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A Conceptual Model for Designing Canal Estates to Maximise Water Quality

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ABSTRACT

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Residential canal estates are constructed waterways that offer the opportunity to reside adjacent to navigable channels connected to estuaries and coastal waters. The shape and character of canal estates varies greatly depending upon their requirements and location. This study aimed to examine the properties of various canal estates in order to increase our understanding of the processes that can lead to the development of poor water quality conditions. Water property data were collected within three different canal estates. Two were connected to adjacent estuaries through open channels while the third was connected through an occasionally opened box culvert structure. It was found that variations in bottom depth and stormwater inflow induced horizontal stratification affects that led to a reduction in water quality. From the experimental results and consideration of land-based processes a conceptual model was developed. Application of the model could lead to designs that minimise occurrences of poor water quality.

ADDITIONAL INDEX WORDS: *Stratification, Gold Coast, flushing, estuary.*

INTRODUCTION

Canal estates are constructed urban environments where housing allotments abut navigable deepwater channels. For the homeowner these channels provide ready access to a mooring (or jetty); the opportunity to undertake a variety of water-based recreational activities from their own backyard; and the aesthetic advantage of direct water views. Consequently, canal estates are popular residential environments of significant commercial value. They are usually constructed by dredging (and digging) a series of interconnected channels within coastal lowlands. The dredged material is either sold to the construction industry or used as landfill to ensure housing allotments are set at a safely elevated level above high water. Estates are connected to an estuary through either an open channel or a gated system. While the purpose of the latter is used to ensure the tidal prism of the estuary is not significantly altered, water exchange between the estate and the estuary will be inhibited.

While the engineering and property development professions appear experienced in the development of canal estates (as evident by their proliferation within coastal communities), no evidence has yet been sighted showing the existence of readily useable design tools that ensures the level of water quality within canals remains acceptable. This is particularly important within Australia, where environmental concerns and new legislation are now placing strong limitations on any new developments. Indeed, within Queensland, Australia, the recently published State Coastal Management Plan — Queensland's Coastal Policy (QUEENSLAND GOVERNMENT, 2002) now specifies that:

In view of the potential adverse impacts of canals and dry land marinas, further development of canals and dry land marinas should proceed only if it does not adversely affect coastal resources and their values, in particular if it does not contribute to:

(a) degradation of water quality;
(b) an increased risk of flooding;
(c) degradation and loss of coastal wetlands;
(d) degradation and loss of declared Fish Habitat Areas; and
(e) degradation and loss of shorebird roost areas.

Therefore, before any new development can be approved, detailed knowledge of how it will affect the environment must be accurately and rigorously assessed, then presented to the appropriate approval agencies. It is clear that any new development can only be considered on land of poor environmental value (items *c, d* and *e*), when it is designed so as not to increase flood levels and does not impact negatively on water quality, both within and adjacent to it. It is evident that these new policy conditions have placed severe restrictions on new developments.

The aim of the project discussed in this paper was to develop a conceptual understanding and model of how to best design canal estates (or to modify existing ones) to maximise water quality. It was not the scope of this work to examine the other environmental impacts that canal estates may have. The paper will first discuss some qualitative studies performed within existing canal estates in order to determine the mechanisms that may lead to degradation of water quality. The outcomes of the studies, and information gathered from the literature, are then used to develop a conceptual design model that should lead to a minimal decline in water quality. This work also highlights the necessity for the development of accurate and simple numerical schemes to maximise canal estate designs.

METHODOLOGY

Study Sites

To help develop the conceptual model it was necessary to undertake field studies within a range of canal estates. For convenience the estates used were located within the Gold Coast region of Queensland, Australia (approximately 28,07 S and 153,28 E), which has the greatest concentration of canal developments within Australia (MORTON, 1992). The Gold Coast is a barrier island environment that experiences heavy summer rainfall periods and drier winters. The area has undergone extensive development and population growth over the past forty (40) years, resulting in significant loss of wetlands and marine habitats.

Longitudinal surveys of the water properties within three (3) canal estates were conducted as part of this study. The estates were Burleigh Waters, Sorrento and canals adjacent to Tallebudgera Creek (see Figure 1). Burleigh Waters (ZIGIC *et al*, 2002) is a constructed waterways system located within the southern end of the Gold Coast. The estate consists of a number of constructed lakes separated from each other by narrow and shallow channels. While the lake depths can exceed 25 m, the nterconnecting channels are typically 1 m deep at low tide. The system is connected to the Nerang River estuary (which in itself is connected freely to the Pacific Ocean) by a box culvert hydraulic lock structure that opens for a period of two (2) hours ievery half tidal cycle (ZIGIC *et al.*, 2002). This opening permits the exchange of estuary and estate water, and was designed to assist in flood mitigation, maintain the lake system as a healthy brackish environment, to and minimise alterations to the tidal prism within the estuary. The report on the health of the Gold Coast Waterways (WALTHAM, 2002) noted the water quality within this estate was generally good; however, it is important to note this report presented data collected only within the upper 1 m, therefore offering no details on water at deeper levels.

As discussed by MORTON (1992) the canal estates located off Tallebudgera Creek (which flows directly into the Pacific Ocean) were constructed within an intertidal wetland that before construction consisted of 90 ha of mangroves, 20 ha of salt marshes and 50 ha of sand and mud flats. This finger-like dead end canal system has predominantly sandy channels that undergo routine dredging to maintain suitable navigation depths. Mid channel depths are typically 3 m at high tide, although some areas are shallower, while others can extend to 8.5 m. The mean annual tidal range at the mouth of the creek is microtidal at 1.03 m. Storm water flows directly into the canal via a series of large drainage pipes located around the estate, but especially concentrated at the ends of small side arm channels. Unlike Burleigh Waters the canals have an open connection to Tallebudgera Creek, and hence the ocean. WALTHAM (2002) found that the upper 1 m of the water column was generally of good quality, with higher nutrients and a reduction in dissolved oxygen occurring in the canal estates.

The canal estate at Sorrento (see Figure 1) was similar to that at Tallebudgera Creek, except it is located off the Nerang River and therefore a significant distance inland from the open ocean. It has a similar tidal range and storm water drain inlet pattern, but the depths in this estate do not exceed 4 m (which occurs in the middle of the largest basin). For the Nerang River system WALTHAM (2002) found that the canal networks (of which there are a large number) did not influence water quality in the lower estuary.

Study Techniques

Water column property data were collected within the three (3) chosen canal estates using a Seabird 19 CTD fitted with conductivity, temperature and pressure sensors. Dissolved oxygen (DO) levels were measured using membrane probes, and for the Sorrento study turbidity was derived using a McVan Instruments 190 Nephelometer. Table 1 lists the types of data collected. The location of each cast was recorded using a differential GPS unit.

RESULTS AND DISCUSSION

As would be expected, the Burleigh Lake system experiences a degree of stratification as a result of its deep lakes and shallow interconnecting channels. The system was found to be salinity stratified (with temperature playing only a minor role). Figure 2 reveals the degree of stratification observed in Burleigh during one particular survey; the bottom water was found to be near oceanic salinity, while the surface water was brackish. This revealed that the upper water was being replenished through tidal flushing, but the bottom was not, as the affects of vertical density stratification isolated it from the outside estuary. As a result of this isolation the bottom water became anoxic and therefore of poor quality. It was found that this water could only be replenished under extreme drought conditions.

While the results in Figure 2 may be unsurprising, it was found that even shallow systems experienced some degree of vertical stratification. For example, Figure 3 presents CTD data collected within the deepest part of the Sorrento estate, which was located at the centre of the largest basin. The water was only 1.5 m deep at the exits and entrances to this basin. The data reveals the deeper water experienced a significant degree of deoxygenation as the vertical exchange of oxygen-rich surface water was retarded by the stratification. The reduction in salinity near the bed was the result of a persistent fine mud layer

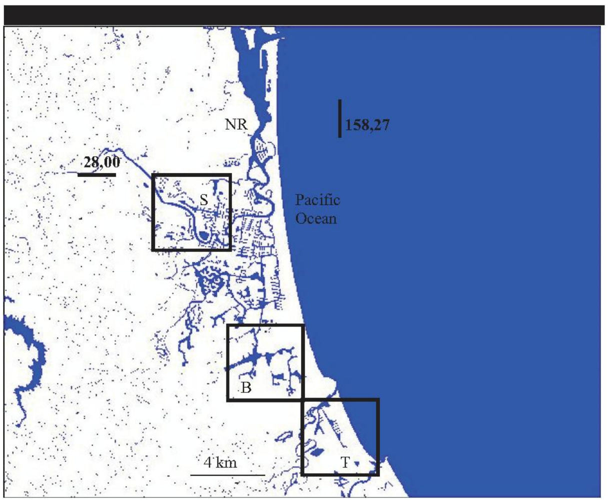

Figure 1. Location of the Southern Gold Coast Region showing the location of the three canal estates used in this study: B - Burleigh Waters, T - Tallebudgera Creek canals and S - Sorrento canals.

indicating the system was poorly flushed at depth. Therefore, even an estate freely connected to an estuary can experience a degree of vertical stratification.

Vertical stratification is an obvious mechanism to limit the exchange of water within a canal estate collected. However, the collected data also revealed the existence of horizontal stratification effects that may lead to poor water quality. Figure 4 shows data collected during a longitudinal transect of the Tallebudgera Creek estate. Data were collected at mid tide over a period of one (1) hour. Figure 4 reveals the basin closest to the estuary experienced some deep vertical stratification, while the second basin did not; indicating that the saline oceanic water was unable to penetrate far into the estate and replenish the deeper bottom waters in all areas. The surface waters were also strongly stratified; this arose from the waters draining into the estate from storm water drains located at the ends of most of the smaller canal arms. The effect of this (including topographic) was to generate a degree of horizontal stratification, which in turn would limit the tidal flushing rate.

In summary, the results from the surveys conducted revealed two (2) distinguishing features of the water within the canal estates. Firstly, the water column usually showed some degree of vertical stratification in salinity (and hence density) even in very shallow environments. Secondly, horizontal stratification could readily exist, especially when storm water flowed freely into the estates.

CONCEPTUAL MODEL

The results from the qualitative experimental program led to the establishment of a number of important points to help develop a conceptual model for designing canal estates with the intent of maximising water quality. The items include the necessity of ensuring strong vertical mixing in order to minimise the likelihood of vertical stratification; adequate flushing; and the necessity to better control the quality of storm water inputs. Vertical mixing should be encouraged by ensuring that; the canals are not too deep with respect to the amount of available wind mixing energy; canals do not have any deep holes that encourage the development of strong stratification;and that no matter what the prevailing direction of the wind is it can always stir the water within canals and

Table 1. *Canal estates studied and the instruments used. Figure 1 shows the locations of the estates.*

Canal Estate	Instruments Used
Burleigh Lake	CTD + DO
Sorrento	CTD, DO, Neph
Tallebudgera Creek	CTD + DO

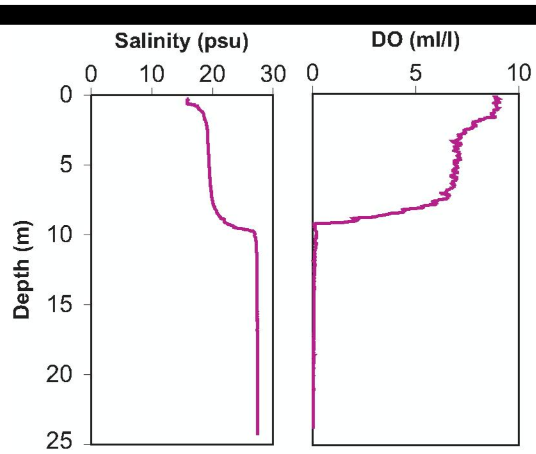

Figure 2. Plots of salinity and DO against depth for data collected within a deep hole in the Burleigh Lake estate area. Data were collected on 8 June 2001 (winter period).

encourage horizontal flows and consequently boundary mixing. An additional stirring method to be considered as a benefit is obtained through boat traffic, as this can also enhance vertical mixing and the cycling of nutrients through the sediment (DODD *et al.*, 2003).

Horizontal mixing also requires encouragement, as this process exchanges canal estate water with adjacent estuarine water. This is best achieved by ensuring no deep holes exist within the estate, and that the channel depths within the estates decreases away from its mouth, thus encouraging any denser water to flow towards and out into the estuary.

Other points to consider when designing canal estates are the influence of the types of banks on the mixing behaviour and the biological activity. It is obvious that the banks should be designed with regions that could encourage flow stagnation, as this will add to the possibility of horizontal stratification and thus contamination concentration increases. However, in most smallcanal estates (as considered here) natural wind mixing and boat traffic is likely to break down and stagnation zones. The material from which the banks are constructed (in not natural) can certainly influence the biological activity, and hence aquatic biodiversity and water quality. For example ARLINGHAUS *et al.*, (2002) found that artificially embanked canal channels encouraged low fish reproduction as a result of elevated currents generated by boat wakes. Therefore, the banks should be constructed in an environmentally friendly way an issue requiring significantly more research.A few other points of consideration are based upon land use. Every effort should be made to encourage best land practices. For example, the use of fertilizers on land adjacent to the channels should be discouraged, or alternatively, the establishment of gardens requiring no fertilization should constitute part of the estates caveats. Further, the ownership of pets also requires significant thought, given their potential to contribute of fecal coliform levels within the waters. Additionally, since it is inevitable that nutrient loaded surface runoff will occur (and result in some degree of horizontal and vertical stratification) all efforts should be made to direct the water out of the estate. If this cannot be achieved, then artificial wetlands should be made part of the estate to minimise the impact of stratification and nutrient loadings on the canal waters. A summary of these conditions is presented in Table 2.

Based on the conditions presented in Table 2, Figure 5 presents conceptual models of what constitutes poor and good canal estate designs. It is important to realise here that the aim of the conceptual model is to maximise water quality and not to maximise profit to the developer. The poor design, as typically found throughout most canal estates (eg. the canal off Tallebudgera Creek) has dead ends that result in flow stagnation zones, untreated stormwater inputs and variable depths, which ultimately will result in horizontal and vertical stratification. On the other hand, the good design minimises (if not eliminates) stagnation zones, treats any storm water before it enters the

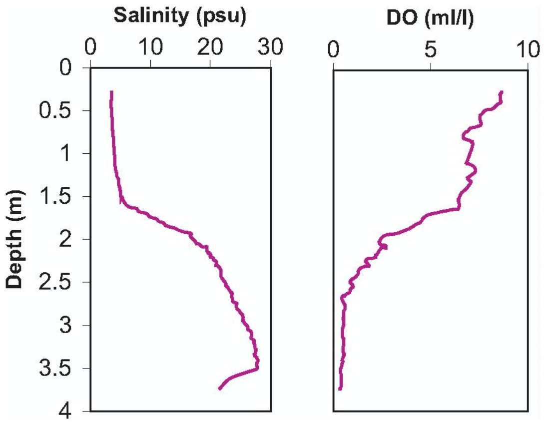

Figure 3. Plots of salinity and DO against depth for data collected within a deep hole in the Sorrento Canal estate. NB the shallow depths compared to Figure 2. Data were collected on 28 Feb 2003 (summer period).

estate and encourages water column mixing and circulation by allowing any wind to cause water movement. The designs do not include bank stabilization material, but it is envisaged that the banks should be stabilized using environmentally friendly material that could filter surface overflows before entering the canal. This could be achieved by using set back zones of natural vegetation but given the desire for householders to have ready access to the water this will be an unlikely practical option. Further, the homes should not be so tightly spaced that they shield the water surface from wind stresses that can act to stir the canal waters.

CONCLUSIONS

Examination of new and historical data collected within a variety of canal estates in the Gold Coast Region (South East Queensland, Australia) revealed the estates experience water quality problems that appear to have arisen from vertical and horizontal stratification influences. Vertical density stratification inhibits the exchange of oxygen-rich surface water to the deeper parts of the canals, while horizontal stratification inhibits the exchange between outside water and estate water. This stratification is the direct result of poor design, construction and possibly maintenance practices.

As a result of the work undertaken a conceptual has been developed. The model aims to eliminate stagnation zones and minimise the influences of land-based inflows. It is anticipated

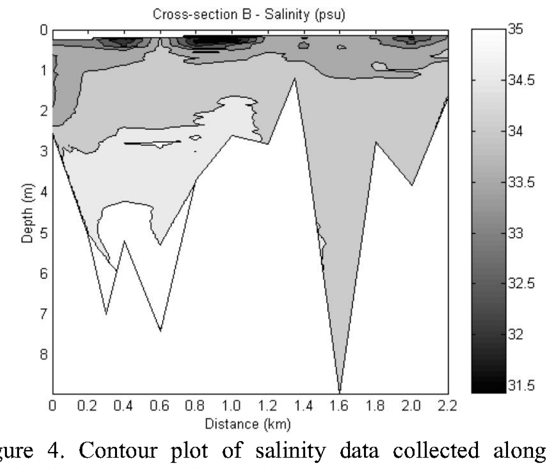

Figure 4. Contour plot of salinity data collected along a longitudinal transect of the Tallebudgera Creek estate (eastern arm). The colour scale represents salinity values in psu. Data were collected on July 22, 2003 (winter period). The sharp changes observed in the bottom line indicate the positions at which the CTD profiles were collected.

Table 2. *Appropriate design features to maximise water quality*

1. Channel depth increases towards the entrance to the canal estate
2. Minimise the channel depth to allow wind stress to mix the water column
3. Align channels to encourage mixing by dominating wind fields
4. Limit the occurrence of no flow zone by avoiding dead ends
5. Create banks that are stable, encourage aquatic habitats and enhance boundary mixing
6. Use constructed wetlands to treat any stormwater before it enters the estate, but preferably do not permit stormwater to enter estates
7. Encourage residents to minimise their use of garden fertilizers which may runoff into the canals
8. Limit pet ownership to avoid fecal contamination within canals
9. Conduct regular bank and channel maintenance to avoid the development of sills which inhibit horizontal mixing
10. For gated estates encourage the exchange of estate water with estuarine/coastal waters through the use of engineered systems

that the adoption of the proposed model would result in a reduction in water quality problems and the enhancement of the environment.

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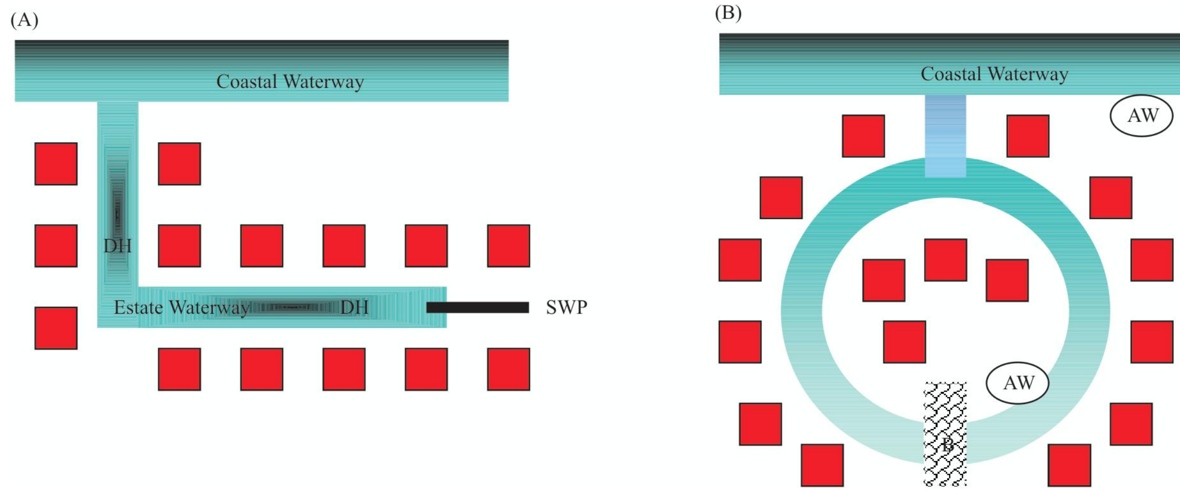

Figure 5. Conceptual model of a (a) poor and a (b) good canal estate deign. NB the good design maximises wind driven mixing opportunities. In the Figure the squares indicate houses, the darker the shading the greater the channel depth, DH deep hole, SWP storm water pipe, AW artificial wetland and B is a connecting bridge under which water can freely flow.