Albany Waterfront Project

Equilibrium 'Box Model' Calculations for Water Quality (Chlorophyll 'a' levels) in Marina Waters

Background

An indication of water quality (in terms of phytoplankton growth potential as measured by chlorophyll 'a' levels) in marina configurations was obtained with an equilibrium (or 'box') model using dissolved inorganic nitrogen (DIN) as the modelled constituent.

Water quality data obtained for Princess Royal Harbour strongly indicate that phytoplankton growth is limited by dissolved inorganic nitrogen supply, and so incorporation of DIN into phytoplankton biomass was used to provide a conservative estimate of potential phytoplankton growth.

The ratio of chlorophyll 'a' to carbon, and of carbon to nitrogen in phytoplankton is relatively uniform (50C:1Chl a, and 5.7C:1N; by mass) and if it is conservatively assumed that <u>all</u> available DIN is utilised by phytoplankton within the marina, the chlorophyll 'a' concentration will be approximately 0.117 times the predicted DIN concentration. This approach provides a guide to potential water quality (in terms of chlorophyll 'a' levels) in <u>relative</u>, rather than absolute, terms. The rate of utilisation of DIN within the marina would typically be less than 100%, and so expected changes with 75% and 50% utilisation were also modelled.

Marina configuration area and volumes

Area: total area 74,000 m^2 (marina area of 57,000m^2 and tug boat harbour area 17,000 m^2).

Volume: marina volume 366,000 m^3.

Note: WorleyParsons calculated e-folding times for the marina as ranging from 3.4 to 6 days over a range of conditions throughout summer, autumn and winter/spring, not full volumetric replacement of marina waters. However, as the e-folding times were calculated from a model that was forced using only wind and tides, the e-folding times were assumed to be conservative. The e-folding times were therefore used as proxies for flushing times.

Nitrogen inputs

Nitrogen inputs from groundwater and sediment release were considered. For the purpose of this exercise, the nitrogen in groundwater and released from sediments was assumed to be all DIN, and the background DIN in the 'source' waters for the model was 9 µg/L (Princess Royal Harbour: baseline monitoring site 1, average concentration of ammonium and nitrate+nitrite). Stormwater inputs were not considered, given that they are episodic events, and of far lesser magnitude that groundwater inputs.

The sediment nitrogen release rate was based on those measured by Lavery et al (1993) for sediments from Shoalwater Bay (2.4 mg N/m2/d respectively) as part of the Perth Coastal Waters study, and comparable to published rates for sandy, carbonate sediments.

Sediment N load marina (2.4 mg/m2/day) = 0.065 tpa

For groundwater inputs, studies by ERM (2006) indicates that the groundwater flux into the proposed marina is ~81 m3/day (= most likely scenario, with a best case scenario of ~13 m3/day, and a worst case scenario of ~209 m3/day), and an associated inorganic nitrogen flux of 0.225 kg/day (0.036–0.580 kg/day).

The input parameters for the equilibrium model are tabulated below. The model assumes that all input parameters remain constant in time. The values are applicable for a range of conditions throughout the year.

PARAMETER	
Volume of water enclosed by marina	366,000 m^3
Groundwater TN load	0.082 tpa (0.013–0.211 tpa)
Sediment TN load from enclosed sediments	0.065 tpa
Residence time	3.4–6 days
DIN concentration in source waters (Princess Royal Harbour site 1)	9 µg/L
Average Chl. a concentration in Princess Royal Harbour site 1	0.6 µg/L (0.5–0.8 µg/L)

Results

The technique used to approximate chlorophyll levels is likely to be of moderate accuracy, as the efficiency with which DIN is converted to chlorophyll depends on a range of other parameters such as availability of other nutrients, light, temperature, phytoplankton species involved, mixing and phytoplankton numbers. The scientific literature indicates 10–50% of gross DIN uptake by phytoplankton may be excreted as dissolved organic nitrogen, depending on the stage in their growth cycle (eg Diaz & Raimbault 2000, Flynn & Berry 1999, Pujo-Pay et al 1997, Slawyk et al, 1998). Nor does the model take into account uptake of DIN by benthic microalgae, uptake of DON by bacteria in the water and sediments, or loss of phytoplankton due to grazing. For these reasons results have been modelled for 100% utilisation of DIN (Table 1), 75% utilisation of DIN – which is considered more realistic (Table 2), and 50% utilisation of DIN (Table 3). Results are shown below, with predicted chlorophyll levels under most likely conditions of groundwater discharge and source water chlorophyll levels highlighted in bold.

Table 1: Predicted chlorophyll levels, assuming 100% conversion of DIN to new growth within marina

Flushing time	Sediment DIN load (tpa)	Groundwater DIN load (tpa)	Chl. level (µg/L) in source water	Final chl. level (µg/L)
3.4 days	0.065	0.013	0.5	1.7
3.4 days	0.065	0.013	**0.6**	1.8
3.4 days	0.065	0.013	0.8	2.0
3.4 days	0.065	**0.082**	0.5	1.9
3.4 days	0.065	**0.082**	**0.6**	**2.0**
3.4 days	0.065	**0.082**	0.8	2.2
3.4 days	0.065	0.211	0.5	2.3
3.4 days	0.065	0.211	**0.6**	2.4
3.4 days	0.065	0.211	0.8	2.6
4 days	0.065	0.013	0.5	1.8
4 days	0.065	0.013	**0.6**	1.9
4 days	0.065	0.013	0.8	2.1
4 days	0.065	**0.082**	0.5	2.0
4 days	0.065	**0.082**	**0.6**	**2.1**
4 days	0.065	**0.082**	0.8	2.3
4 days	0.065	0.211	0.5	2.5
4 days	0.065	0.211	**0.6**	2.6

Flushing time	Sediment DIN load (tpa)	Groundwater DIN load (tpa)	Chl. level (µg/L) in source water	Final chl. level (µg/L)
4 days	0.065	0.211	0.8	2.8
5 days	0.065	0.013	0.5	1.8
5 days	0.065	0.013	**0.6**	1.9
5 days	0.065	0.013	0.8	2.1
5 days	0.065	**0.082**	0.5	2.1
5 days	0.065	**0.082**	**0.6**	**2.2**
5 days	0.065	**0.082**	0.8	2.4
5 days	0.065	0.211	0.5	2.7
5 days	0.065	0.211	**0.6**	2.8
5 days	0.065	0.211	0.8	3.0
6 days	0.065	0.013	0.5	1.9
6 days	0.065	0.013	**0.6**	2.0
6 days	0.065	0.013	0.8	2.2
6 days	0.065	**0.082**	0.5	2.2
6 days	0.065	**0.082**	**0.6**	**2.3**
6 days	0.065	**0.082**	0.8	2.5
6 days	0.065	0.211	0.5	2.9
6 days	0.065	0.211	**0.6**	3.0
6 days	0.065	0.211	0.8	3.2

Table 2: Predicted chlorophyll levels, assuming 75% conversion of DIN to new growth within marina

Flushing time	Sediment DIN load (tpa)	Groundwater DIN load (tpa)	Chl. level (µg/L) in source water	Final chl. level (µg/L)
3.4 days	0.065	0.013	0.5	1.4
3.4 days	0.065	0.013	**0.6**	1.5
3.4 days	0.065	0.013	0.8	1.7
3.4 days	0.065	**0.082**	0.5	1.6
3.4 days	0.065	**0.082**	**0.6**	**1.7**
3.4 days	0.065	**0.082**	0.8	1.9
3.4 days	0.065	0.211	0.5	1.9
3.4 days	0.065	0.211	**0.6**	2.0
3.4 days	0.065	0.211	0.8	2.2
4 days	0.065	0.013	0.5	1.4
4 days	0.065	0.013	**0.6**	1.5
4 days	0.065	0.013	0.8	1.7
4 days	0.065	**0.082**	0.5	1.6
4 days	0.065	**0.082**	**0.6**	**1.7**
4 days	0.065	**0.082**	0.8	1.9
4 days	0.065	0.211	0.5	2.0
4 days	0.065	0.211	**0.6**	2.1
4 days	0.065	0.211	0.8	2.3
5 days	0.065	0.013	0.5	1.5
5 days	0.065	0.013	**0.6**	1.6
5 days	0.065	0.013	0.8	1.8

Flushing time	Sediment DIN load (tpa)	Groundwater DIN load (tpa)	Chl. level (µg/L) in source water	Final chl. level (µg/L)
5 days	0.065	**0.082**	0.5	1.7
5 days	0.065	**0.082**	**0.6**	**1.8**
5 days	0.065	**0.082**	0.8	2.0
5 days	0.065	0.211	0.5	2.1
5 days	0.065	0.211	**0.6**	2.2
5 days	0.065	0.211	0.8	2.4
6 days	0.065	0.013	0.5	1.5
6 days	0.065	0.013	**0.6**	1.6
6 days	0.065	0.013	0.8	1.8
6 days	0.065	**0.082**	0.5	1.8
6 days	0.065	**0.082**	**0.6**	**1.9**
6 days	0.065	**0.082**	0.8	2.1
6 days	0.065	0.211	0.5	2.3
6 days	0.065	0.211	**0.6**	2.4
6 days	0.065	0.211	0.8	2.6

Table 3: Predicted chlorophyll levels, assuming 50% conversion of DIN to new growth within marina

Flushing time	Sediment DIN load (tpa)	Groundwater DIN load (tpa)	Chl. level (µg/L) in source water	Final chl. level (µg/L)
3.4 days	0.065	0.013	0.5	1.1
3.4 days	0.065	0.013	**0.6**	1.2
3.4 days	0.065	0.013	0.8	1.4
3.4 days	0.065	**0.082**	0.5	1.2
3.4 days	0.065	**0.082**	**0.6**	**1.3**
3.4 days	0.065	**0.082**	0.8	1.5
3.4 days	0.065	0.211	0.5	1.4
3.4 days	0.065	0.211	**0.6**	1.5
3.4 days	0.065	0.211	0.8	1.7
4 days	0.065	0.013	0.5	1.1
4 days	0.065	0.013	**0.6**	1.2
4 days	0.065	0.013	0.8	1.4
4 days	0.065	**0.082**	0.5	1.2
4 days	0.065	**0.082**	**0.6**	**1.3**
4 days	0.065	**0.082**	0.8	1.5
4 days	0.065	0.211	0.5	1.5
4 days	0.065	0.211	**0.6**	1.6
4 days	0.065	0.211	0.8	1.8
5 days	0.065	0.013	0.5	1.2
5 days	0.065	0.013	**0.6**	1.3
5 days	0.065	0.013	0.8	1.5
5 days	0.065	**0.082**	0.5	1.3
5 days	0.065	**0.082**	**0.6**	**1.4**
5 days	0.065	**0.082**	0.8	1.6
5 days	0.065	0.211	0.5	1.6
5 days	0.065	0.211	**0.6**	1.7

Flushing time	Sediment DIN load (tpa)	Groundwater DIN load (tpa)	Chl. level (µg/L) in source water	Final chl. level (µg/L)
5 days	0.065	0.211	0.8	1.9
6 days	0.065	0.013	0.5	1.2
6 days	0.065	0.013	**0.6**	1.3
6 days	0.065	0.013	0.8	1.5
6 days	0.065	**0.082**	0.5	1.4
6 days	0.065	**0.082**	**0.6**	**1.5**
6 days	0.065	**0.082**	0.8	1.7
6 days	0.065	0.211	0.5	1.7
6 days	0.065	0.211	**0.6**	1.8
6 days	0.065	0.211	0.8	2.0

The model results suggest that, with 100% utilisation of DIN in new phytoplankton growth, the chlorophyll ‘a’ concentrations of 1.7–3.0 µg/L may be expected in the Protected Harbour during most conditions (flushing times 3.4–5 days), and 1.9–3.2 µg/L in calmer conditions (6 days). Predicted chlorophyll levels in the marina are thus 2.5–5.4 times greater than those of outside water during most conditions (flushing times 3.4–5 days), and 2.7–5.8 times greater in calmer conditions. If <100% of nitrogen inputs are converted to phytoplankton biomass within the harbour, the predicted chlorophyll ‘a’ concentrations obviously decrease. At 75% conversion the model predicts chlorophyll ‘a’ concentrations of 1.4–2.4 µg/L (2.2–3.9 times greater than those of outside water) during most conditions, and 1.5–2.6 µg/L (2.3–4.6 times greater than those of outside water) in calmer conditions. At 50% conversion, the model predicts chlorophyll ‘a’ concentrations of 1.1–1.9 µg/L (1.8–3.2 times greater than those of outside water) during most conditions, and 1.2–2.0 µg/L (1.8–3.4 times greater than those of outside water) in calmer conditions.

The above results for 75–100% utilisation of DIN are not inconsistent with data for other marinas in Perth’s coastal waters: for example, data for 1999/2000 summer in Hillary’s Boat harbour of 3.4 µg/L (modelled flushing time ~4 days, chlorophyll values ~3.4 times those of ‘outside’ waters), and 2.1 µg/L for Success Harbour (modelled flushing time ~1 day, chlorophyll values ~2.1 times those of ‘outside’ waters) (BBG, 2001).

The Jervoise Bay Northern Harbour in Cockburn Sound has a modelled flushing time of 10–11 days (BBG, 2001), and recorded chlorophyll levels of ~2.0–2.2 µg/L in summer 2005/2006, 3.4–3.7 times those of outside waters (Oceanica 2006). Modelled flushing times for the Protected Harbour in Albany are more similar to those of Hillary’s Boat harbour than the Jervoise Bay Northern Harbour. It would therefore not be unreasonable to expect chlorophyll levels in the Protected Harbour will be around 3 to 4 times those of outside waters, which agrees with the results tabled earlier. However, water quality in the Jervoise Bay Northern Harbour is influenced by large nitrogen inputs from groundwater (estimated as over 60 tonnes/year in 2000; DAL, 2001), and although these have declined significantly in recent years due to a groundwater recovery scheme (with a resultant improvement in water quality; Oceanica 2006) they are still considerable. Groundwater nitrogen input/unit area for the Protected Harbour is about 0.011 tonnes/hectare (0.082 tpa, harbour area 7.4 hectares) compared to about 0.7 tonnes/hectare (50 tpa, harbour area 73 hectares) in the Jervoise Bay Northern Harbour, and indicate that the modelled results for the Protected Harbour are, if anything, over-estimates.

Potential influence of mitigation techniques

Although it is not anticipated that water quality within the marina will be unacceptable, some simple modelling was undertaken to examine the potential impact of mitigation measures on marina flushing times. For the purpose of this exercise, pumps capable of moving 5,000m^3/day were examined: such pumps are commonly used for site dewatering, and so are readily available. The potential impact of 1–3 pumps is shown in Table 4. The modelling is simplistic as calculations of the volume of water exchanged each day for the original flushing time assume this is entirely with clean seawater (i.e. incoming tides do not partially re-introduce poorer water quality that has previously flowed out of the marina on outgoing tides): as such, it would tend to slightly under-estimate original flushing volumes and therefore slightly over-estimate the relative influence of the pumps. This overestimation of the influence of the pumps would, however, be offset by placing the pumps in the most poorly flushed part of the marina, thus ensuring a proportionally greater effect on flushing times. As can be seen in Table 4, the use of pumps could potentially ensure flushing times of 3–4 days were achieved under almost all conditions, if required.

Table 4: Potential impact of mitigation measures (pumps) on marina flushing times

Original flushing (e-folding time)		Flushing with 1 pump		Flushing with 2 pumps		Flushing with 3 pumps	
Days	Average volume/ day	Days	Average volume/ day	Days	Average volume/ day	Days	Average volume/ day
3.4 days	68,044 m^3	3.2 days	73,044 m^3	3 days	78,044 m^3	2.8 days	83,044 m^3
4 days	57,837 m^3	3.7 days	62,837 m^3	3.4 days	67,837 m^3	3.2 days	72,837 m^3
5 days	46,270 m^3	4.5 days	51,270 m^3	4.1 days	56,270 m^3	3.8 days	61,270 m^3
6 days	38,558 m^3	5.3 days	43,558 m^3	4.8 days	48,558 m^3	4.3 days	53,558 m^3

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