

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*.

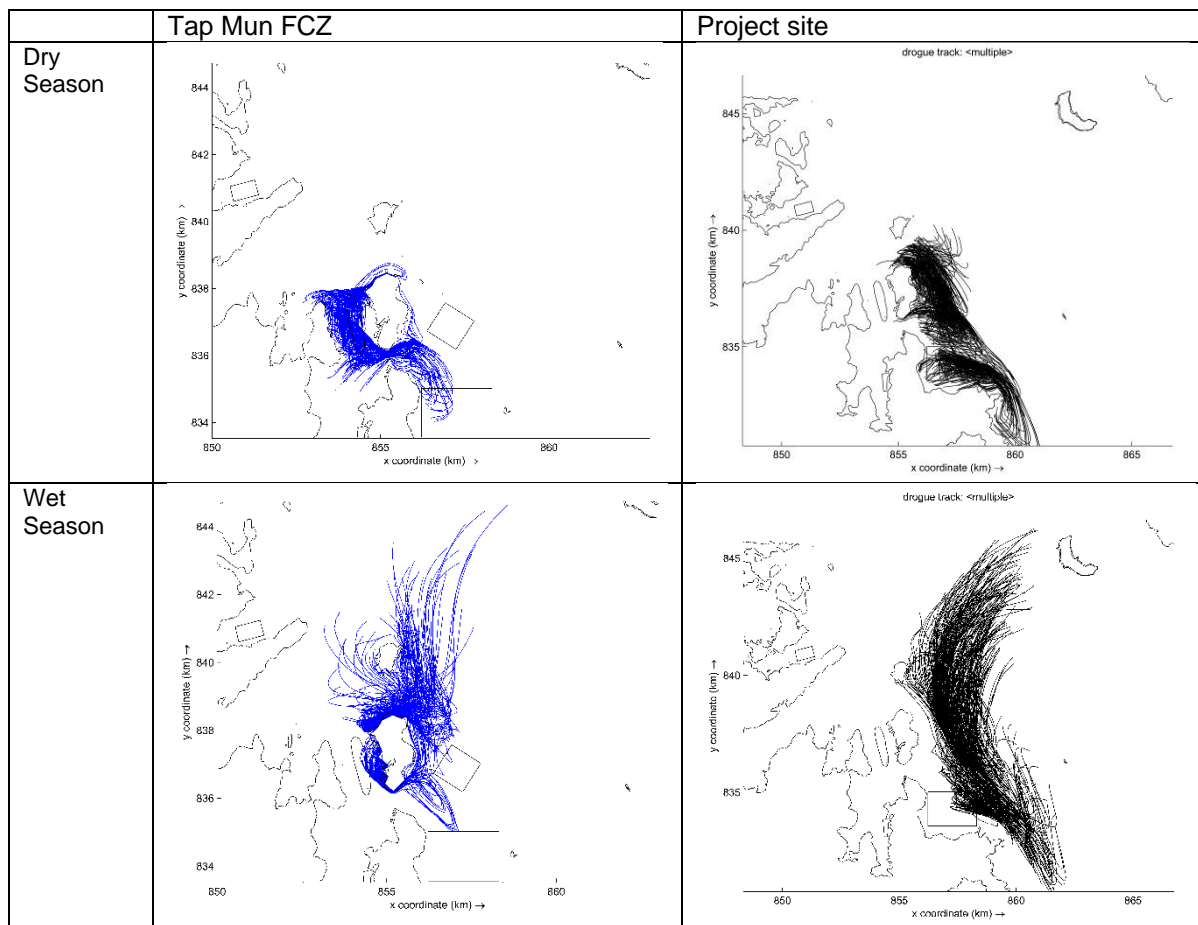
3B.1.1 Flushing Time Estimation

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



In dry season, drogues tend to move counter-clockwise while in wet season, they tend to move out of the embayment in the north-eastern direction. Drogues from the surrogated site of Tap Mun typically remains within 4 km from the release location in dry season and reaches about 5 km in wet season, and that from the Project site can reach up to 6 to 7 km. As shown, drogue tracks from the Project site move notably faster and cover much larger swath of water. For this Study, two sensitivity tests of tracer dispersion modelling exercise were conducted to evaluate the effect of different interpretation the drogue simulation results for drogue tracks for each of the Tap Mun FCZ and the Project site.

Figure 3B.1.2 shows two initial tracer settings for sensitivity tests for Tap Mun FCZ and **Figure 3B.1.3** shows those for the Project site. 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. For drogue tracks from Tap Mun FCZ, initial tracer would cover the entire Long Harbour as well as the opening of the Tolo Channel. For drogue tracks from the Project site, this would cover the Long Harbour, Nam She Wan and a large swath of water to the north and east of the Project site. 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** and **Figure 3B.1.3**. 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.1.4** and **Figure 3B.1.5**.

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

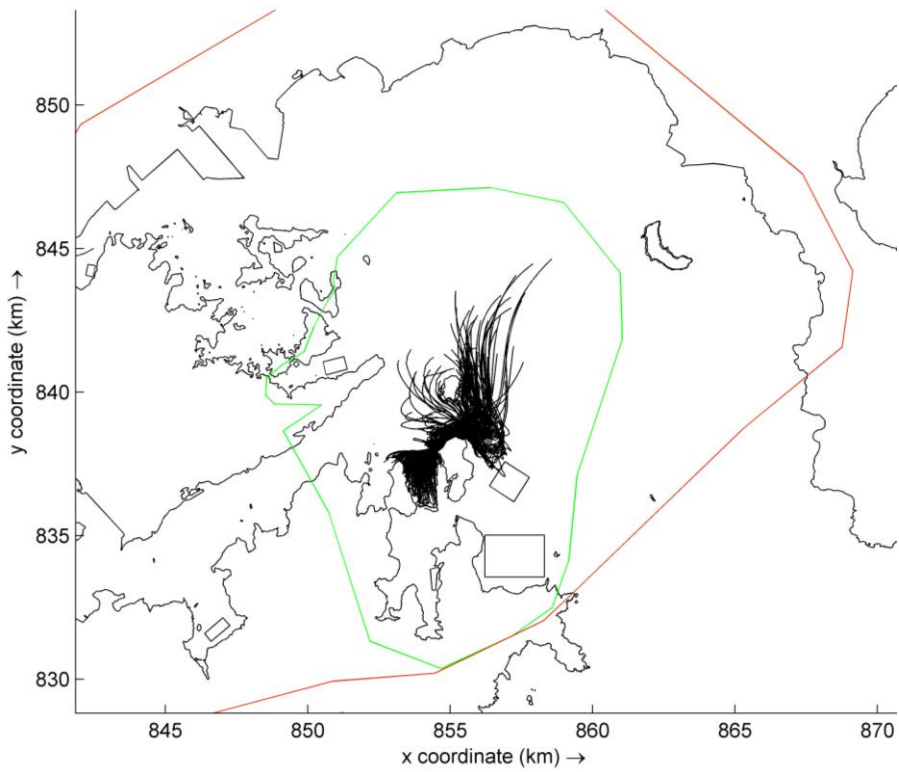


Figure 3B.1.3 Drogue Tracks and Initial Tracer Settings for Sensitivity Tests for the Project site

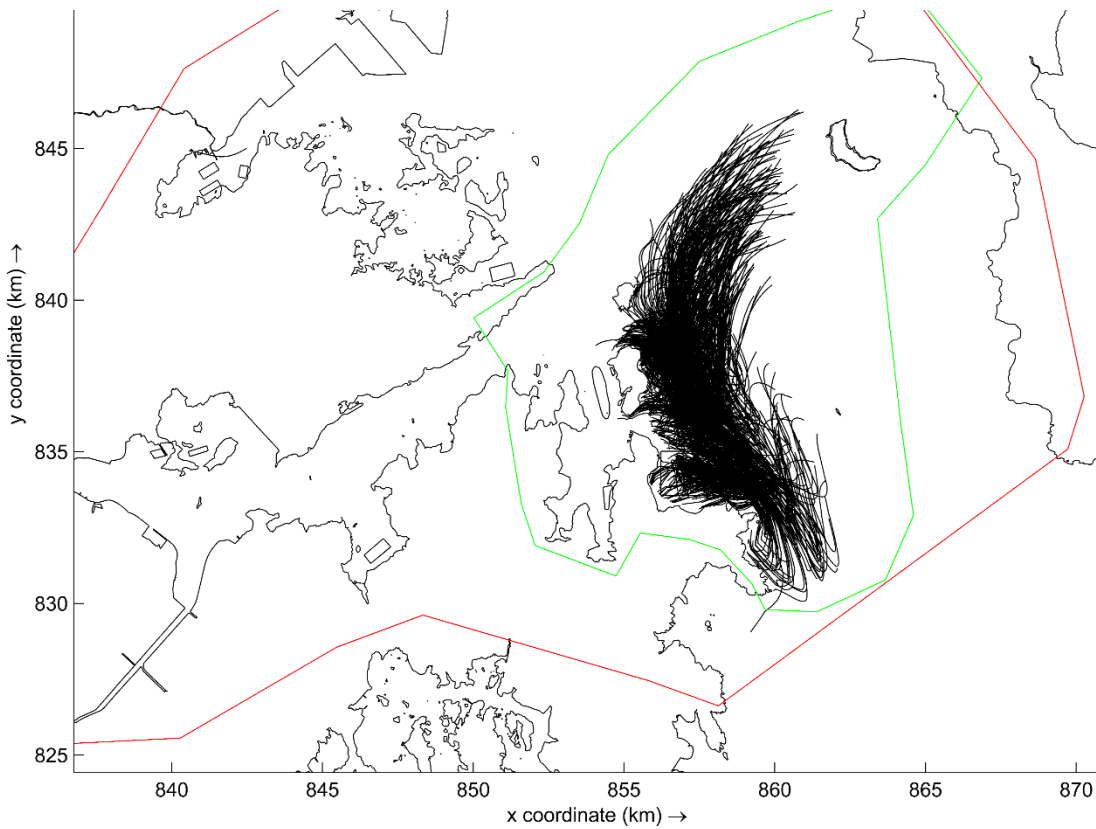
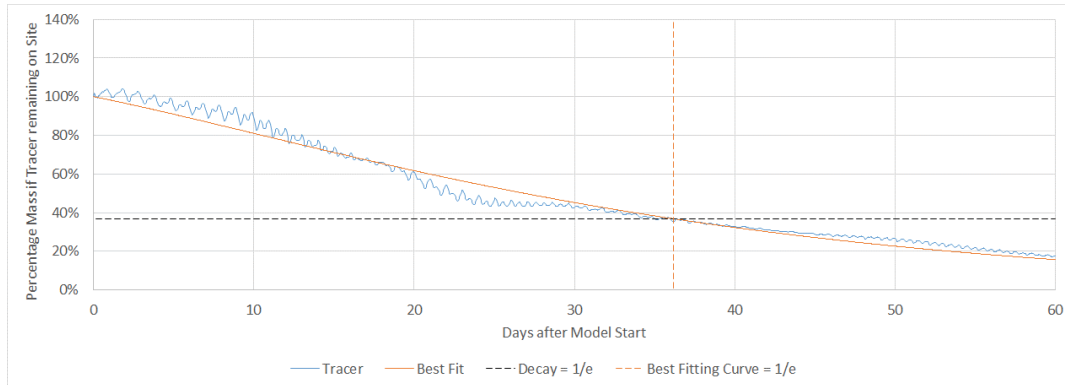
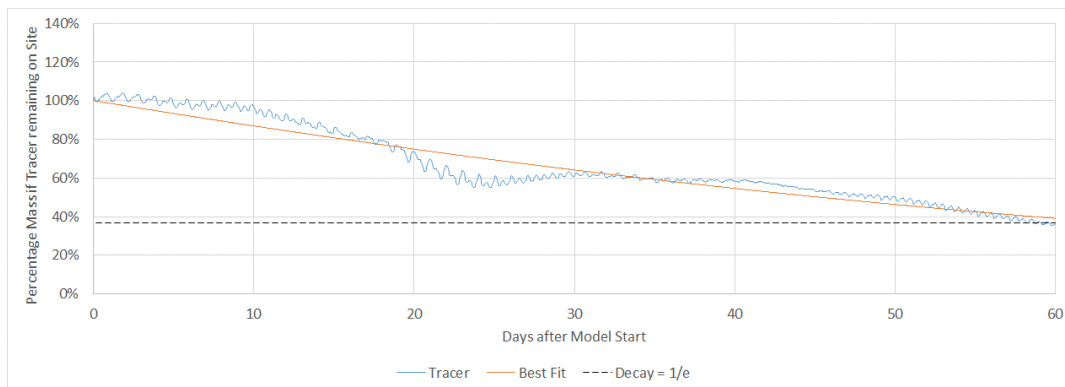


Figure 3B.1.4 Average Tracer Decay Curve at Project site for Three Scenarios in Dry Season (Horizontal dashed line indicates tracer mass at a fraction of e [base of natural logarithm], vertical dashed line indicates estimated flushing time)

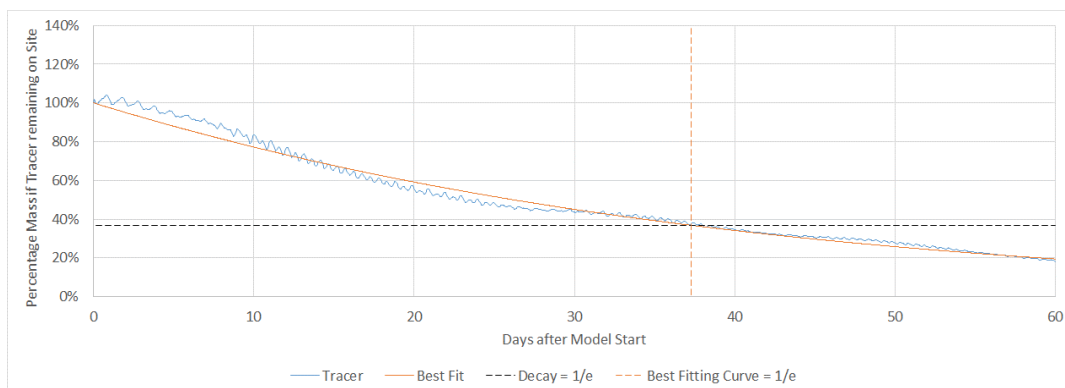
Dry Season – Scenario 1 Average of Project site (Northern Part) (K_1 : 0.04, K_2 : 0.06)



Dry Season – Scenario 2 Average of Project site (Northern Part) (K_1 : 0.02, K_2 : 0.03)



Dry Season – Scenario 1 Average of Project site (Southern Part) (K_1 : 0.03, K_2 : 0.05)



Dry Season – Scenario 2 Average of Project site (Southern Part) (K_1 : 0.01, K_2 : 0.02)

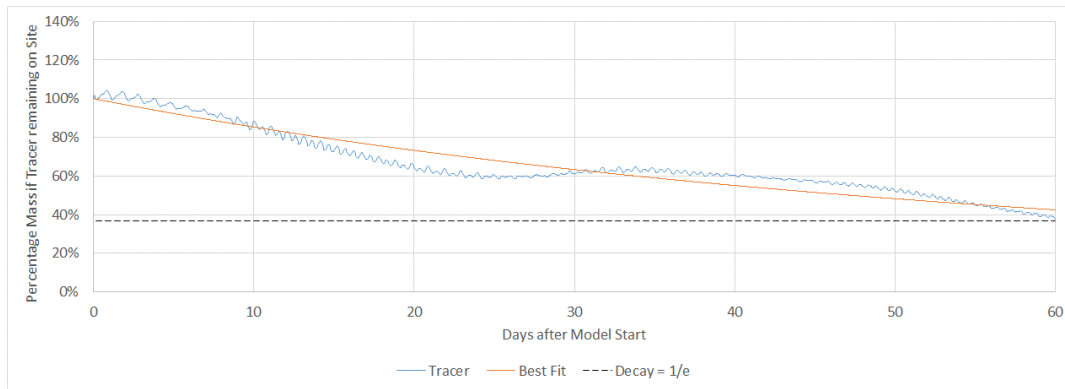
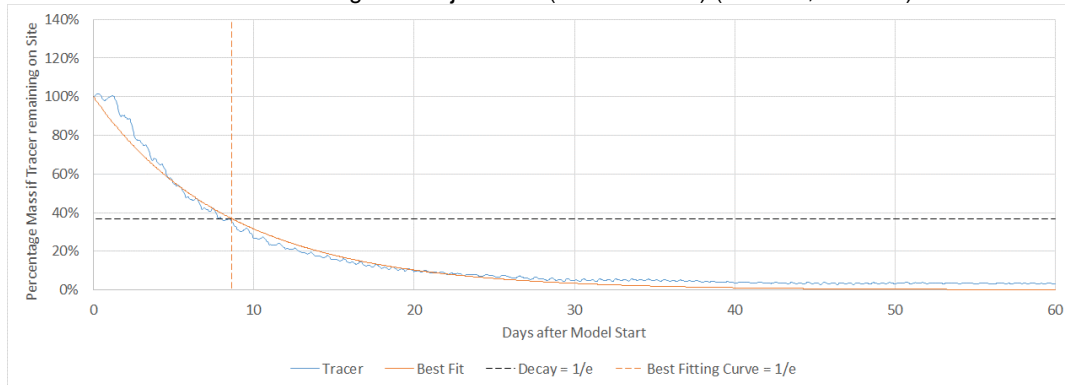
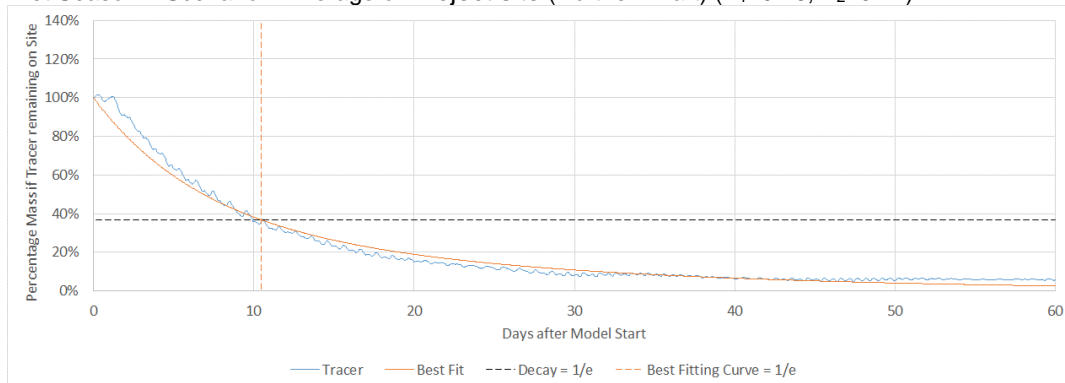


Figure 3B.1.5 Average Tracer Decay Curve at Project site for Three Scenarios in Wet Season (Horizontal dashed line indicates tracer mass at a fraction of e [base of natural logarithm], vertical dashed line indicates estimated flushing time)

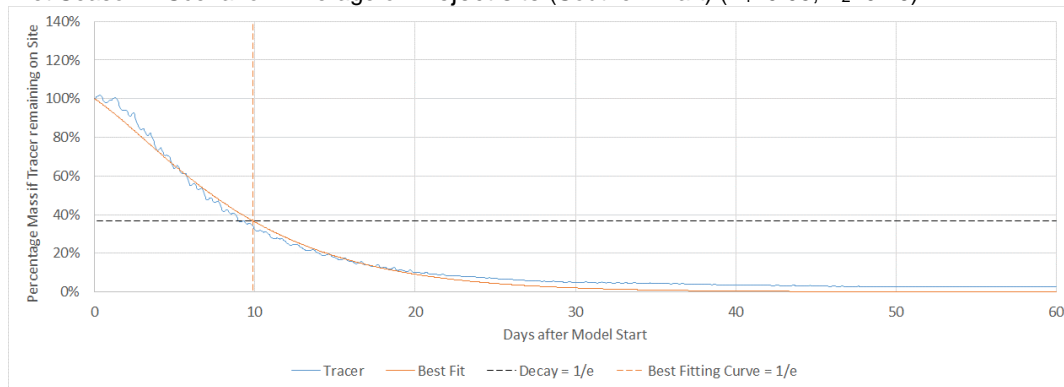
Wet Season – Scenario 1 Average of Project site (Northern Part) (K_1 : 0.11, K_2 : 0.23)



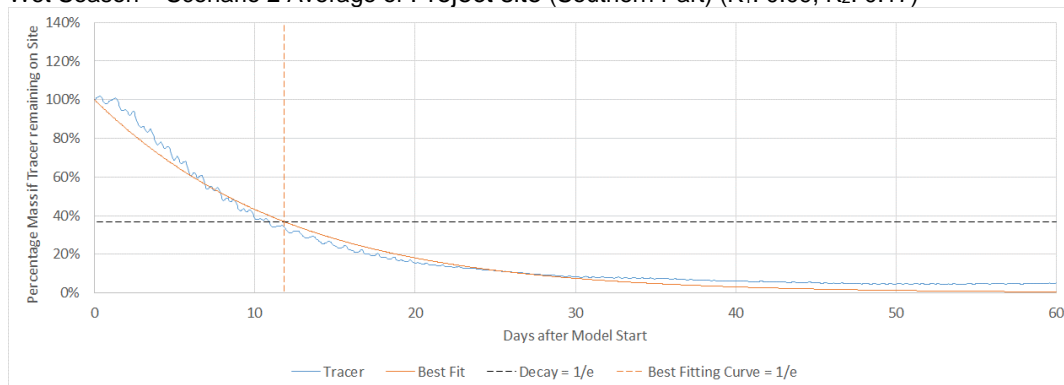
Wet Season – Scenario 2 Average of Project site (Northern Part) (K_1 : 0.16, K_2 : 0.22)



Wet Season – Scenario 1 Average of Project site (Southern Part) ($K_1: 0.05, K_2: 0.16$)

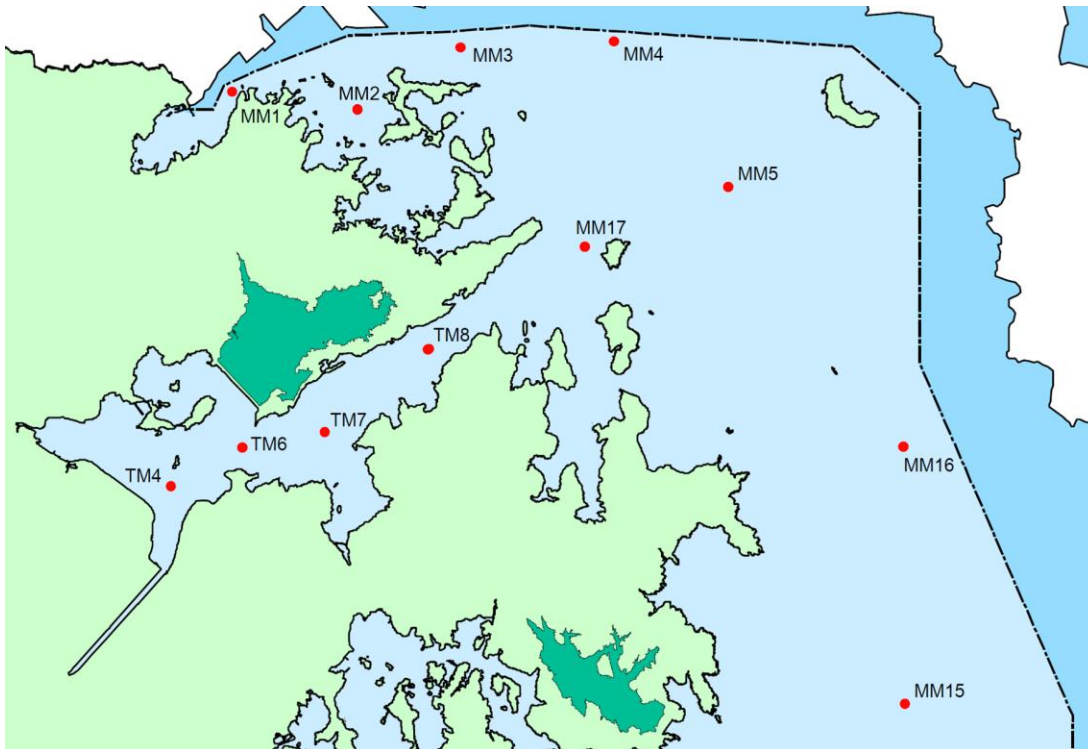


Wet Season – Scenario 2 Average of Project site (Southern Part) ($K_1: 0.09, K_2: 0.17$)



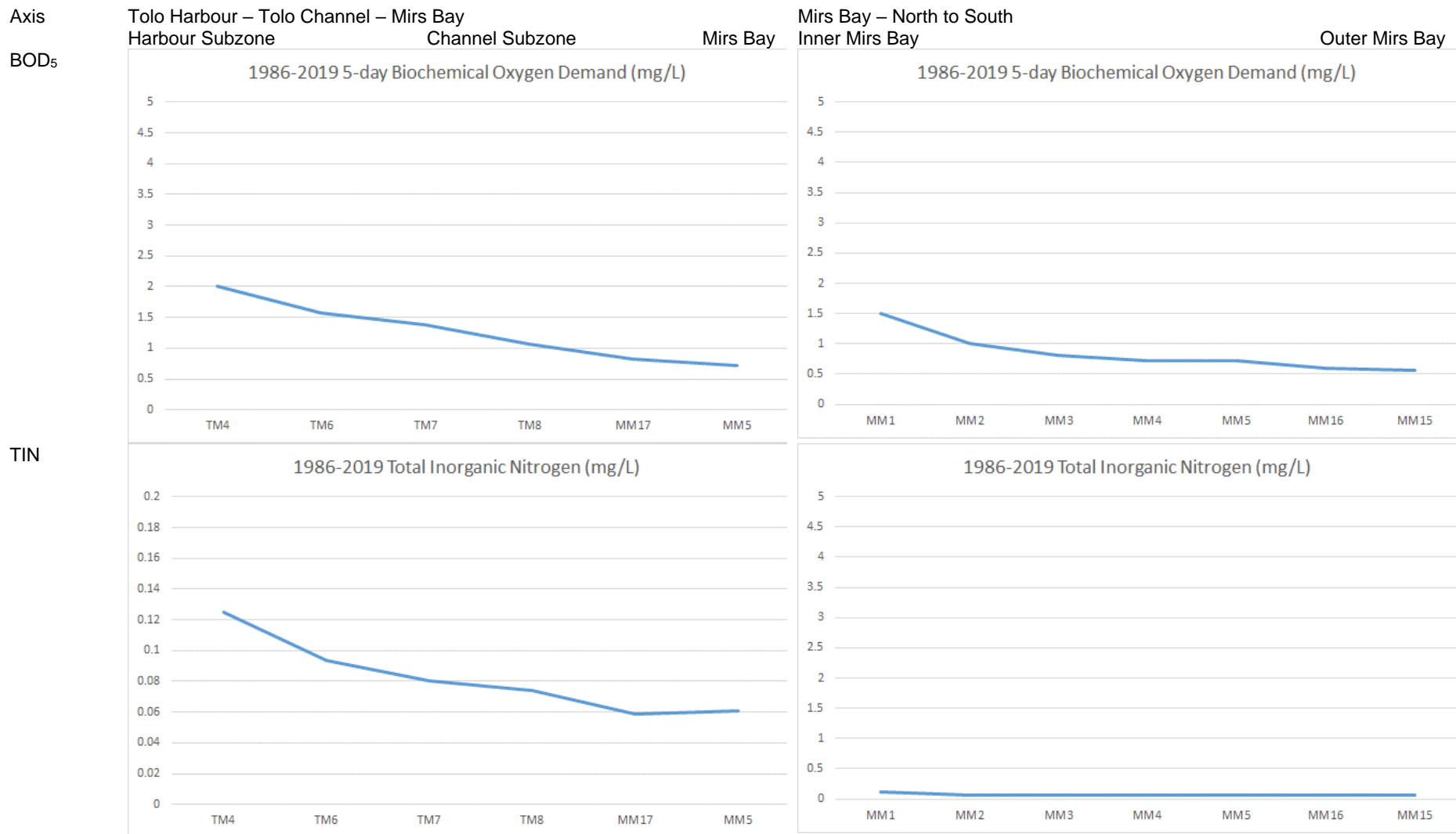
As shown, there are notable increase in estimated flushing time by the expansion of initial tracer area from Scenario 1 to Scenario 2, particularly in dry season. Review of long term marine water quality monitoring data by EPD along the lines from the inner embayment to opening of both embayments has 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.1.6**. 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.1.7**. 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 flatten 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.

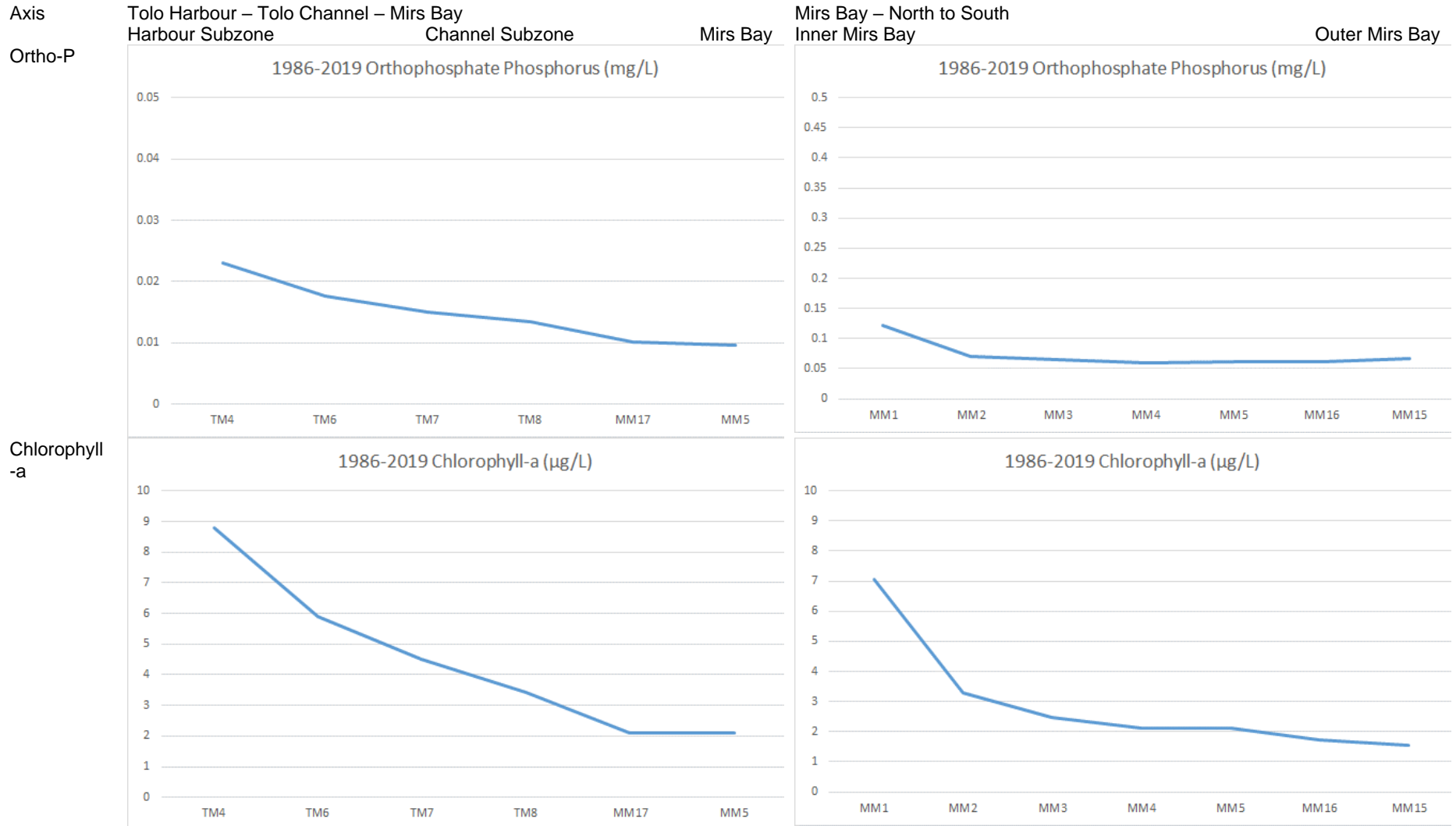
Figure 3B.1.6 **Locations of EPD Marine Water Quality Stations Reviewed**



Source: EPD Marine Water Quality Report, 2019

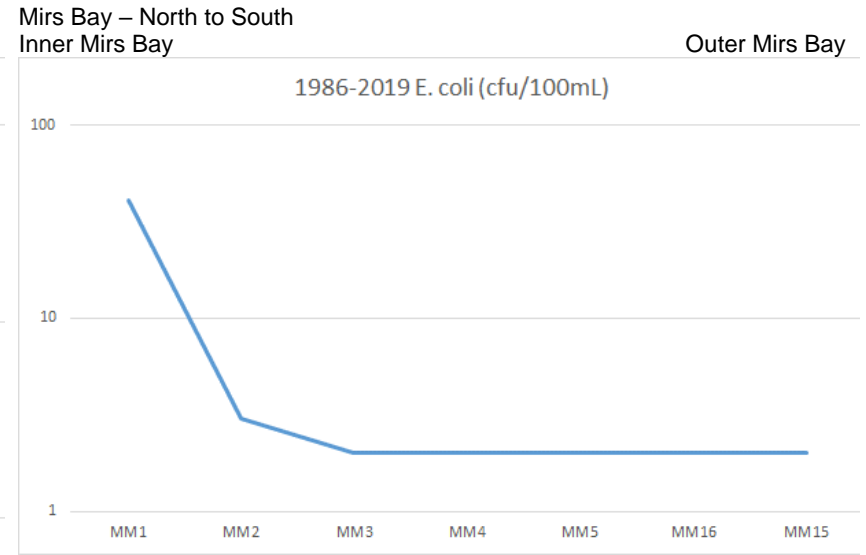
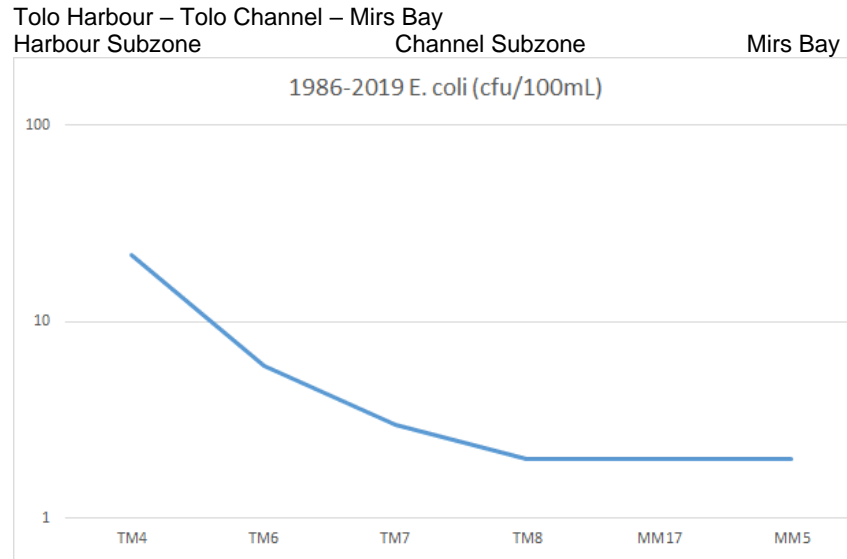
Figure 3B.1.7 Long Term Average Water Quality along the Major Axes of Tolo Harbour and Mirs Bay





Axis

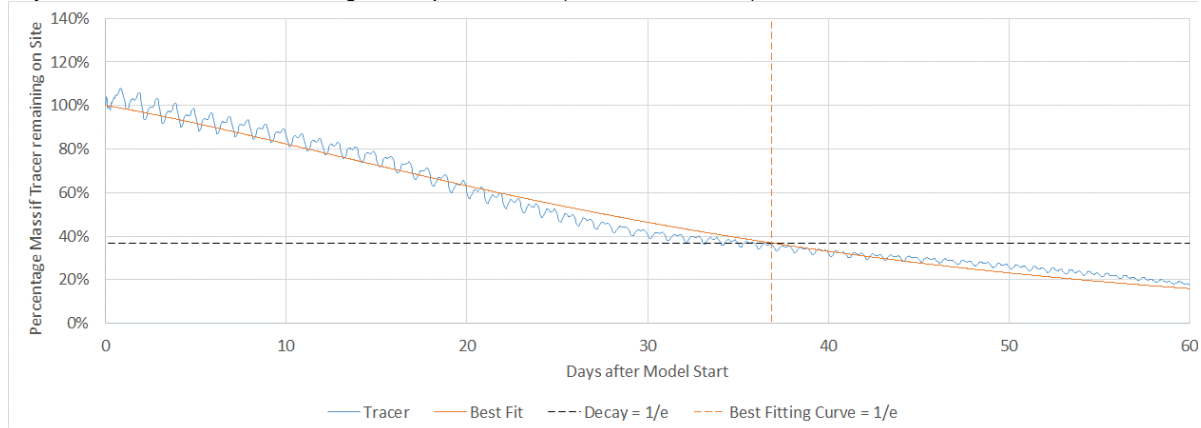
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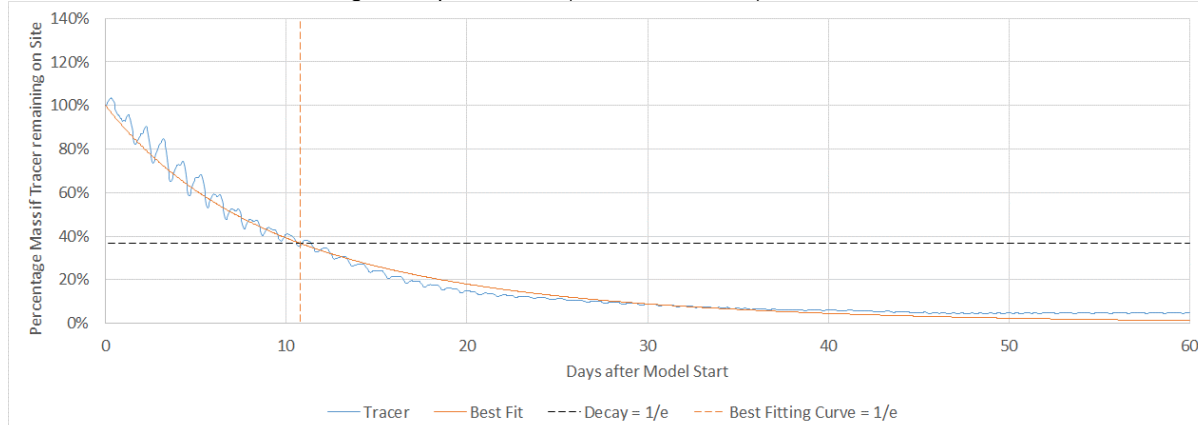
Tracer decay curves for dry and wet seasons at the existing Tap Mun FCZ are shown in **Figure 3B.1.8**.

Figure 3B.1.8 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 1 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 flushing time for two parts of the Project site are provided separately to illustrate their slightly different flushing time. 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 (Northern part)	34.0	8.7
Project site (Southern part)	36.7	9.3
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

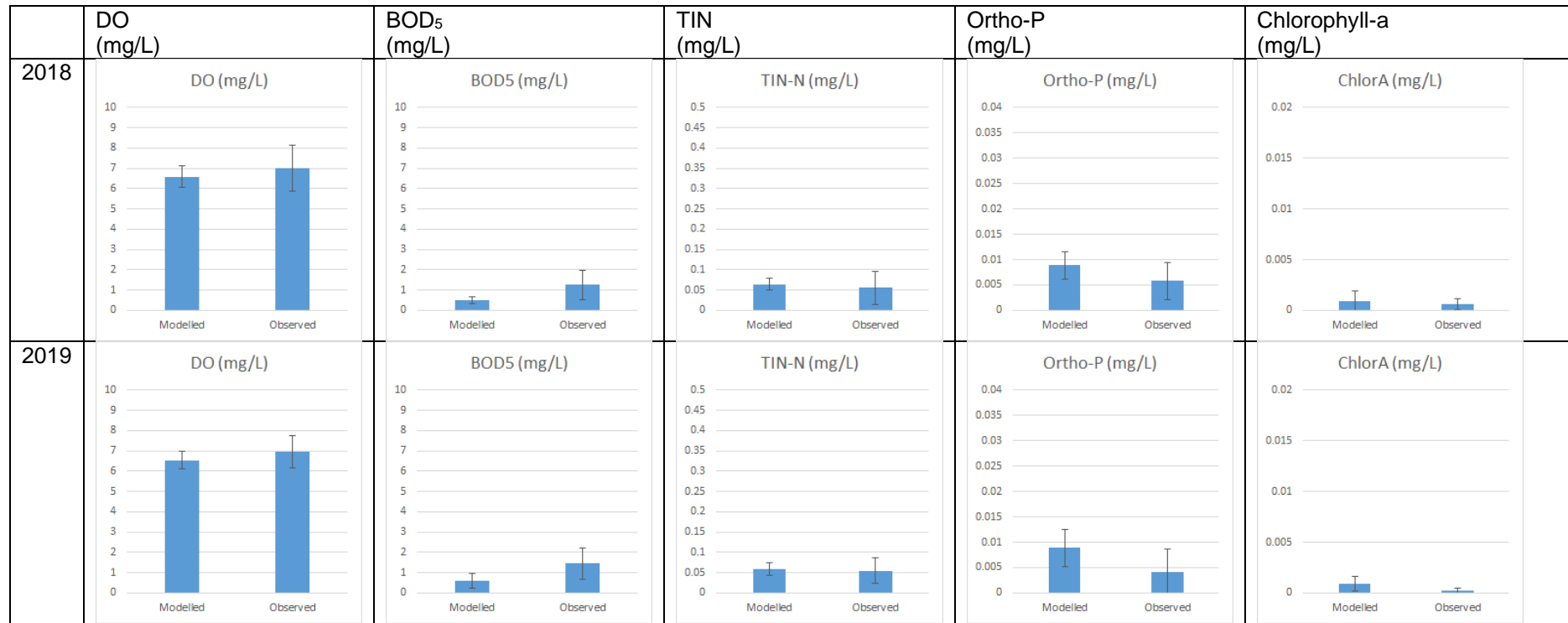
The predicted water quality at the Tap Mun FCZ is compared against the observed water quality to ensure the WATERMAN Hindcast Model is able to reproduce the water quality conditions at the FCZ. Given both part of model input (background water quality from nearby EPD Marine Water Quality Monitoring Stations 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 predictions at similar level of 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	<p>DO (mg/L)</p> <table border="1"> <tr><th>Category</th><th>Value (mg/L)</th></tr> <tr><td>Modelled</td><td>~6.2</td></tr> <tr><td>Observed</td><td>~7.2</td></tr> </table>	Category	Value (mg/L)	Modelled	~6.2	Observed	~7.2	<p>BOD5 (mg/L)</p> <table border="1"> <tr><th>Category</th><th>Value (mg/L)</th></tr> <tr><td>Modelled</td><td>~0.8</td></tr> <tr><td>Observed</td><td>~2.0</td></tr> </table>	Category	Value (mg/L)	Modelled	~0.8	Observed	~2.0	<p>TIN-N (mg/L)</p> <table border="1"> <tr><th>Category</th><th>Value (mg/L)</th></tr> <tr><td>Modelled</td><td>~0.08</td></tr> <tr><td>Observed</td><td>~0.07</td></tr> </table>	Category	Value (mg/L)	Modelled	~0.08	Observed	~0.07	<p>Ortho-P (mg/L)</p> <table border="1"> <tr><th>Category</th><th>Value (mg/L)</th></tr> <tr><td>Modelled</td><td>~0.011</td></tr> <tr><td>Observed</td><td>~0.012</td></tr> </table>	Category	Value (mg/L)	Modelled	~0.011	Observed	~0.012	<p>ChlorA (mg/L)</p> <table border="1"> <tr><th>Category</th><th>Value (mg/L)</th></tr> <tr><td>Modelled</td><td>~0.001</td></tr> <tr><td>Observed</td><td>~0.002</td></tr> </table>	Category	Value (mg/L)	Modelled	~0.001	Observed	~0.002
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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 <i>et. al.</i> , 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

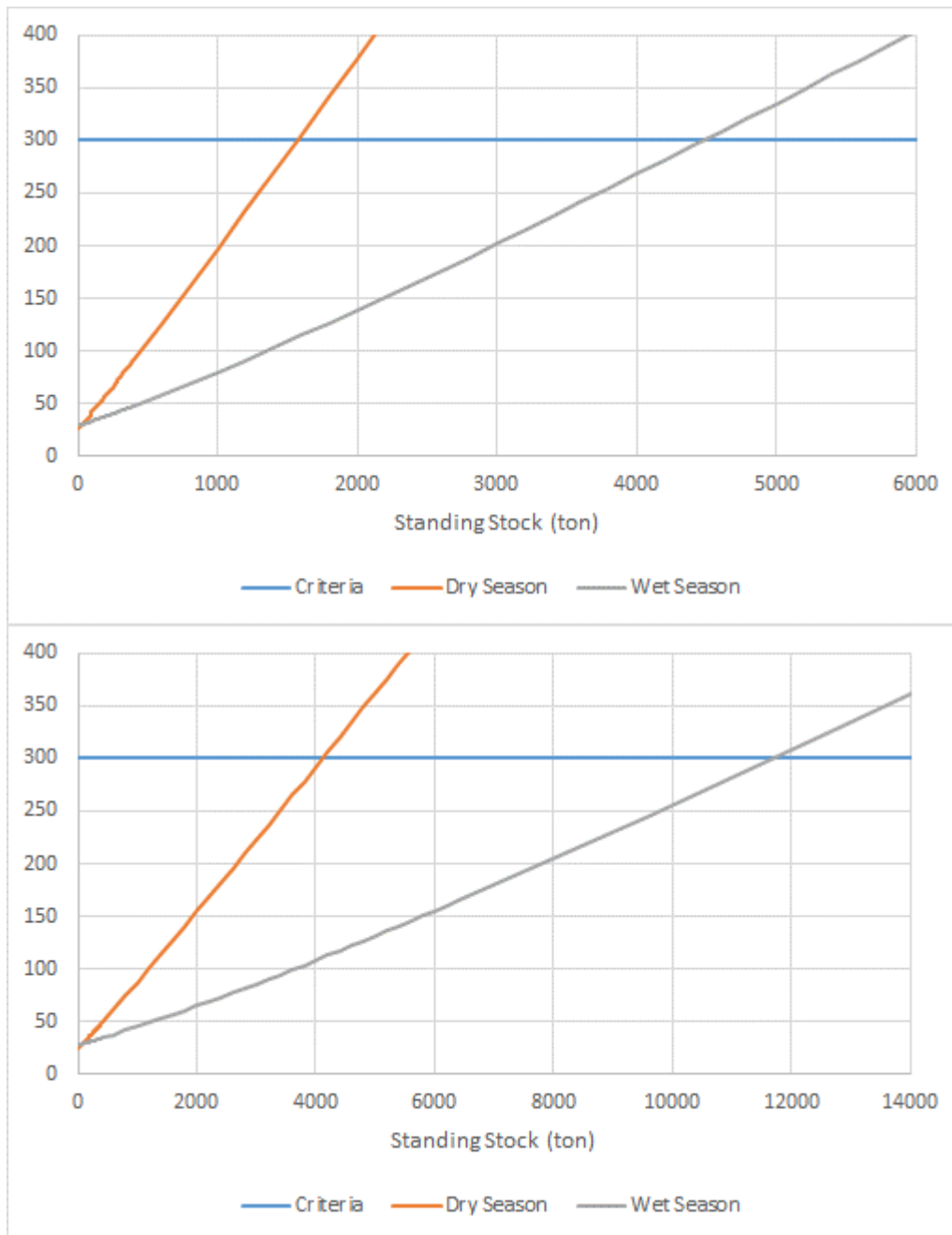
3B.1.3 Estimation of Carrying Capacity

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.1.9**.

As shown, among all the assessment criteria, TIN is found to be the critical water quality parameters at the Project site. Carrying capacity at the northern part of the Project site is estimated to be 1573.4 ton of standing stock under typical average condition and is predicted to be limited by TIN in dry season. For the southern part of the Project site, the estimated carrying capacity is 4110.1 ton of standing stock under typical average condition and is also limited by TIN in dry season as well. The total estimated carrying capacity at the Project site is 5683.5 ton of standing stock under typical average condition. 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.1.9 Predicted TIN Level ($\mu\text{g/L}$) at the Project site under Various Mariculture Standing Stock in Both Seasons – Upper Plot: Northern Part; Lower Plot Southern Part



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 $3 \times 3 \times 3$ 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 and at both parts

of Site C. This means while the estimated carrying capacity of 5683.5 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 1275.3 ton and 1239.1 ton of standing stock respectively for the northern part of the Project site. Those for the southern part of the Project site are 3403.3 ton and 3370.5 ton 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 5683.5 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 the Northern Part of the Project site	Pollution Load Generated for Standing Stock at its Carrying Capacity at Southern Part of the Project site
Oxidized-N (g/day)	1.4	2203	5754
Ammonia-N (g/day)	236	371319	969976
Org-N (g/day)	38.2	60103	157005
TIP (g/day)	1.7	2675	6987
TOP (g/day)	3.5	5507	14385
BOD (g/day)	540.3	850100	2220669
TSS (g/day)	26.7	42009	109739

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%
Project site (Northern Part)				
80%	80%	1740.3	1740.3	1740.3
	100%	1459.8	1480.2	1502.5
	120%	1216.5	1233.5	1252.1
100%	80%	1835.6	1835.6	1835.6
	100%	1549.1	1573.4	1599.8
	120%	1290.8	1311.1	1333.0
120%	80%	1952.8	1952.8	1952.8
	100%	1658.1	1686.8	1717.8
	120%	1381.8	1405.8	1431.5
Project site (Southern Part)				
80%	80%	5055.8	5137.6	5226.9
	100%	4044.6	4110.1	4181.5
	120%	3370.5	3425.1	3484.5
100%	80%	5055.8	5137.6	5226.9
	100%	4044.6	4110.1	4181.5
	120%	3370.5	3425.1	3484.5
120%	80%	5055.8	5137.6	5226.9

Flushing Capacity Scaling	Stock to Production Ratio Scaling	Maximum Algal Growth Rate Ratio		
		80%	100%	120%
	100%	4044.6	4110.1	4181.5
	120%	3370.5	3425.1	3484.5

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
Northern Part of Project Site						
Dry Season	7.3	0.2	0.30	0.009	0.013	<0.001
Wet Season	6.4	0.4	0.11	0.007	0.007	0.001
Southern Part of Project Site						
Dry Season	7.3	0.1	0.30	0.009	0.013	<0.001
Wet Season	6.4	0.4	0.11	0.007	0.006	0.001

Note: Values presented are mean depth-average values.