Tomlinson and Webb (1989), Webb and Tomlinson (1992), Tomlinson (1993) and Tomlinson and Braddock (1996)). The basis of the system is that the recycled water which is excess to other requirements is released into the Seaway entrance channel on the outgoing tide. The release is stopped before the tide turns, thereby limiting the amount of release that re-enters the Broadwater. There are two outfall diffusers discharging into the Seaway. One receives on average 61 ML/day from the Coombabah Treatment Plant via a pipeline across the Broadwater and has a multiple outlet configuration. The diffuser on the southern side receives 48 ML/day from the Elanora and Merrimac Treatment Plants via the Benowa storage lagoon and a pipeline that runs up the Spit, and has a single point diffuser.

The current release strategy is that the discharges commence at 45 minutes after the local high tide, and continue until the storages reach a certain level (usually 20% capacity). The release is limited by the occurrence of low water.

2.1 Previous Studies

At the time the Seaway ebb-tide release scheme was proposed, studies were undertaken including the original physical modelling studies by Willoughby et al (1978) of the initial dispersion characteristics within the Seaway channel, and Wilkinson et al (1979) who looked at the likelihood of effluent released on the ebb tide re-entering the Broadwater on the subsequent flood tide. Tomlinson (1986, 1990) subsequently carried out extensive experimental studies of the tidal exchange characteristics.

During the 1990s a number of Griffith University projects were carried out to attempt to validate both the earlier experimental results, and the key aspect of the operational strategy –namely, that the return flow during the flood tide was relatively small. These studies included the following:

- Laboratory physical model studies examining the role of alongshore currents on the behaviour of the ebb tide flow and the tidal exchange (Walsh, 1997)
- Field experiments using the natural isotope of nitrogen (N15) as a tracer to quantify the tidal exchange ratio (Persson, 1997 and Dilworth, 1997).
- A major tidal gauging exercise was carried out in 1999 to look at the correlation between the water level and the flow reversals.
- In 2005 and 2006 flow measurements were carried out as part of the GEMS model calibration and verification program.
- As part of the current Broadwater Assimilative Capacity Study, dye release studies of advection and dispersion were carried out in the Seaway.

2.2 Ebb-tide Release Strategy – Key Processes

Tidal exchange

On release from the diffuser, the recycled water is rapidly mixed with the outgoing tidal flow within the Seaway entrance channel. These processes were initially studied by Willoughby et al (1978) and they showed that high initial dilution and mixing would take place. Once mixed with the out-going tide, the fate of the recycled water discharge is then dependent on the fate of the ebb tidal flow. An ebb-staged release scheme relies on the natural asymmetry in tidal flow at a tidal entrance. With reference to Figure 1, the jet flow pattern associated with the outgoing ebb tide transports effluent away from the coast, entraining coastal water. The flow pattern on the flood tide is distinctly different, resembling flow towards a sink. Because of this difference, a portion of the ebb tide is not returned with the flood tide, but is replaced by coastal water.

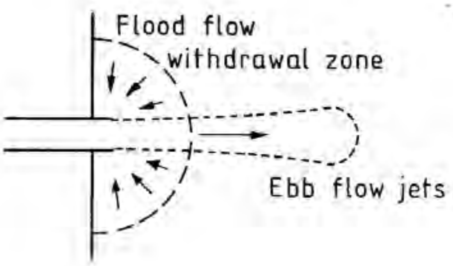

Figure 1: Flow asymmetry between ebb and flood tide flows (Webb and Tomlinson, 1992).

Provided recycled water discharge is timed to coincide with the non-return portion of the ebb tide, then there is a good chance that no recycled water will be re-entrained into the Broadwater (Figure 2). In practice however, the recycled water release is required to occur over as long a portion of the ebb tide as possible. In this case a nonzero portion of the discharge will return to the entrance on the subsequent ebb-tide. A discussion of experimentation undertaken examining tidal exchange is provided in Appendix 1.

Tidal hydrodynamics

A critical aspect of the ebb-tide release strategy is to ensure that the recycled water is released only on the out-going tide. When the strategy was first made operational in the late 1980s it was believed that the operating cycle was controlled by tidal predictions at the Fort Denison tide gauge in Sydney Harbour. This was reasonable given that coastal studies at the time often used Fort Denison for the Gold Coast region. However, what was not taken into account was the phase lag between the change in tide level and the reversal of flow. This lag is characteristic of complex estuaries such as the Broadwater, but the magnitude of the lag needs to be determined either by field measurement or computer modelling. In the case of the Seaway, these measurements were not undertaken until the late 1990s as part of the continuing Griffith University research into tidal entrance behaviour.

Typical results from this field work (see Appendix 1 Table 1) demonstrated that the time lag is highly variable ranging from 0 minutes to 114 minutes. The average time lag was 68 minutes from high water for ebb tide reversal, and 64 minutes from low water for flood tides. The median value for both was 66 minutes.

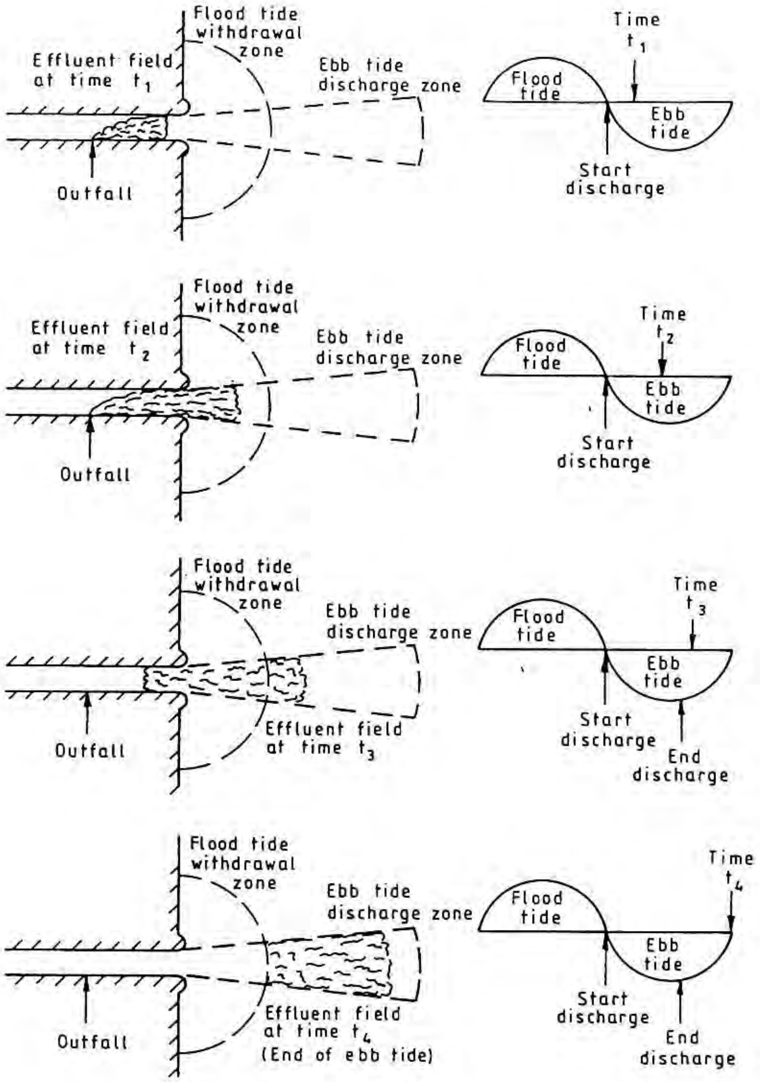

Figure 2: An ideal release strategy to ensure minimal return of discharge during flood tide (Webb and Tomlinson, 1992).

Broadwater Flow Dynamics and Water Quality

The ebb-tide release strategy, as implemented, requires that discharge only occurs on the out-going tide, and hence in the past there has been no examination of the aspects of recycled water entering the Broadwater. Water quality issues have been examined as part of the Ecosystem Health Monitoring Program (EHMP) in recent years at a limited number of sites. This followed on from a 30 year program of water quality measurement by the EPA both within and outside of the Broadwater as reported by Moss and Cox, 2001. There have also a number of specific research projects which have obtained water quality data, but these have not been systematic.

The EPA water quality study indicates that the Broadwater is relatively clean, and that there is no suggestion in the data that the ebb-tide release strategy has not been effective. There are also no data suggesting that there is a significant return fraction into the Broadwater.

Apart from a few limited studies of the hydrodynamics of the Broadwater as part of the management of the Seaway entrance by the Department of Transport, the first major assessment of Broadwater flow dynamics has been the GEMS project which commenced in 2004 and which has now delivered a calibrated hydrodynamic model. This has been used as the basis of the release scenario simulation modelling for the Broadwater Assimilative Capacity Study. The initial GEMS study findings showed that as expected, the Broadwater is dominated by tidal flow and has very high flushing characteristics. The flow patterns are also dominated by the channel configurations.

2.3 Overview of Previous Findings

The current release scenario simulation modelling provides an opportunity to validate and expand on the conceptual understanding and experimental findings of previous studies.

The objective of an ebb-tide staged release scheme is to utilise the fundamental differences in ebb tidal flow and flood tidal flow to transport recycled water released into the outgoing flow away from the Seaway, and not to be re-entrained into the incoming tidal flow. In reality it is impossible to completely negate any return flow unless the discharge can be stopped well before the turn of the tide and usually not under realistic coastal flow conditions. These realistic conditions include the presence of currents running along the shore due to tides and other forcing. These conditions act to keep the ebb-tide flow confined near the entrance. However, other realistic conditions such as wave induced mixing can increase the dispersion of the discharge.

From experimentation using idealised conditions it is estimated that around 10 to 20 percent of the ebb-tide discharge will return on the subsequent flood tide. Depending on the configuration of the estuary or waterway leading to the entrance this return may or may not be a problem. For example, early estimates for the Broadwater suggested that it would have a high tidal flushing and hence it would be expected that anything returning to the Broadwater on a flood tide would leave again on the next ebb tide.

The operational protocol for the release originally was based on remote tide levels, but has since been prescribed based on local water level and a delay in release due to a measured phase lag between water level and flow reversal. Previous studies have identified that there is a considerable opportunity to optimise the release strategy, provided the tidal flow dynamics were understood (Note: A proposal was prepared by Griffith University in 1999 to carry out a research project to develop an operating decision support system).

Water quality data and anecdotal evidence appeared to support the view that the current ebb-staged release strategy has not had any significant impact on Broadwater water quality, and that the Broadwater has the assimilative capacity to deal with an increase in recycled water discharge at the Seaway.

3. BROADWATER ASSIMILATIVE CAPACITY STUDY REVIEW

3.1 Overview

The main purpose of this review is to examine the broader aspects of the Broadwater Assimilative Capacity study in the context of the need to increase the discharge capacity of the Seaway diffusers. Being considered are options to manage the increase the volume of recycled water to be released in future years, either by simply increasing the discharge within the current EPA licence requirements or if necessary too increase the length of time over which the release occurs. The review is carried out with reference to the background knowledge and conceptual understanding gained from studies of the release strategy and the dynamics of the Seaway over the last 20 years.

From the current understanding of the processes involved in the ebb-tide release strategy, the major issues for consideration would be:

- concentration levels of various constituents at particular locations, both close to the diffusers in the initial mixing zone and further afield in the Broadwater,
- temperature changes due to increases in recycled water release
- increase in mass loading throughout the Broadwater relative to ambient levels from the existing release, diffuse sources and other point sources
- the configuration of the model in terms of boundary conditions and environmental forcing
- the validity of model output with regard to previous studies and conceptual understanding
- The significance of the scenario results in terms of the EPA licence conditions and the environmental health of the Broadwater

The approach adopted by Gold Coast Water to progress this study has been to commission a modelling study of the impact of various scenarios, and based on the outcomes of the modelling to propose appropriate strategies to meet current and/or future EPA licence requirements. The modelling work has been separated into two components, namely: the establishment of a calibrated advection–dispersion model, and secondly the use of this model to examine a number of scenarios for release.

The use of an advection-dispersion model is justified given the nature of the hydrodynamics of the area being dominated by tidal flow, and hence the likelihood of advection being the main mixing mechanism. This approach was also validated by the Expert Panel convened to review the dye release experiments. It would have been inappropriate to attempt to develop a more comprehensive water quality model because of the time constraints imposed on the project; the need for an extensive data acquisition program; and the current general good health of the Broadwater and adjacent ocean.

3.2 Modelling Approach

GEMS Framework

The use of the Gold Coast Estuarine Study (GEMS) modelling framework as the model platform is very appropriate. The hydrodynamic model developed under GEMS is perhaps one of the most robust of its kind developed worldwide. An extensive data collection program was undertaken to calibrate and validate the hydrodynamics, resulting in excellent results. The model was available and ready to be utilised and the model software used for GEMS was developed by the parent organisation of the DHI Water & Environment which has undertaken the release scenario simulation modelling.

Dye release experiments and Advection Dispersion Modelling

As noted earlier there had been no study undertaken of the mixing characteristics of the Broadwater or the Seaway other than the original design study undertaken in 1978 by Willoughby et al. The dye release experiments carried out in June and July 2007 were an essential requirement for the establishment of an assimilative capacity model. The expert review panel have confirmed that the experimental methodology was of a high standard, and the results of the exercise provided a satisfactory level of data for model calibration. The dye release experiment confirmed that advection dominates the mixing processes and that recycled water discharges into the Seaway will follow flow paths controlled by the main channels and the strength of the tidal flow.

Release Scenario Simulation Modelling

The approach proposed by GCW was to use the hydrodynamic modelling capability developed in GEMS, and to add a calibrated advection-dispersion module. This enabled the configuration of the model for the purposes of the assimilative capacity study to be implemented in a short time frame and to facilitate the introduction of FLEXIMESH into the GEMS modelling framework, thereby providing fine detail resolution in the Seaway and the initial mixing zone.

Track record of Modelling Team

DHIW&E are world leader in water quality modelling and the DHI software has been adopted by Council for most of its modelling activities including GEMS. The team assembled to carry out the release scenario simulations benefited from the expertise of Peter Rasch who is acknowledged as a leader in the development and application of the FLEXIMESH modelling system. The adoption of this system for this study represents world's best practice.

3.3 Assimilative Capacity Model Configuration

In preparing for the release scenario simulations, a number of decisions were made in regard to the configuration of the model to appropriately deal with the situation. These included: the choice of boundary conditions; the extent of the model grid; the need for 2D or 3D modelling; the choice of numerical coefficients for model stability; the choice of time periods for simulation.

The approach adopted by DHIW&E team was to establish a FLEXI MESH grid for the region of interest and to treat the model as a subset of the more regional GEMS model in terms of dynamic boundary conditions. This is accepted practice, and is most appropriate in this context given the extensive work undertaken to calibrate the GEMS hydrodynamic and advection-dispersion models.

A major inclusion was to increase the offshore extent of the model and to apply dynamic tide level forcing at these boundaries. This was essential given the known characteristics and importance to the performance of the recycled water release strategy, of the fate of ebb-tidal flow offshore. Limiting the extent of the model to the southern portion of the Broadwater helped limit computational time, but this decision has been demonstrated appropriate by the team with a sensitivity analysis of the likely ”loss” of recycled water across the zero flux boundaries.

The team also examined the need for a 3D (layered 2D) model in a section of their report. This detailed examination of the near vicinity of the diffusers has adequately demonstrated that because the model is only examining tidal flow and as there is very rapid initial mixing of the discharge, then the flow can be resolved without the need for the 3D model. Vertical profiling of temperature and conductivity during field work in 1997 showed that the flow throughout the tidal cycle was well-mixed with depth. A particularly significant outcome of both the detailed modelling and previous studies was the identification of the horizontal flow reversals in the northern part of the Seaway. These would appear to be real and have been observed in field monitoring in the past as well (Figure 5). The asymmetry of the velocity profile across the seaway channel highlights needs to be considered in the operational protocols for the Coombabah release, as it will affect the initial mixing and release times.

The model was set up to run for two separate periods – March-April and June-July 2007. It was found that the model output was stable after about a month and these two period demonstrated very clearly the role of tidal magnitude on the flushing characteristics of the Broadwater and consequently on the concentrations of constituents in the release.

3.4 Release Scenario Simulation results

The outputs from the release scenario simulations fall into two categories.

Release Concentrations

Concentration distributions are presented for the various scenarios and median concentrations are reported at various sites including existing EHMP sites. The main variable is the release time which is set to enable the discharge of the design release volumes for each scenario. The results obtained are realistic and there is no reason to challenge any specific value, given the robust formulation and calibration of the model in the first place. The dominant role of tidal magnitude is clearly shown in the results with the very low residence times in the Broadwater during the spring tide period resulting in low concentrations, with the higher residence times during the neap tide period resulting in increasing concentrations particularly for the higher release scenarios.

The description of the spread of the release plumes is as expected, consistent with the findings during the dye release experiments and the model results show clearly that advection is the dominant mixing process.

In the context of the Seaway it is reasonable to set an initial mixing zone as that section of the entrance channels bounded by extremities of Wave Break Island and the seaward end of the Seaway breakwaters (Ramsay and Everett, 2002). Even with the worst case scenario, the increases in concentration only become significant in this initial mixing zone.

Seaway Hydrodynamics

The second category of results is the descriptions of the hydrodynamics of the Broadwater/Seaway system. These results provide a validation of the initial design concept for an ebb-staged release scheme, and also correspond favourably with previous field and experimental measurements.

The model clearly demonstrated a known characteristic of shallow estuaries, that is, the phase lag between tide level and tidal flux. This lag was measured previously as discussed above, and the ability of the model to demonstrate similar lag values is further evidence of the robustness of the modelling approach. Although it was not necessary for an interrogation of the full model output, it is expected that the phase lag would vary from tide to tide as shown in the measurement values (Appendix 1 Table 1).

The most significant feature of the modelling is the development of the plume during the ebb tide along the shore to the north of the entrance. The model has shown that the re-entrainment of this plume into the entrance on the subsequent flood tide is a major influence on median concentration levels, particularly at the sensitive EHMP 119 site. Thus it is critical to verify that this feature is real. In the model, the plume develops in this fashion due to the tidal boundary conditions which are applied offshore and which result in a northerly current during the ebb tide. During experimental studies (Tomlinson, 1986 and Walsh, 1998) these features of the modelled plume were observed if a cross flow was applied to an ebb discharge, as shown typically in Figure 3. However, there are a number of coastal processes which could result in a different behaviour. These include the presence of the East Australia Current which flows to the south, and transient flow features due to the unsteady dynamics of the ebb discharge (Tomlinson, 1986).

Figure 3: Ebb discharge under the influence of a cross-current. (Walsh, 1998)

The unsteady nature of the tidal flow results in the formation of a rotational flow feature, which will migrate away from the entrance regardless of the return flow during the flood tide (Figure 4). Under the right conditions this has the potential to transport ebb discharge well away from the shore. The current image on Google earth is shown as Figure 5, and it appears to show residual flow features from previous ebb discharge at both Jumpinpin and the Seaway which are migrating to the south.

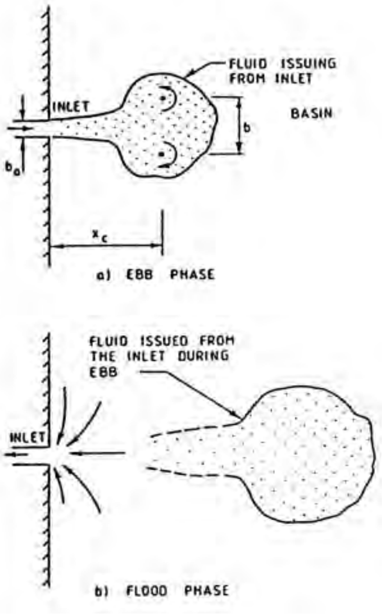

Figure 4: Idealised unsteady flow characteristics (Tomlinson, 1990)

Figure 5: Current Google Earth image showing residual ebb discharge features.

Based on these likely alternative fates for the ebb discharge, it can be said that the modelling results are very conservative. Experimental estimates of tidal exchange, for example, under cross flow conditions were higher than for discharges without a cross-flow.

The quantification of the tidal prism and Broadwater volumes has been useful in classifying the Broadwater as a well flushed system. It would appear that for average tidal conditions the residence time in the southern section of the Broadwater is of the order of no more than a day. Hence it is not surprising that the scenario results show rapid flushing of recycled water releases, even under the higher release rates. For spring tides the volume of water exchanged with the ocean during a tide is nearly twice that of the volume of the Broadwater below low water. It is not surprising then that the long term water quality monitoring by the EPA does not identify any impact of the Seaway releases.

The other feature of the hydrodynamics is that the flows are primarily confined to the main channels within the Broadwater. This means that the recycled water release will be constrained to move back and forth along the main north and south channels leading from the Seaway. There is little likelihood of the release impacting in a significant way on the western sections of the Broadwater, except under the continuous release scenario where the influence of the observed residual flow path around Wave Break Island may cause a recirculation.

3.5 General Comments and Summary

The release scenario simulation modelling has been comprehensive and a conservative approach has been taken at all times. The resulting concentrations for each scenario can be considered to represent the worst case outcome, and in general will always overestimate the impact of the releases. It would appear that through the optimisation of the operational strategies for each release (see Recommendations) it will be possible to continue with the current strategy without major modification for many years to come.

The modelling has provided a validation of the original ebb-tide staged release scheme and has added considerably to the knowledge of the system hydrodynamics.

4. RECOMMENDATIONS

The results of the release scenario simulation modelling, and of previous studies show that there is further capacity to extend the operational life of the ebb-staged release scheme by refining the operational protocols and possibly re-designing the diffusers. It is recommended that both these opportunities be investigated.

4.1 Optimising Timing of Release

At present, the release times are restrained by the EPA licence to start at 45 minutes after the local high tide and to end no later than the local low tide. There are four findings from the scenario modelling, and previous work, which provide the basis for a change to these conditions.

- Phase Lag between water level and flow direction reversal
- Differences in phase lag and velocity profiles between the diffuser sites on either side of the Seaway
- Asymmetry between ebb tide and subsequent flood tide
- Variability in coastal ocean dynamics

The phase lag between the high and low water mark and the time of flow reversal has been observed previously during the current measurement exercise in 1999 and has been demonstrated with the scenario modelling. The modelling has also shown that there is significant capacity to increase the time of discharge by starting earlier and possibly finishing later. The overall impact on water quality in the Broadwater is only a marginal decrease as a result.

The major change required in the current operational protocols is to link the discharge start and stop times to the flow reversal rather than to the water level. This can be achieved by placing a continuously recording current meter in the Seaway, and the output telemetered to the operational control location. Use of a side-cast Acoustic Doppler Current Meter (ADCP) has the advantage of determining the variation in tidal flow on either side of the Seaway.

The asymmetry between ebb and flood tide could be monitored via tidal height measurements in the Seaway, and these data combined with the velocity measurements using a mathematical correlation to determine operational discharge times. Further combination of these data with other environmental parameters available in real-time such as wind, wave and coastal current strength could indicate times when the ebb-tide release are likely to be transported well away from the Seaway and longer release time can be used.

Wind and wave data are readily available through the Bureau of meteorology and the EPA, however it would useful to monitor offshore conditions of currents and temperature. This could be done with a small coastal ocean reference station moored offshore either near the EAP wave buoy or the Narrowneck Reef marker buoy for safety. The reference station would consist of a bottom mounted ADCP with acoustic modem and radio links for data transmission.

A more robust approach is to develop a decision support system for discharge operation integrating data measurement and modelling. This can take two paths:

- Undertake measurements for a limited period of say 12 months to acquire data for model calibration covering a wide range of conditions. The model can then run for these conditions to create a matrix of optimum operational parameters which are added to a database within the DSS.
- Environmental data can be measured and feed into a Neural Network Analysis, which can be “trained” to recognise optimum operating conditions for a set combination of environmental parameters. After a period of time the training will become accurate enough to determine the operating parameters without the need for measurement. Of course the longer the data set the more accurate the model. With this approach it is still useful to have the numerical model operational to assess the details of discharge behaviour. The advantage of this approach is that provided one or more of the environmental parameters can be predicted (eg waves, wind, tides) the model can be used as predictor of unexpected events.

Information on ADCP velocity measurement is provided in Appendix 2. Water level measurement only requires a straightforward pressure transducer and data logging set-up. Telemetering of data to shore via acoustic modems and then radio links is possible and can be integrated into existing data systems in use near the Seaway.

4.2 Diffuser Re-design

The scenario modelling indicates that a concentrated plume from the northern outfall during an incoming tide will remain “attached” to the northern wall. Preliminary modelling undertaken by DHIW&E showed that discharge at a site further into the channel results in a reduction in concentrations in the Broadwater. Anecdotal information suggests that the plume does cling to the wall, and it is to be expected given that the outfall consists of a line of diffuser outlets along a line parallel to the wall. Detailed modelling is recommended to identify an optimum configuration and location for a re-designed diffuser. The release scenario simulations indicate that there is not likely to be any benefit from changing the southern diffuser.

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APPENDIX 1

SUMMARY OF PREVIOUS EXPEIMENTAL AND FIELD STUDIES

Tidal Exchange

Experimental studies for the Nerang (now Seaway) tidal exchange were undertaken in the late 1970s to estimate the likely level of return fraction for an operational strategy which required release throughout the out-going tide (Wilkinson et al, 1979). The flow characteristics at a tidal entrance can be expressed in terms of a set of characteristic parameters (Tomlinson, 1986). In terms of the tidal prism, P_T, the mean cross-sectional area of the channel, A_C, and the mean depth of flow in the channel, d_o, the characteristic length scale, L, is given by:

$$L = [\, \pi^2 P_T^2 / A_C d_o]^{1/3}$$

This characteristic scale gives a representation of a typical distance offshore that the ebb flow will travel. Typical values of this for tidal entrances range from 7 km to 19 km. The actual behaviour of the ebb tidal flow is related to this length relative to the width and depth of the tidal entrance. Again for typical tidal entrances the corresponding entrance depth ratio, L/d_o, ranges from 1,000 to 6,000, and the entrance width ratio, L/b_o from 8 to 77. The characteristic length scale and entrance parameters for the Seaway entrance were estimated for a spring tide as:

$L = 8\text{km}$

$L/b_o = 33.7$

$L/d_o = 1090$

Using these parameters an experimental study was carried out using a scaled physical model to estimate the fraction returning under a range of conditions. The results of the experiments using a dye release are shown in Figure A1. The mixing that would occur in a real case was only partially reproduced in the model due to the very much lower Reynolds Number which existed in the model. Concentration levels were continuously monitored during tests to determine the exchange efficiency and it was found that the strength of the offshore current had negligible effect on the fraction of flow returning to the entrance on the flood tide. The return fraction dropped rapidly to a concentration fraction of 0.2 of the release concentration within one hour after the flow reversal and then steadily reduced to zero by the end of the flood cycle. The total return fraction was found to be 0.14 with no offshore current, and 0.14 for the 50% exceedance current and 0.17 for the 0% exceedance current.

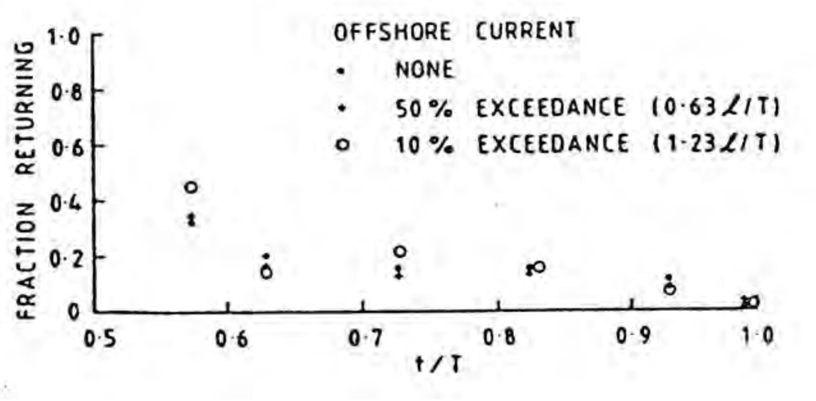

Figure A1: Case Study – Seaway Tidal exchange (Tomlinson, 1990)

More recent studies by Walsh (1998) determined very similar tidal exchange fractions and also demonstrated the influence of asymmetry between the strength of the ebb tide relative to that of the subsequent flood tide. The impact of this asymmetry is as follows:

- For a relatively weak ebb tide followed by a stronger flood tide, it is expected that more of the ebb release will be re-entrained into the flood tide and returned to the entrance.
- For a relatively strong ebb tide followed by a weaker flood tide, it is expected that less discharge will return to the entrance.

The results shown in Figure A2 show the tidal strengths in terms of the entrance width ratio, and indicate a range of tidal exchange ratios for the Seaway of 0.14 to 0.18.

In 1997, an attempt was made to quantify tidal exchange in the field using a natural isotope of nitrogen (N15) as a tracer. The experiment involved dosing the Benowa storage basin with the isotope and monitoring the assimilation into the outgoing tidal flow and subsequent incoming tide using the concentration of the isotope in phytoplankton as the measure (Persson, 1997 and Dilworth, 1997). The quantity of the isotope used was limited by funding and as result it was less than satisfactory as a marker over a tidal cycle. However, an analysis of the ambient nitrogen levels within the Broadwater and the ocean showed that there was a significant difference, and a mass balance was obtained which yielded a tidal exchange ratio of between 0.07 and 0.13.

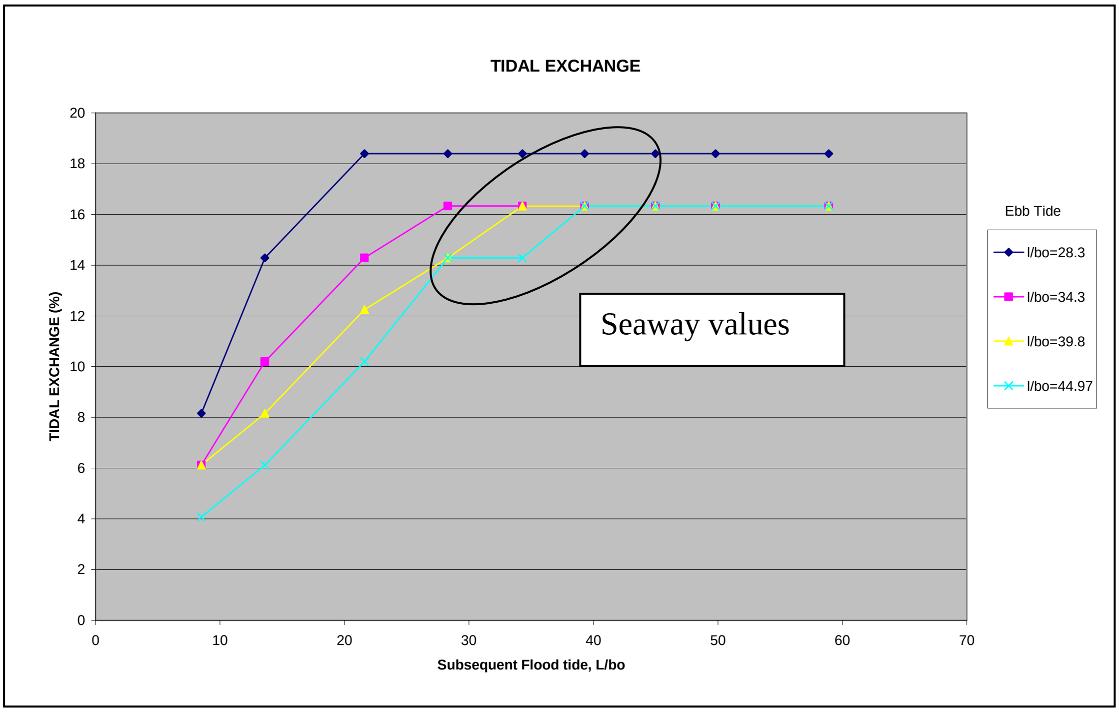

Figure A2: Experimental tidal exchange ratios for entrances similar to the Seaway (Walsh, 1998).

Tidal Hydrodynamics

Two exercises were carried out using 3 current meters located on a transect across the entrance to the Seaway. The first, in July 1997 was for only 2-3 days as part of the tidal exchange experiment. Results from this exercise are shown in Figure A3 below.

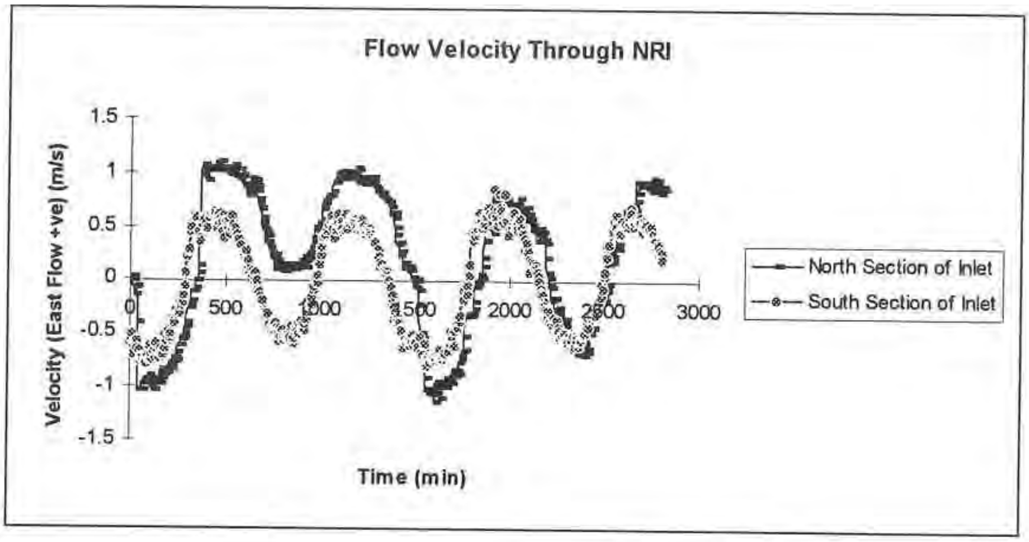

Figure A3: Velocity measurement taken in the Seaway on 26, 27 and 28th July 1997.

The second was for a period of 6 weeks in 1999. Although there was data recovery problems, a good dataset was obtained for the southern section of the channel. In 2001, the data was analysed on behalf of GCW to determine the time lag between the high and low water marks and the subsequent flow reversal, as part of a submission to the EPA on the operational licence.

Table A1 below represents a 9-day sample period and demonstrated that the time lag is highly variable ranging from 0 minutes to 114 minutes. The average time lag was 68 minutes from high water for ebb tide reversal, and 64 minutes from low water for flood tides. The median value for both was 66 minutes.

Table A1 – Typical values of Flow Reversal Time Lag

High Water Level	Low Water Level	Tidal Range Ebb	Tidal Range Flood	Lag Ebb (minutes)	Lag Flood (minutes)
6.371				78	
	5.396	0.975			114
7.016			1.62	84	
	5.52	1.496			108
6.426			0.906	96	
	5.704	0.722			54
6.952			1.248	114	
	5.529	1.423			90
6.388			0.859	114	
	5.725	0.663			6
6.768			1.043	66	
	5.559	1.209			78
6.354			0.795	42	
	5.755	0.599			36
6.614			0.859	60	
	5.572	1.042			84
6.452			0.88	48	
	5.879	0.573			18
6.61			0.731	36	
	5.614	0.996			78
6.546			0.932	114	
	5.896	0.65			78
6.571			0.675	66	
	5.657	0.914			48
6.678			1.021	90	
	5.879	0.799			66
6.537			0.658	0	
	5.542	0.995			54
6.721			1.179	48	
	5.764	0.957			36
6.477			0.713	36	
	5.516	0.961			60
6.811			1.295	72	
	5.751	1.06			72
6.512			0.761	66	

APPENDIX 2:

Instrumentation for Entrance Velocity Measurement

Teledyne RD Instruments
Acoustic Doppler Products
WORKHORSE
H-ADCP

MARINE MEASUREMENTS
NAVIGATION
WATER RESOURCES

Workhorse H-ADCP

LONG-RANGE HORIZONTAL ADCP

Real-time current profiling and waves measurement in a single package

Teledyne RD Instruments' **Horizontal Acoustic Doppler Current Profiler** (H-ADCP) is a monitoring system that 'looks' horizontally across a water body, measuring water currents at various locations. The H-ADCP's narrow 1-degree beam, combined with Teledyne RDI's patented BroadBand signal processing, provides unparalleled data range, resolution, and quality. The H-ADCP provides a complete measurement of the flow structure at a single depth out to 200 meters.The H-ADCP can also be upgraded to include Teledyne RDI's patented Waves Array. Now a single instrument can provide you with precisely the data you require—when and where you need it most.

The Workhorse H-ADCP is ideal for use:

- In ports and harbors for real-time pier-mounted monitoring for vessel navigation and safety
- In estuaries for defining complex circulation patterns and lateral mixing
- On oil platforms, seismic vessels, and in hydroelectric and tidal power plants

What sets us apart:

- *Narrow Beam:* *<1° beam ensures maximum profiling range while reducing the probability of contamination caused by surface and/or seabed reflections.*
- *Currents and Waves:* *Combined capability in a single package.*
- *Increased Data:* *The H-ADCP provides users with the capability to measure from 1 to 128 data points, which represents an exponential increase in data quality and accuracy.*
- *Superior Data Quality:* *Teledyne RDI's three-beam configuration provides a third beam to screen out biased data due to the passage of vessels through the sample volume.*

TELEDYNE
RD INSTRUMENTS
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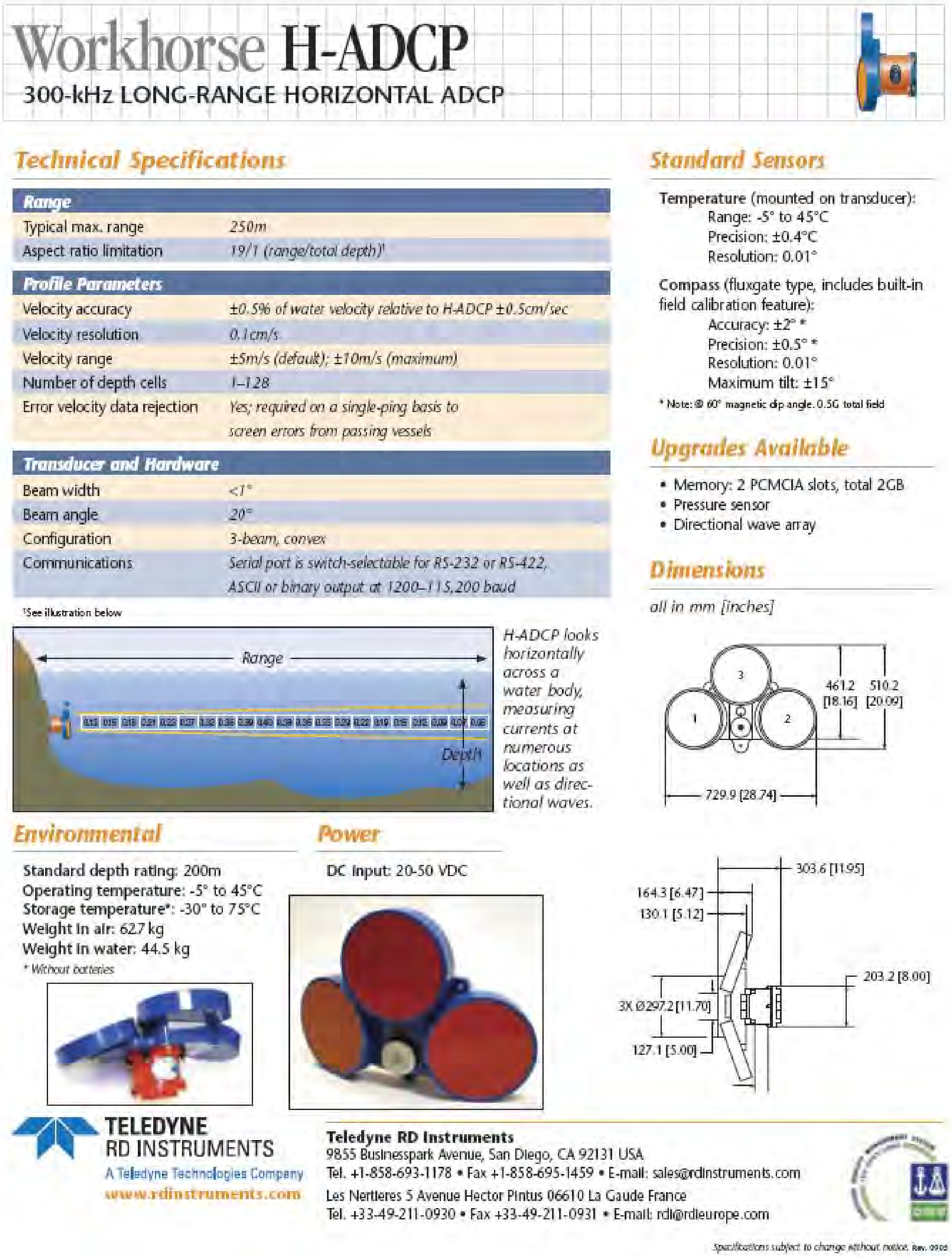
MEASURING WATER IN MOTION AND MOTION IN WATER



Workhorse H-ADCP

300-kHz LONG-RANGE HORIZONTAL ADCP

Technical Specifications

Range	
Typical max. range	*250m*
Aspect ratio limitation	*19/1 (range/total depth)*[1]
Profile Parameters	
Velocity accuracy	*±0.5% of water velocity relative to H-ADCP ±0.5cm/sec*
Velocity resolution	*0.1cm/s*
Velocity range	*±5m/s (default); ±10m/s (maximum)*
Number of depth cells	*1–128*
Error velocity data rejection	*Yes; required on a single-ping basis to screen errors from passing vessels*
Transducer and Hardware	
Beam width	*<1°*
Beam angle	*20°*
Configuration	*3-beam, convex*
Communications	*Serial port is switch-selectable for RS-232 or RS-422, ASCII or binary output at 1200–115,200 baud*

[1] See illustration below

H-ADCP looks horizontally across a water body, measuring currents at numerous locations as well as directional waves.

Environmental

Standard depth rating: 200m
Operating temperature: -5° to 45°C
Storage temperature*: -30° to 75°C
Weight in air: 62.7 kg
Weight in water: 44.5 kg

* *Without batteries*

Power

DC input: 20-50 VDC

Standard Sensors

Temperature (mounted on transducer):
Range: -5° to 45°C
Precision: ±0.4°C
Resolution: 0.01°

Compass (fluxgate type, includes built-in field calibration feature):
Accuracy: ±2° *
Precision: ±0.5° *
Resolution: 0.01°
Maximum tilt: ±15°

* Note: @ 60° magnetic dip angle, 0.5G total field

Upgrades Available

- Memory: 2 PCMCIA slots, total 2GB
- Pressure sensor
- Directional wave array

Dimensions

all in mm [inches]

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Specifications subject to change without notice. Rev. 0905