An Evaluation of Tidal Flushing for Shelter Island Yacht Basin Using a Simple Tidal Prism Model

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The San Diego Regional Water Quality Control Board (SDRWQCB) has found elevated total dissolved copper levels in the Shelter Island Yacht basin (1.6 to 9.1μg/L) that exceed the state water quality criterion (3μg/L). These findings have lead to subsequent action by the board to develop a TMDL for copper in the basin. To facilitate development of this TMDL the Unified Port District of San Diego in consultation with SDRWQCB directed MEC Analytical Systems, Inc. to develop a box model for estimating tidal flushing of the Shelter Island Yacht basin.

To generate an estimate of tidal flushing in the Shelter Island Yacht basin a simple one-dimensional box model was employed. The model (equation 1) assumes a one-dimensional volume exchange between the system of interest and adjacent waters and that complete mixing occurs on each tidal cycle. The number of tidal cycles required to achieve a specified dilution is calculated using the following equation:

$$N = \frac{\ln (C_o/C_n)}{\ln (1 + V_P/V_L)} \quad \text{(equation 1)}$$

where N = number of tidal cycles;
C_o = initial concentration (dimensionless);
C_n = final concentration (dimensionless);
V_P = Volume (ft^3) of the tidal prism;
V_L = Volume (ft^3) of the basin at Mean Lower Low Water (MLLW).

When compared to empirically derived flushing rates the model tends to be conservative (i.e., overestimate flushing rates). However, based on a review by Walton (1983) this one-dimensional box model represents a reasonable "back-of the envelope" calculation for canals and marinas and compares favorably with more complex/costly physical models. Modifications have been developed over the years to account for the discrepancies between empirically derived data and estimates from the model. Gibson (1959) and Ketchum (1951) modified the above equation by dividing the system under consideration into segments and assumed different efficiencies of exchange between the segments. Kuferman (1974) modified the model to incorporate empirically derived exchange coefficients. Callaway (1981) used a decay coefficient for concentration to simulate mixing in South Beach Marina in Oregon.

In order to calculate flushing for the Shelter Island Yacht basin, estimates of the basin volume at MLLW were determined from recent bathymetry by the Port of San Diego (Table 1). The surface area estimate at MLLW was then used to calculate volume estimates for the tidal prism (Table 2) using mean and maximum tidal ranges measured in San Diego Bay (P.F. Wang et al., 1998). An examination of the tide charts for San Diego indicates that the median tidal range resides somewhere between the mean and the maximum (i.e., more often than not the tidal range will be between 3 to 5 feet).

Consequently, use of the maximum and mean tidal range offers a reasonable approximation of the median tidal range. In calculating these volume estimates it was assumed that the surface area of the basin did not change over the tidal ranges evaluated. To estimate the number of tidal cycles required to affect a 50% change in concentration of the constituent of interest, C_o was set to a value of 10 and C_n was set to a value of 5 (i.e., a 50% reduction). Since it is unlikely that each tidal cycle results in a 100% exchange between V_P and V_L a range of exchange efficiencies (100 to 25%) was used to evaluate the effect of exchange efficiency on model estimates. In order to account for differences in exchange efficiency the equation was modified:

$$N = \frac{\ln (C_o/C_n)}{\ln (1 + ((V_P/V_L) \times \alpha)))} \quad \text{(equation 2)}$$

where α = fractional rate of exchange.

Results of the model estimates are provided in table 3. The number of tidal cycles required to achieve of 50% reduction in concentration; ranged from 2 to 28 tidal cycles or about 1 to 14 days for the range of assumptions used (table 3). As indicated earlier, estimates calculated using this model likely underestimate the actual time and number of tidal cycles required. The difference in 'N' between the mean and the maximum tidal ranges for a given efficiency of exchange is approximately 2-foldEfficiency of exchange has a profound effect on the model estimate (i.e. about a 6-fold difference over the range examined herein [12.5 to 100%]). Efficiency of exchange is also the single largest source of uncertainty (i.e., we have no basis upon which to develop an estimate) in calculating flushing rates via this simple tidal prism model for the Shelter Island Yacht Basin.

Table 1: Volume (ft^3) estimates to MLLW for Shelter Island Yacht basin based on bathymetry (POSD, 2000).

Elevation (ft. MLLW)	Planimeter reading	Area (ft^2)	%change in surface area	Average Area (ft^2)	Depth Interval (ft)	Average Volume (ft^3)
0	201.35	8054000	3.2*	7921600	4.00	31686400
-4	194.73	7789200	5.3	7583400	4.00	30333600
-8	184.44	7377600	41.3	5853966.5	4.00	23415866
-12	108.25	4330333	25.2	3784366.5	4.00	15137466
-16	80.96	3238400	70.6	2095200	4.00	8380800
-20	23.8	952000			4.00	
Total						108954132

* Because the percent change in surface area is relatively small from –4 feet to 0 (MLLW) it is reasonable to assume no significant change in surface area over the tidal ranges evaluated in this modeling effort.

Table 2: Volume (ft^3) estimates of tidal prism for Shelter Island Yacht basin based on ranges reported by P.F. Wang et al. (1998) for San Diego Bay.

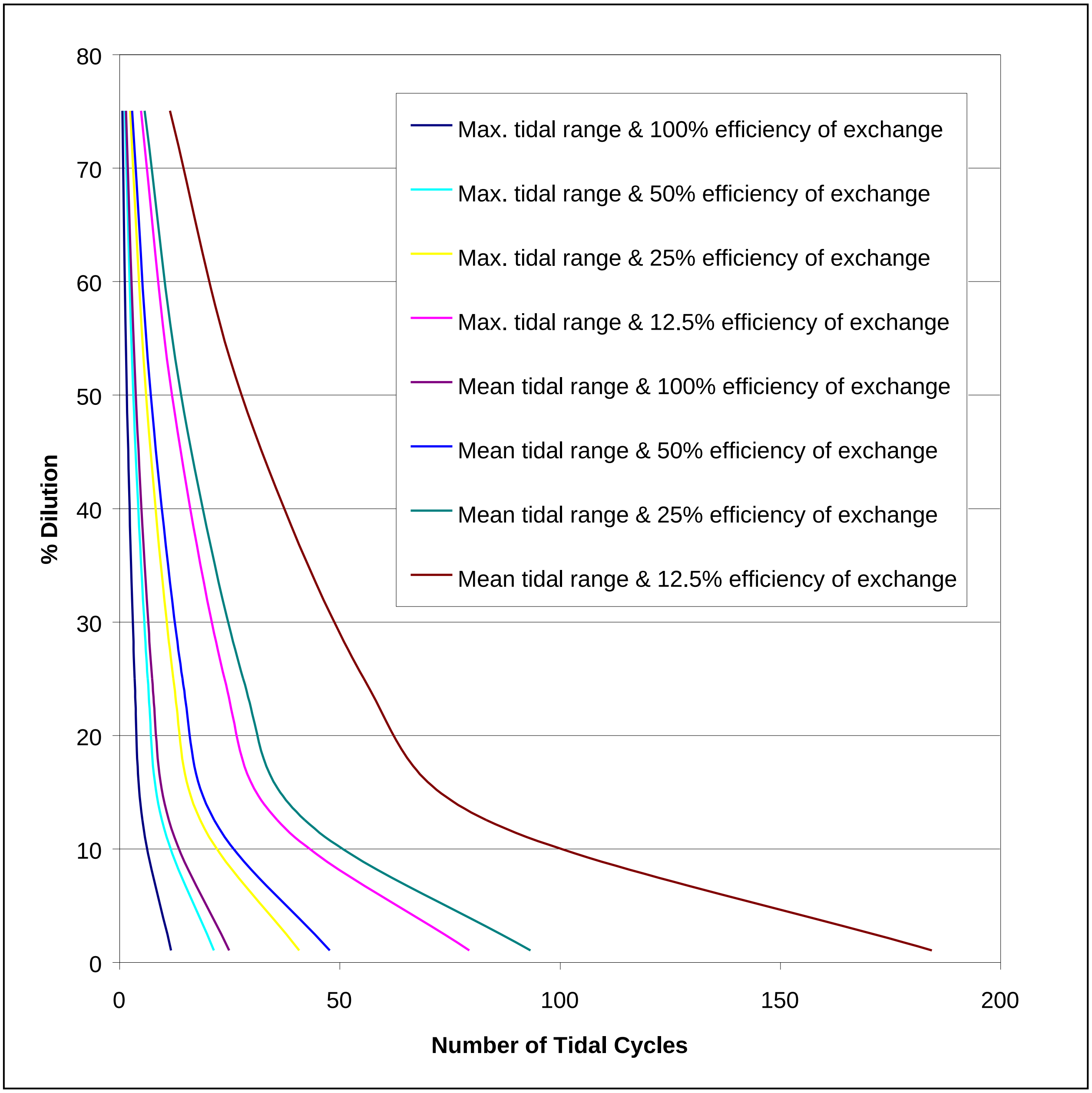
Assumed Tidal Range	Tidal Ht. (ft)	Est. Vol. of Tidal prism (ft^3)
Max. Tide	6.56	51965696
Mean Tide	2.78	22022048

Table 3: Number of tidal cycles 'N' required to affect a 50% change in concentration 'C' for a range of tidal prism heights (see table 2) and assumed efficiencies of exchange 'α'. ($T_{1/2}$ represents the time in days required to affect a 50% change in concentration for the assumed scenarios).

Co	Cn	V_P (ft^3)	V_L (ft^3)	α	N	$T_{½}$ (d)	N	Assumptions
10	5	51965696	108954132	1.0	1.78	0.89	1.78	Max. tidal range & 100% efficiency of exchange
10	5	22022048	108954132	1.0	3.77	1.88	3.77	Mean tidal range & 100% efficiency of exchange
10	5	51965696	108954132	0.5	3.24	1.62	3.24	Max. tidal range & 50% efficiency of exchange
10	5	22022048	108954132	0.5	7.20	3.60	7.20	Mean tidal range & 50% efficiency of exchange
10	5	51965696	108954132	0.25	6.15	3.08	6.15	Max. tidal range & 25% efficiency of exchange
10	5	22022048	108954132	0.25	14.06	7.03	14.06	Mean tidal range & 25% efficiency of exchange
10	5	51965696	108954132	0.125	11.97	5.98	11.97	Max. tidal range & 12.5% efficiency of exchange
10	5	22022048	108954132	0.125	27.78	13.89	27.78	Mean tidal range & 12.5% efficiency of exchange

To further evaluate the combined effects of tidal range and the efficiency of exchange assumptions on estimates of tidal flushing a second simulation was conducted examining the effect of these two parameters over a range of assumed dilutions. In addition to the 50% reduction in concentration modeled above, the number of tidal cycles required to achieve a 75%, 25%, 12.5%, and 1% dilution were simulated and the results are presented in figure 1. Results of this simulation indicate that as efficiency of exchange decreases, tidal range has a greater effect on the number of tidal cycles required to achieve a given percent dilution of the initial concentration. Thus, results of this simulation also indicate the importance of efficiency of exchange as a determining factor in tidal flushing using the tidal prism model.

Figure 1: Evaluation of tidal range and efficiency of exchange on dilution of initial concentration using the tidal prism model (equation 2).



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