APPENDIX 3B ASSESSMENT OF CARRYING CAPACITY OF THE PROJECT SITE

3B.1 Assessment of Carrying Capacity of The Project Site

This ***Appendix*** details the findings for carrying capacity assessment for the Project site, which has been conducted in accordance with the agreed *Water Quality Modelling Plan*.

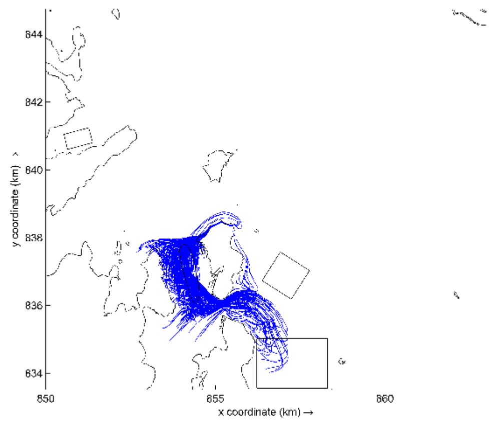
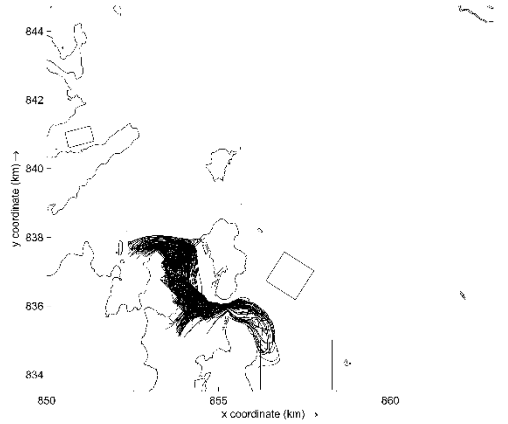
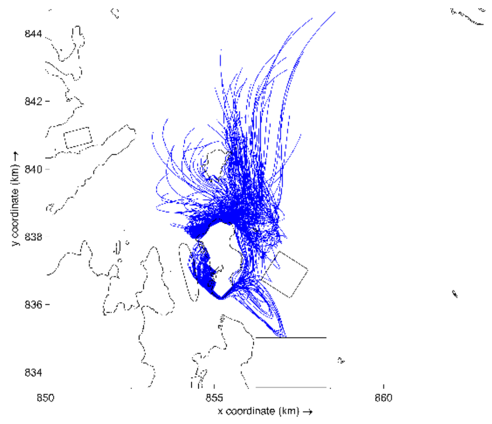
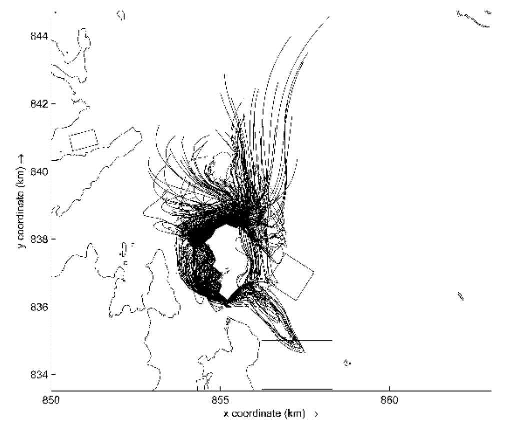
3B.1.1 Flushing Time Estimation

For flushing rate estimation, hydrodynamic modelling scenarios were conducted using Delft3D FLOW to achieve the following:

- Determination of initial dye area; and
- Estimation of flushing time of the Project site.

For the determination of initial dye area, one (1) modelling scenario would be conducted for each of the wet season and dry season. Drogues were released at 2-hour interval from near the boundary and corners of the Project site and the nearby surrogate site for a period of 15-day. The resulted drogue tracks were reviewed to determine the tidal excursion and the immediate proximity suitable for setting up initial tracer for tracer dispersion modelling to determine system-wide flushing time. Drogue tracks for the simulation of drogue release from the Project site and the nearby surrogate site of Tap Mun FCZ are shown in ***Figure 3B.1.1*** below.

Figure 3B.1.1 Drogue Tracks from Tap Mun FCZ (Blue) and Project site (Black) in Dry (Top) and Wet (Bottom) Seasons

	Tap Mun FCZ	Project site
Dry Season		
Wet Season		

In dry season, drogues tend to move into the embayment while in wet season, they tend to move out of the embayment in the north-eastern direction, following the direction of the prevailing wind. Drogues typically move only for less than 4 km from the locations they are released within one flood-ebb cycle in dry season but could be up to about 8 km in wet season (as drogue tends to move to more open water at the outer Mirs Bay quickly). For this Study, two sensitivity tests of tracer dispersion modelling exercise were conducted to evaluate the effect of different interpretation the drogue simulation results. ***Figure 3B.1.2*** shows two initial tracer settings for sensitivity tests. Scenario 1 (green polygon) is a simple interpretation of the drogue track results. In this scenario, initial tracer covers area within a short distance from all drogue tracks including the entire Long Harbour as well as the opening of the Tolo Channel. Scenario 2 (red polygon) is a more expansive interpretation considers all part of the inner Mirs Bay and Tolo Harbour embayment “behind” (in the sense relative to opening of the Mirs Bay in the SE) to be covered with tracer. These two scenarios essentially differ by the interpretations on where “clean” water beyond the influence of Project site (as well as other pollution sources) starts. The initial tracer coverage for the two sensitivity test scenarios are shown in ***Figure 3B.1.2***. The average tracer decay curves (for 7 cases), together with the corresponding best fit curves, for the two different scenarios in both seasons are shown in ***Figure 3B.1.3*** and ***Figure 3B.1.4***.

Figure 3B.1.2 Drogue Tracks and Initial Tracer Settings for Sensitivity Tests

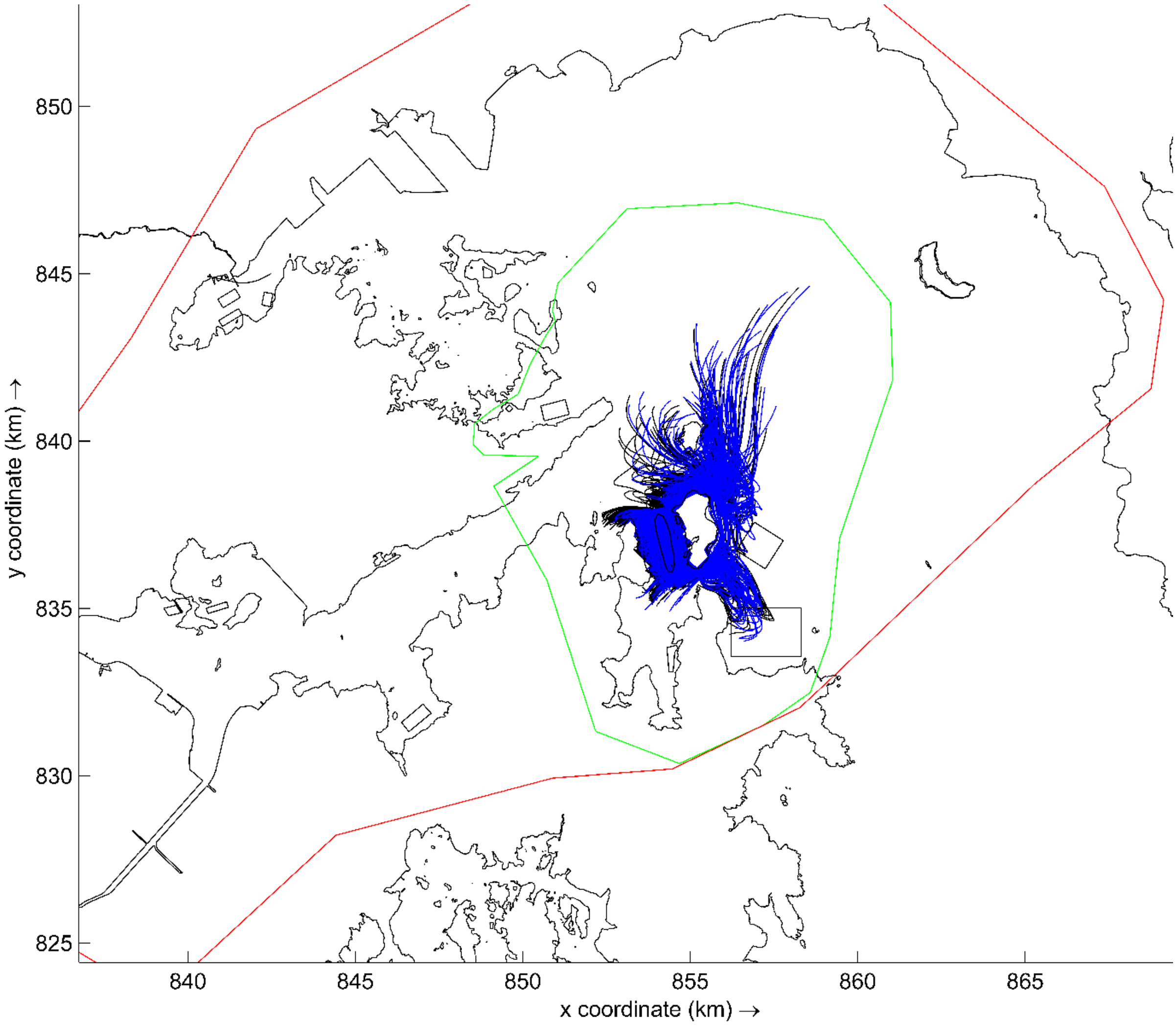
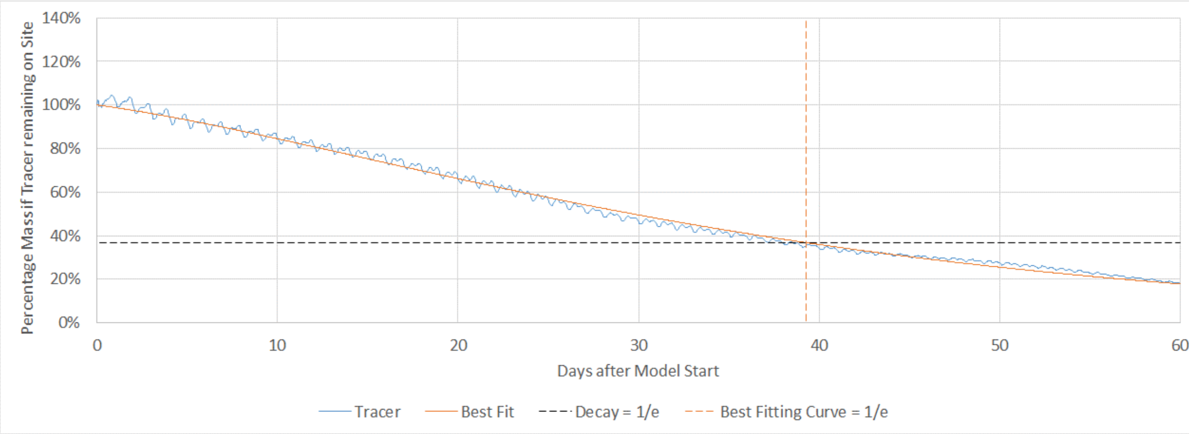

850
845
840
835
830
825
840
845
850
855
860
865
y coordinate (km) →
x coordinate (km) →

Figure 3B.1.3 Average Tracer Decay Curve at Project site for Two Scenarios in Dry Season (Horizontal dashed line indicates tracer mass at a fraction of e [base of natural logarithm], vertical dashed line indicates estimated flushing time)

Dry Season – Scenario 1 Average of Project site (K_1: 0.04, K_2: 0.05)



Dry Season – Scenario 2 Average of Project site (K_1: 0.03, K_2: 0.03)

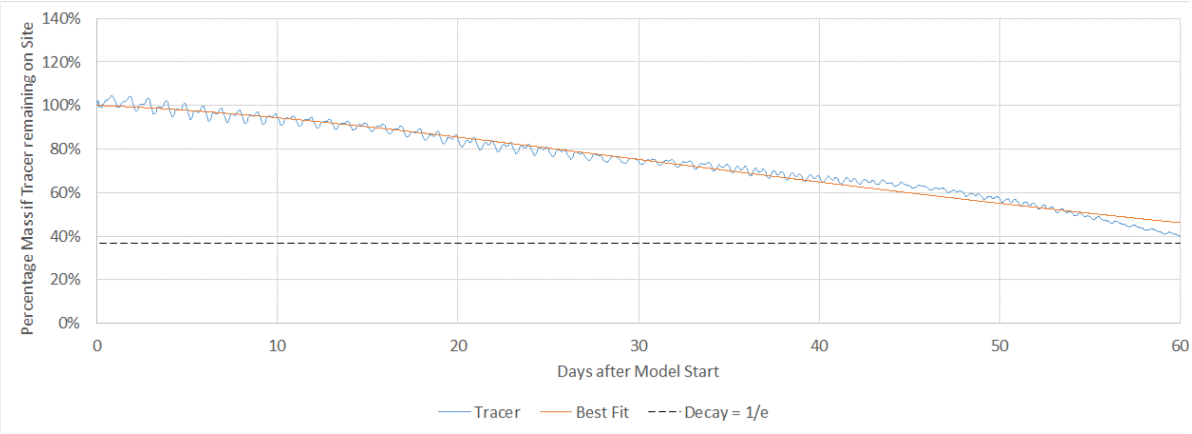
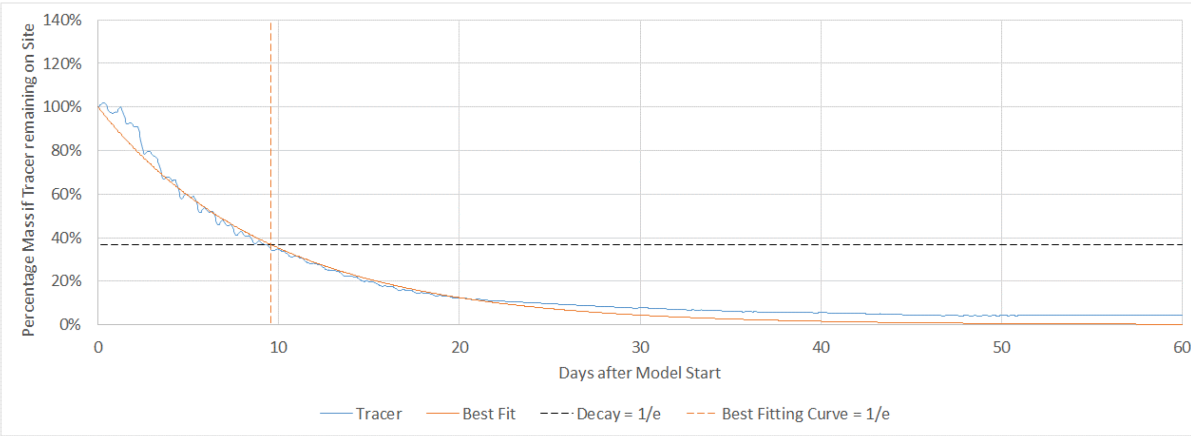
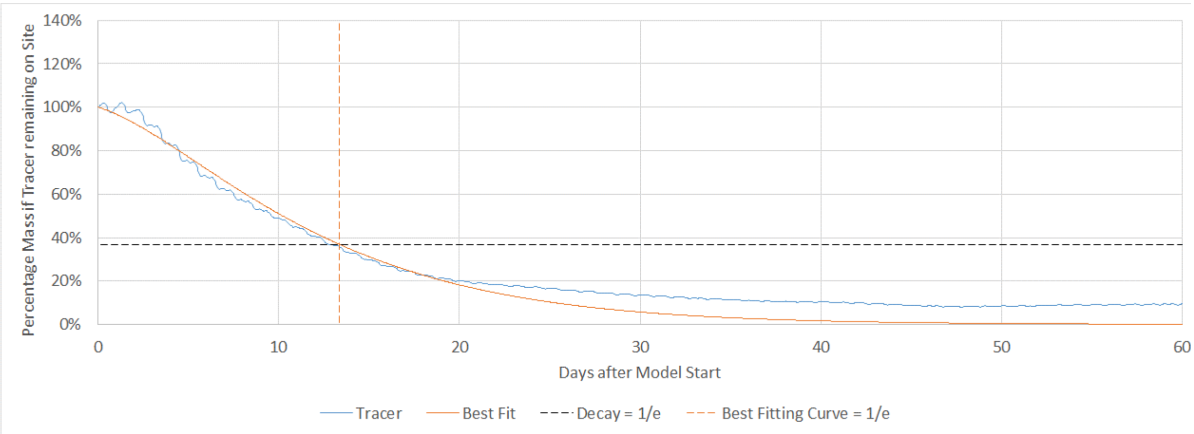


Figure 3B.1.4 Average Tracer Decay Curve at Project site for Two Scenarios in Wet Season (Horizontal dashed line indicates tracer mass at a fraction of e [base of natural logarithm], vertical dashed line indicates estimated flushing time)

Wet Season – Scenario 1 Average of Project site (K_1: 0.10, K_2: 0.21)

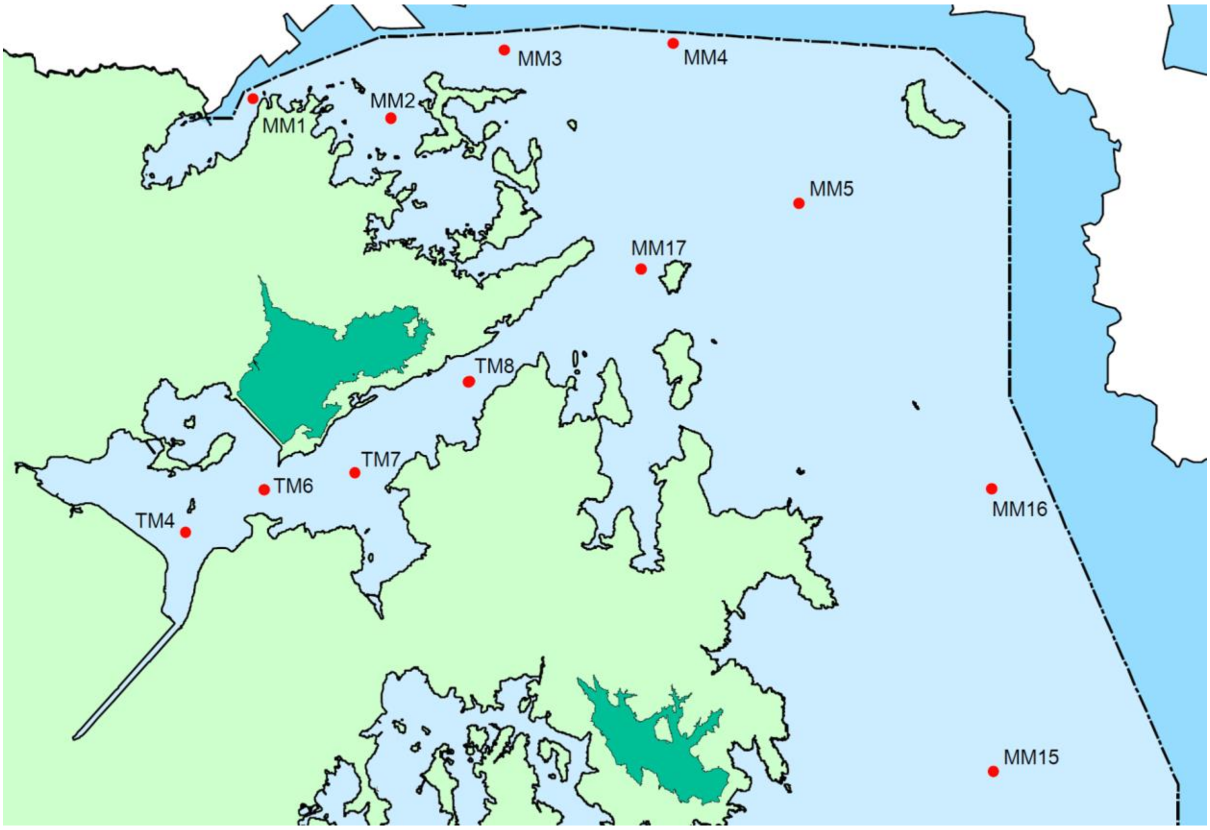


Wet Season – Scenario 2 Average of Project site (K_1: 0.14, K_2: 0.16)



As shown, there are notable increase in estimated flushing time by the expansion of initial tracer area from Scenario 1 to Scenario 2, particularly in dry season. Review of long term marine water quality monitoring data by EPD along the lines from the inner embayment to opening of both embayments has been conducted to help with the selection of suitable initial tracer settings among the two. EPD Marine Water Quality Monitoring Stations reviewed are shown in ***Figure 3B.1.5***. Two lines were considered. First line includes TM4, TM6, TM7, TM8, MM17 and MM5, which represents the contrast inside and outside of the Tolo Harbour. The second line include MM1, MM2, MM3, MM4, MM5, MM16 and MM15, which represents the contrast inside and outside of the Mirs Harbour. The long-term average water quality at these selected water quality parameters along these two lines are shown in ***Figure 3B.1.6***. As shown, water quality along the first line shows a clear gradient for all selected parameters. Such gradient typically flattens at around MM17 or TM8. For the second line, the gradient flattens at MM3. This means the effect of major pollution sources from the Tolo Harbour and the Starling Inlet is mostly dissipated at the end of Tolo Channel and the North of Crooked Island respectively. This means treating the entire back side of Tolo Harbour and Mirs Bay as polluted (assumption under Scenario 2) is an overestimation.

Figure 3B.1.5 Locations of EPD Marine Water Quality Stations Reviewed



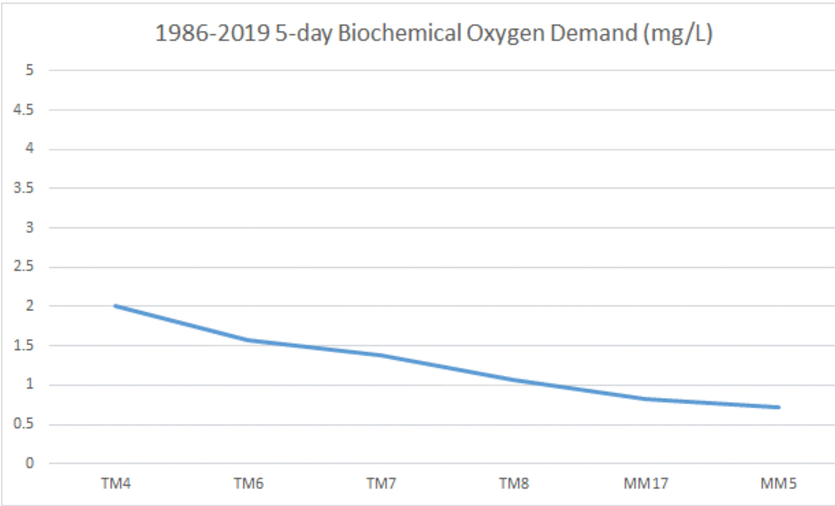
Source: EPD Marine Water Quality Report, 2019

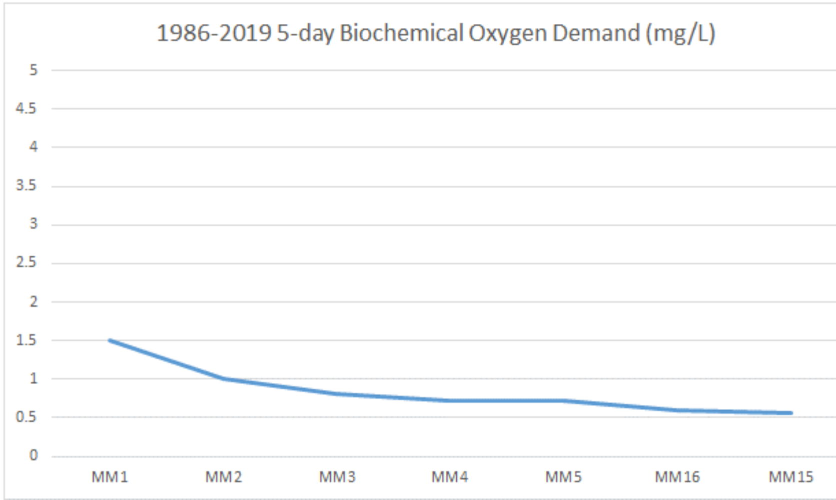
Figure 3B.1.6 Long Term Average Water Quality along the Major Axes of Tolo Harbour and Mirs Bay.

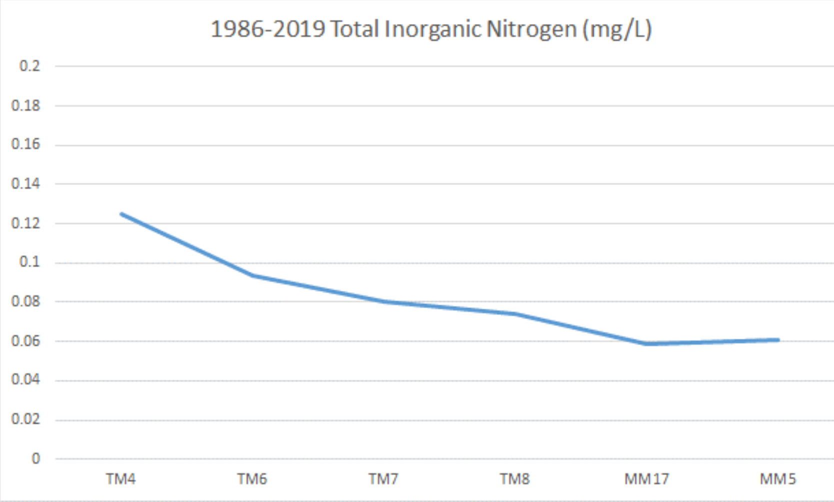
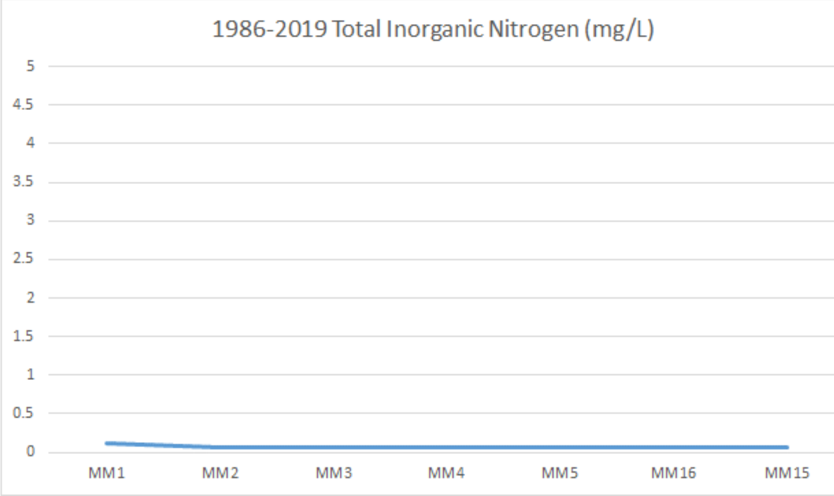
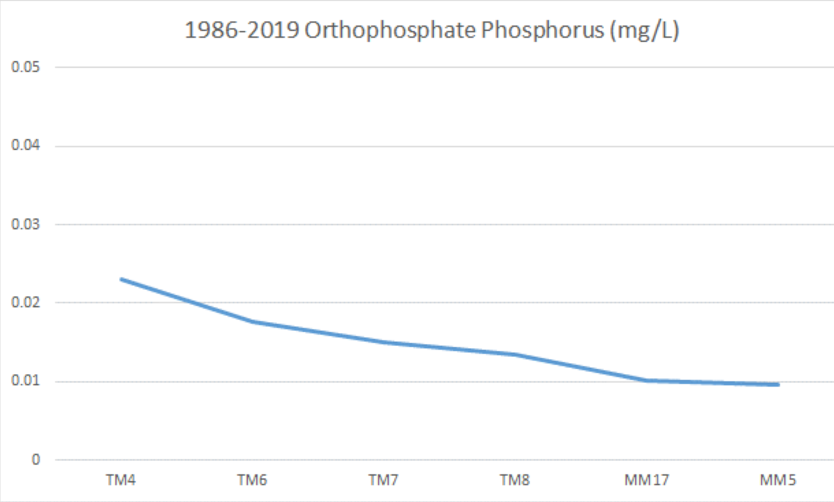
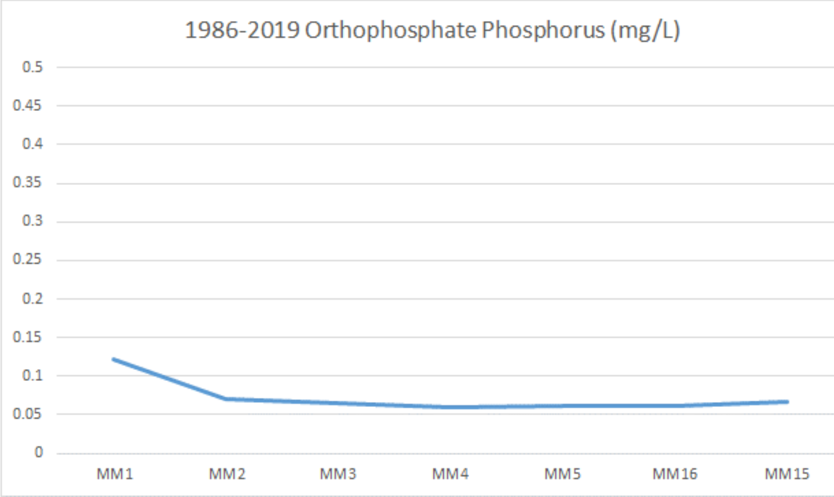
Axis — Tolo Harbour – Tolo Channel – Mirs Bay; Mirs Bay – North to South

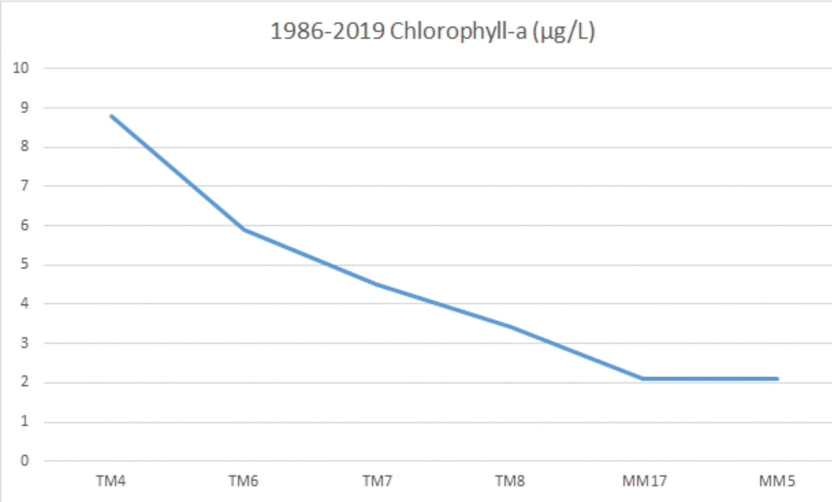
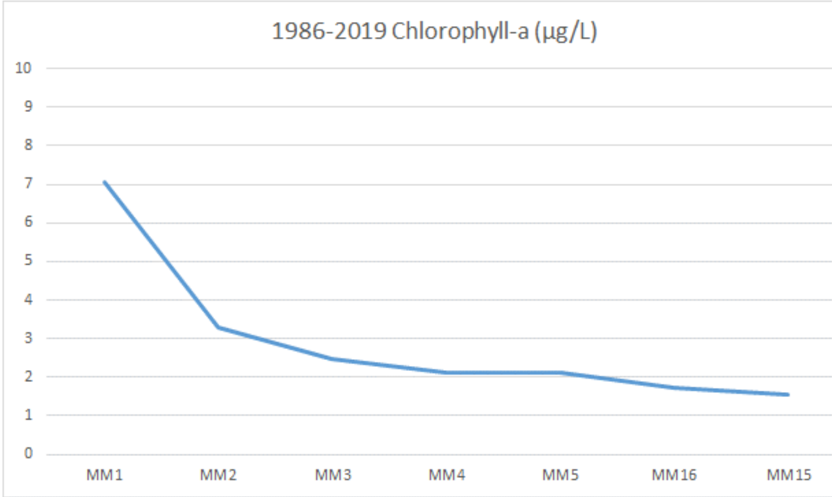
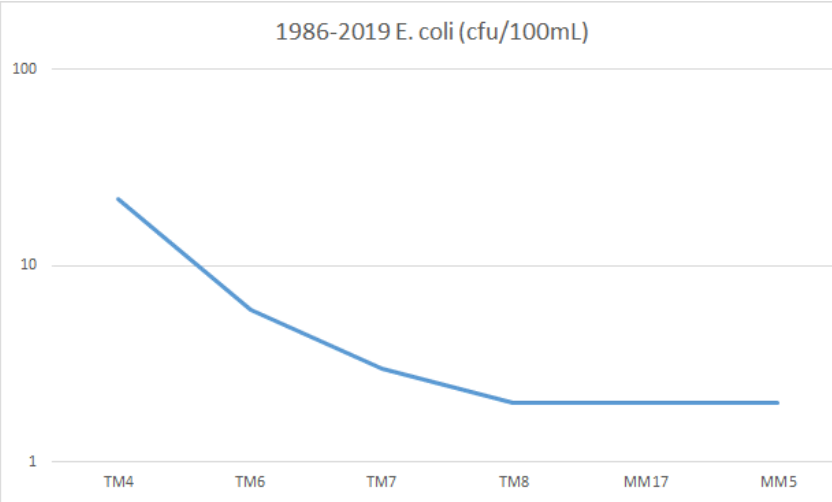
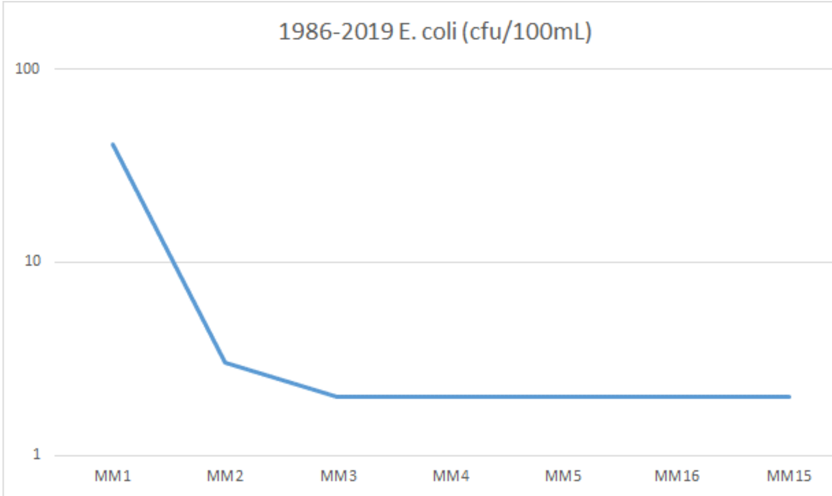
Harbour Subzone | Channel Subzone | Mirs Bay | Inner Mirs Bay | Outer Mirs Bay

BOD_5





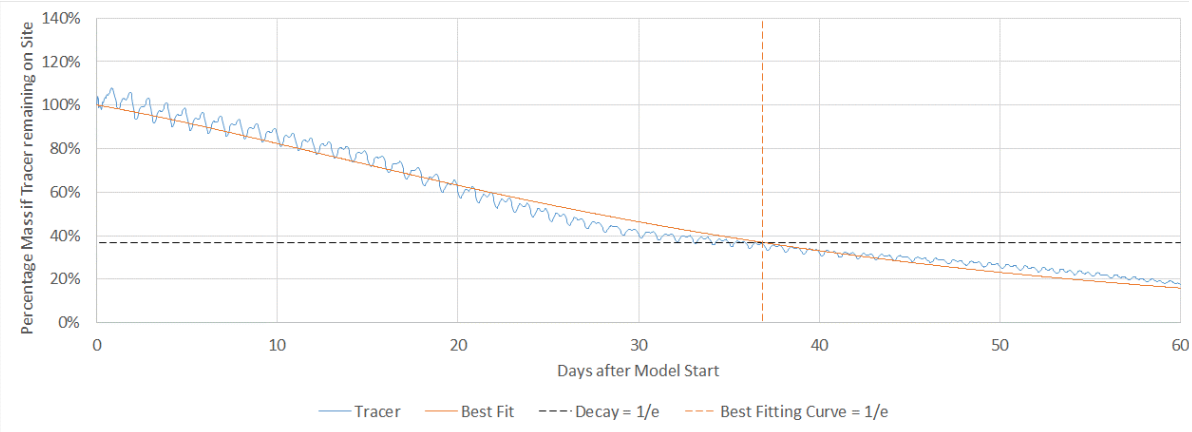
Axis	Tolo Harbour – Tolo Channel – Mirs Bay	Mirs Bay – North to South
	Harbour Subzone · Channel Subzone · Mirs Bay	Inner Mirs Bay · Outer Mirs Bay
TIN		
Ortho-P		

Axis	Tolo Harbour – Tolo Channel – Mirs Bay Harbour Subzone — Channel Subzone — Mirs Bay	Mirs Bay – North to South Inner Mirs Bay — Outer Mirs Bay
Chlorophyll-a		
E.coli (Note: log. scale y-axis)		

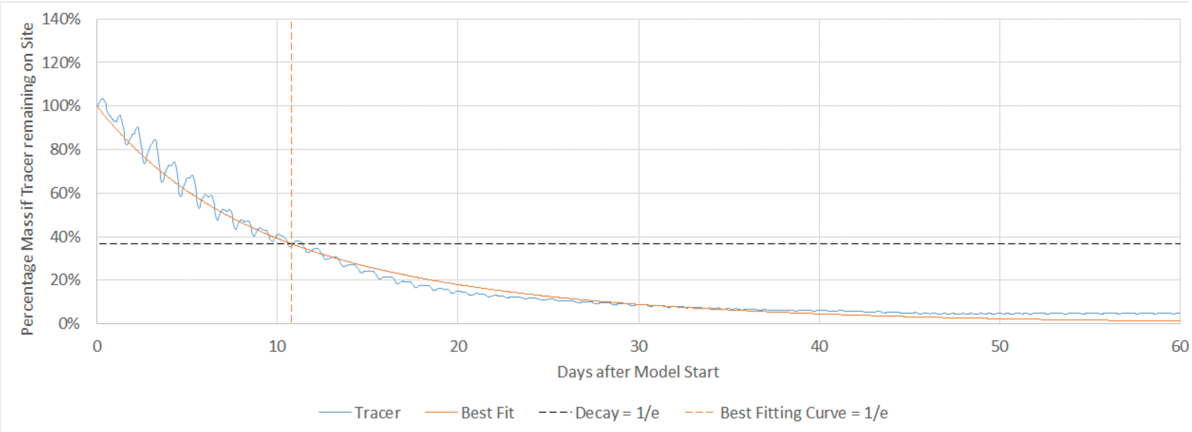
Tracer decay curves for dry and wet seasons at the existing Tap Mun FCZ are shown in ***Figure 3B.1.7***

Figure 3B.1.7 Tracer Decay Curves for the Existing Tap Mun FCZ under Scenario 1 (Horizontal dashed line indicates tracer mass at a fraction of e [base of natural logarithm], vertical dashed line indicates estimated flushing time)

Dry Season – Scenario 2 Average of Tap Mun FCZ (K_1: 0.04, K_2: 0.06)



Wet Season – Scenario 2 Average of Tap Mun FCZ (K_1: 0.07, K_2: 0.17)



For this Study, the flushing time estimation would be based on initial tracer settings under Scenario 1. The flushing time for Project site, together with the surrogated site for calibration (existing Tap Mun FCZ), in both seasons under Scenario 1 are listed in ***Table 3B.1.1*** below. The estimated flushing time at the Tap Mun FCZ was adopted for calibration of the WATERMAN Carrying Capacity Model.

Table 3B.1.1 Estimated Flushing Time for Project site and the Tap Mun FCZ

Flushing Time (Day)	Dry Season	Wet Season
Project site	36.6	9.6
Tap Mun FCZ	34.5	11.7

3B.1.2 Calibration of Water Quality Rate Kinetics and Equilibrium Parameters using WATERMAN Hindcast Modelling Tool

Annual production from 2015 to 2019 from the Tap Mun FCZ was obtained from AFCD to estimate the average daily pollution load from the fish farming operation at Tap Mun FCZ based on the estimated unit pollution load established in the Methodology Paper. The annual fish production rate as well as the corresponding estimated pollution load are shown in ***Table 3B.1.2***.

Table 3B.1.2 Annual Fish Production from 2015 to 2019 and Estimated Pollution Load at the existing Tap Mun FCZ

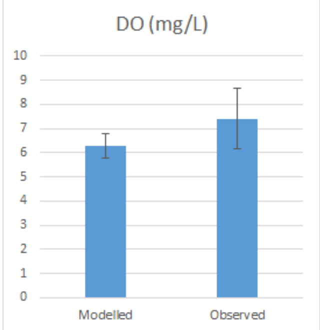
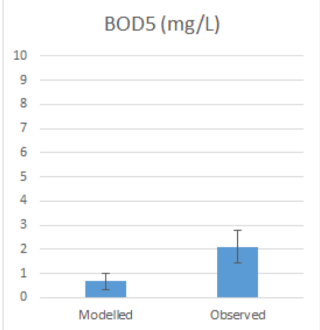
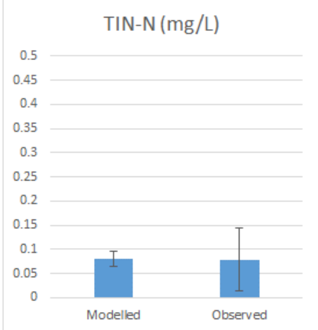
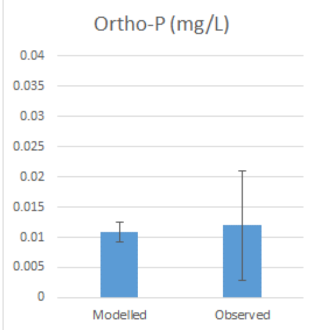
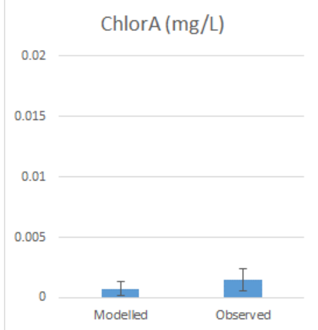
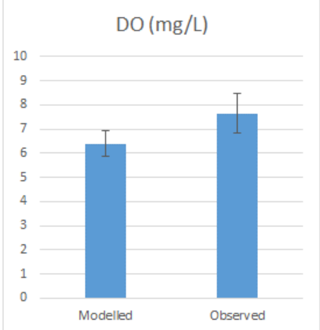
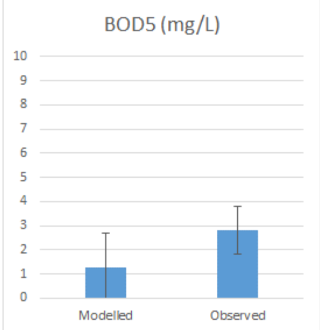
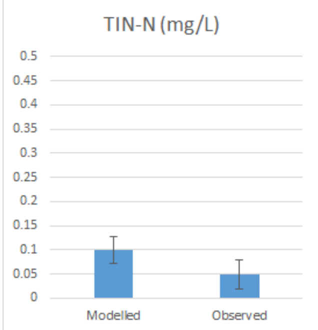
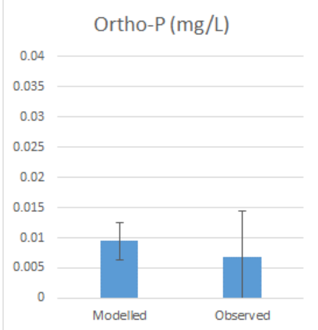
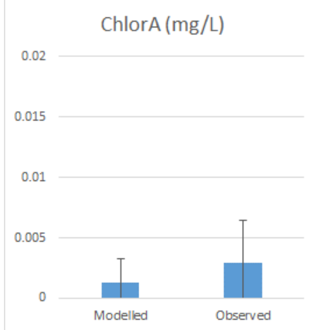
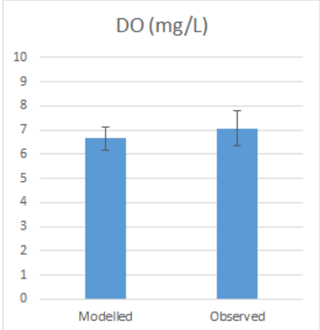
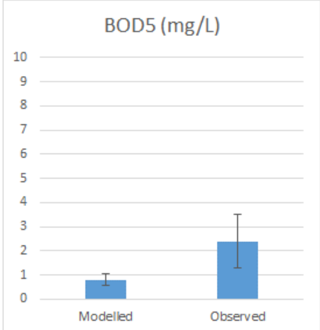
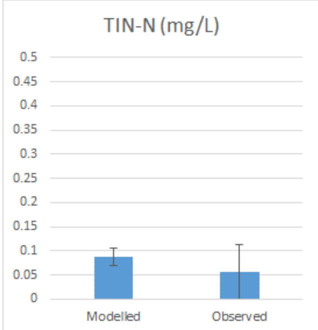
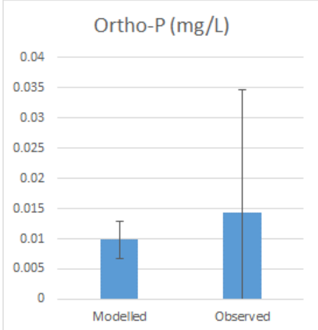
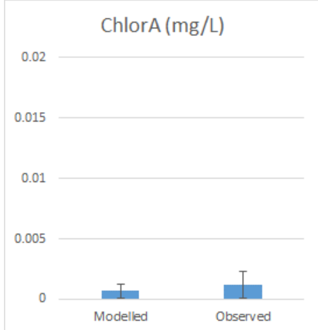
Item	Unit	Unit Load	2015	2016	2017	2018	2019
Annual Production	**Ton/year**	-	46.98	34.00	31.75	25.12	26.39
Estimated Pollution Load							
Oxidized- N	**g/day**	1.3738	64.55	46.71	43.62	34.50	36.25
Ammonia-N	**g/day**	244.8073	11502.26	8324.46	7773.49	6148.61	6459.77
TON	**g/day**	188.7786	8869.76	6419.25	5994.38	4741.39	4981.33
TIP	**g/day**	16.9120	794.61	575.08	537.02	424.76	446.26
TOP	**g/day**	20.2749	952.62	689.43	643.80	509.23	535.00
BOD	**g/day**	1130.8930	53134.97	38455.05	35909.82	28403.66	29841.04
TSS	**g/day**	676.4462	31782.80	23001.97	21479.54	16989.72	17849.49

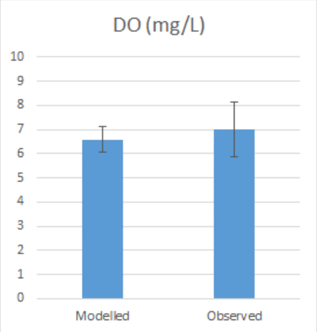
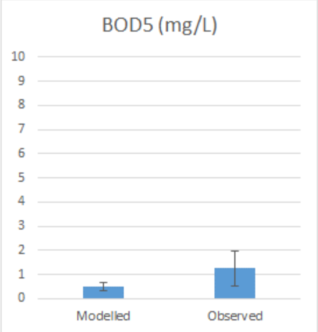
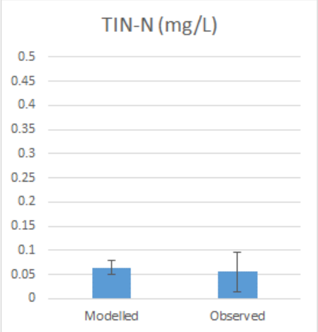
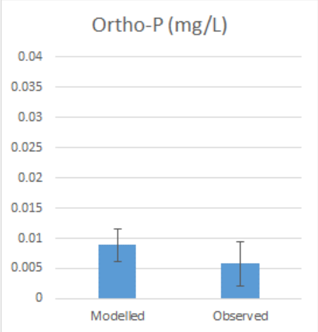
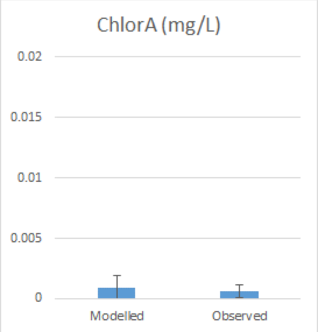
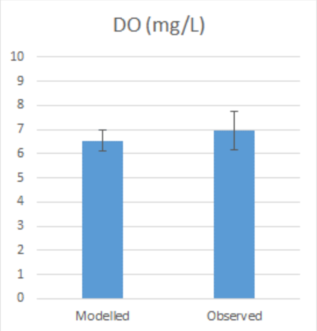
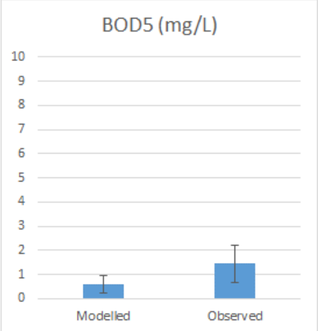
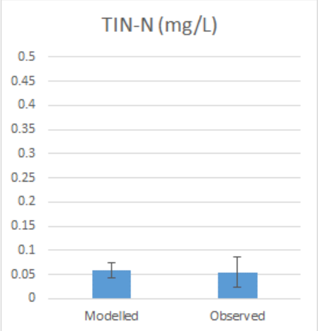
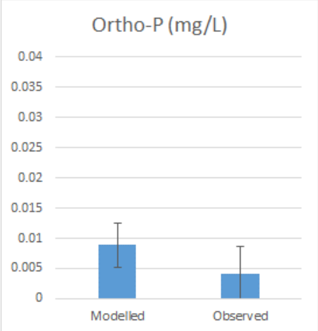
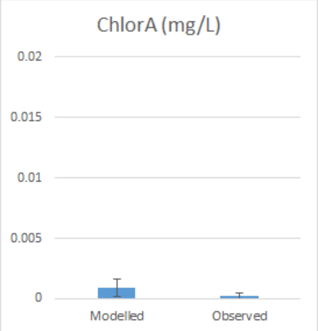
The predicted water quality at the Tap Mun FCZ is compared against the observed water quality to ensure the WATERMAN Hindcast Model is able to reproduce the water quality conditions at the FCZ. Given both part of model input (background water quality from nearby EPD Marine Water Quality Monitoring Stations MM5, MM6 and MM16) as well as target for comparison (observed water quality at Tap Mun FCZ) has relatively low data frequency of once per month (and the sampling dates of both sources are not the same), the calibration and validation exercise targeted to reproduce the average water quality instead of the actual time series of specific water quality parameters.

To avoid over-calibrating the modelling parameters, the observed water quality data for year 2015-2017 would first be used to calibrate the modelling parameters and the data for year 2018 and 2019 would be used to compare the model prediction from the calibrated model. Comparison of the observed water quality as well as the predicted water quality using the WATERMAN Hindcast Model at the Tap Mun FCZ from 2018 and 2019 are provided in ***Table 3B.1.3***. The calibrated model generally produces prediction at similar level to the observed water quality. The corresponding set of calibrated water quality parameters are provided in ***Table 3B.1.4*** below. For most of the water quality parameters, the calibrated values are the same as that in the previous WATERMAN study by Wong *et. al.*, 2012 [(1)].

(1) Wong *et. al.* 2012. Project WATERMAN - Carrying Capacity of Fish Culture Zones in Hong Kong.

Table 3B.1.3 Comparison of Results for Model Calibration using the WATERMAN Carrying Capacity – Unsteady State Hindcast Tool (Modelled: Left; Observed: Right [AFCD Monitoring Data at Tap Mun FCZ])

	DO (mg/L)	BOD_5 (mg/L)	TIN (mg/L)	Ortho-P (mg/L)	Chlorophyll-a (mg/L)
2015					
2016					
2017					

	DO (mg/L)	BOD_5 (mg/L)	TIN (mg/L)	Ortho-P (mg/L)	Chlorophyll-a (mg/L)
2018					
2019					

Note: Values presented are mean depth-average of the specified years and error bars are the range for mean values ± one standard deviation.

Table 3B.1.4 Kinetic Parameters used in the WATERMAN Water Quality Model for this Study and in Wong *et. al.*, 2012

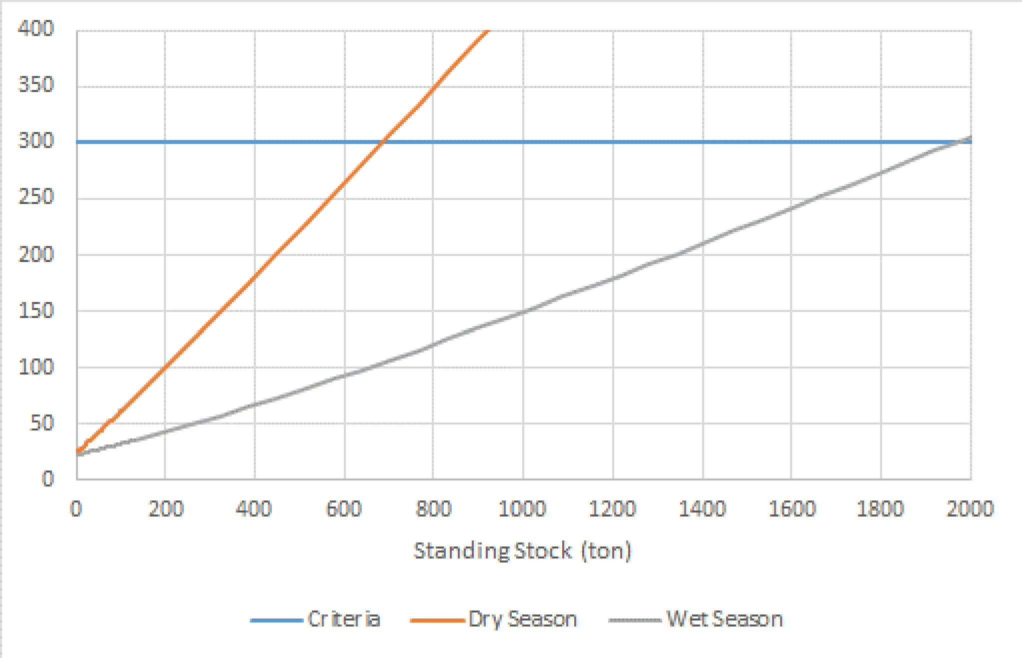
Parameters	Unit	Value for this Study	Value adopted by Wong *et. al.*, 2012
Maximum algal growth rate	d^{-1}	2	2.1
Temperature coefficient for growth at 20°C	-	1.066	1.066
Algal respiration rate	d^{-1}	0.11	0.11
Temperature coefficient for respiration at 20°C	-	1.080	1.080
Algal mortality	d^{-1}	0.02	0.02
Nitrification rate	d^{-1}	0.1	0.1
Temperature coefficient for nitrification at 20°C	-	1.080	1.080
Organic nitrogen mineralization rate	d^{-1}	0.025	0.025
Temperature coefficient for organic nitrogen mineralization at 20°C	-	1.080	1.080
Denitrification rate	d^{-1}	0.1	0.1
Temperature coefficient for denitrification at 20°C	-	1.045	1.045
Organic phosphorus mineralization rate	d^{-1}	0.060	0.060
Temperature coefficient for organic phosphorus mineralization at 20°C	-	1.080	1.080
Deoxygenation coefficient	d^{-1}	0.210	0.210
Temperature coefficient for deoxygenation at 20°C	-	1.047	1.047
Re-aeration coefficient	d^{-1}	0.543	0.543
Settling velocity of particulate	m/d	1.0	1.0
Half-saturation constant for N uptake	µg N/L	50.0	50.0
Half-saturation constant for P uptake	µP N/L	1.0	1.0
Half-saturation constant for oxygen limitation of nitrification	mg O_2/L	2.0	2.0
Half-saturation constant for oxygen limitation	mg O_2/L	0.5	0.5
Fraction of algal decay into organic nitrogen	-	0.5	0.5
Fraction of algal decay into organic phosphorus	-	1.0	1.0
Fraction of settleable organic matter	-	0.5	0.5
Fraction of dissolved phosphorus in water	-	0.8	0.8

3B.1.3 Estimation of Carrying Capacity

Based on the selected set of kinetic parameters, carrying capacity at the Project site was estimated using the steady state forecast tool WATERMAN Steady State Forecast Model. The estimation involves simulation of a number of scenarios with different scales of mariculture production. Results of water quality simulation were compared against the corresponding water quality criteria to determine the marginal case which has the highest mariculture production without exceedance of water quality criteria (i.e. carrying capacity). Predicted water quality for relevant water quality criteria are presented in ***Figure 3B.1.8***.

As shown, among all the assessment criteria, TIN is found to be the critical water quality parameters at Project site. Carrying capacity at Project site is estimated to be 684.5 ton of standing stock under typical average condition and is predicted to be limited by TIN in dry season. Other non-TIN water quality parameters were found to be less sensitive and critical at or below the estimated carrying capacity. A summary of the predicted water quality condition at Project site when operating at its carrying capacity are provided in ***Table 3B.1.7***.

Figure 3B.1.8 Predicted TIN Level (µg/L) at the Project site under Various Mariculture Standing Stock in Both Seasons



Fluctuations in the weather, hydrodynamic and environmental conditions as well as the farming practices could result in different carrying capacity. Sensitivity tests were conducted to determine how the estimated carrying capacity respond to variations on three key selected parameters, namely, flushing time, stock to production ratio and maximum algal growth rate. Three (3) sensitivity test settings (by increasing or decreasing each of these parameters by 20%, i.e. 80%, 100% and 120% of the original values) for each of the above parameters were considered and a total of 3 × 3 × 3 was conducted for each season for the Project site. The carrying capacities with safety margin of 90th- and 95th-percentile were estimated accordingly based on these 27 tests for each season. This means while the estimated carrying capacity of 684.5 ton of standing stock would not result in significant deterioration of water quality under the typical average condition, the case with safety margin of 90th- and 95th-percentile would ensure no significant deterioration in water quality under 90% and 95% of likely condition. The estimated carrying capacity for sensitivity test scenarios with 90% and 95% safety margin are 565.7 ton and 549.9 ton of standing stock respectively. The estimated carrying capacity for the rest the sensitivity test scenarios are provided in ***Table 3B.1.6***. As shown, estimated carrying capacity varies under different tested conditions while responded minimally to some other conditions, i.e. maximum algal growth rate under some conditions. This indicates under the specific conditions (for flushing time and stocking ratio) the algal growth rate is not limited by the specified maximum and thus the change in maximum algal growth rate would not result in material change in water quality and thus carrying capacity.

For subsequent Delft3D modelling, pollution load from mariculture activities was estimated based on standing stock of 684.5 ton of standing stock under typical average condition as shown below in ***Table 3B.1.5***.

Table 3B.1.5 Estimated Pollution Loading from Mariculture Activities at the Project site at its Carrying Capacity under Typical Average Condition

Sources	Pollution Load Generated Per 1 ton of Standing Stock	Pollution Load Generated for Standing Stock at its Carrying Capacity at Project site
Oxidized-N (g/day)	1.4	958
Ammonia-N (g/day)	236	161532
Org-N (g/day)	38.2	26146
TIP (g/day)	1.7	1164
TOP (g/day)	3.5	2396
BOD (g/day)	540.3	369812
TSS (g/day)	26.7	18275

Table 3B.1.6 Estimated Carrying Capacity (ton) for All Sensitivity Test Scenarios

Flushing Capacity Scaling	Stock to Production Ratio Scaling	Maximum Algal Growth Rate Ratio		
		80%	100%	120%
80%	80%	741.9	741.9	741.9
	100%	631.0	642.7	655.4
	120%	627.5	535.5	546.2
100%	80%	781.4	781.4	781.4
	100%	670.5	684.5	699.7
	120%	558.7	570.4	583.1
120%	80%	830.0	830.0	830.0
	100%	718.5	735.0	753.0
	120%	598.7	612.5	627.5

Table 3B.1.7 Predicted Water Quality by WATERMAN Steady State Forecast Model under Typical Average Condition when the Project site Operates at its Predicted Carrying Capacity

	Dissolved Oxygen (mg/L)	Biochemical Oxygen Demand (mg/L)	Total Inorganic Nitrogen (mg/L)	Unionized Ammonia (mg/L)	Ortho-Phosphate Phosphorus (mg/L)	Chlorophyll-a (mg/L)
Criteria	**5**	**5**	**0.30**	**0.021**	**0.018**	**0.020**
Dry Season	7.3	0.2	0.30	0.009	0.012	<0.001
Wet Season	6.4	0.4	0.10	0.007	0.006	0.001

Note: Values presented are mean depth-average values.