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DETERMINATION OF WASTE ASSIMILATIVE CAPACITY (WAC) OF RIVERS LOCATED WITHIN THE DESARU REGION, JOHOR

Desaru is a popular tourist destination located on the east coast of the state of Johor. The area has been identified for further development to enhance tourism. This presents a pollution risk to its surrounding watercourses. The purpose of this study was to assess the potential risk of contamination towards rivers located in the crux of the development region, namely the Terumpah, Che Minah, Semangar, Beluntu, Penawar Besar, and Mertang Besar Rivers. Water quality and hydraulic measurements were made at these rivers, with the intention of developing a numerical model. The model results showed deterioration in BOD_5 and NH_3-N in the Semangar River, up to 4.0 mg/dm^3 and 0.34 mg/dm^3, respectively. The Beluntu River experienced the highest degradation, to about 14.0 mg/dm^3 of BOD_5 and 0.8 mg/dm^3 of NH_3-N. The waste assimilative capacity (WAC) for the Matang Besar, Che Minah and Beluntu Rivers were very limited, with a class III BOD_5 limit of 15, 43, and 10 kg/day, respectively, whereas the Terumpah River is not able to accept any BOD load without breaching the same threshold.

1. INTRODUCTION

This study entails the sampling and benchmarking of water quality characteristics of rivers located within Desaru, Johor. Desaru is a popular tourist destination that hails visitors from various parts of Malaysia as well as Singapore. The beach is located on the eastern tip of the Malay Peninsula, approximately 88 km east of Johor Bahru.

The primary objective of the study was to establish baseline attributes of water quality of rivers within the region. The results of the monitoring exercise was used to develop numerical water quality models for the Terumpah, Che Minah, the Semangar River, Beluntu, Penawar Besar and Mertang Besar Rivers. This is important, in view of various proposals to develop the area as a prominent tourism hub. Improper planning and management may lead to deterioration of water quality. The recently completed the

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Senai-Desaru River expressway/bridge aims to further propel the development objective.

There are many small, tidally affected rivers located along the Desaru coastline from Lompat on the northern region (road to Balau) to Pungai near Batu Layar. Most of the rivers empty into the South China Sea, save perhaps the Semangar River which passes through Bandar Penawar and empties into Johor. That being the case, the Semangar River is still considered to be a tidally affected river, as tidal retention is still prevalent on the downstream reaches. Some rivers were already quite polluted, as debris and other floatables could be seen on the surface of the water, such as in the case of the Beluntu River. These floatables were likely brought in by the tide either from the Desaru beach or from the Batu Layar beach and act as reminder of the potential impacts of tourism. It is therefore important, to assess the potential impact of the proposed development, to pave the way for sustainable water quality management.

2. METHOD

The location of the sampling stations for baseline model development is listed in Table 1. These rivers are located in the middle of the development plan and are therefore the primary focus of the study. Based on the field survey, most of the rivers are tidally affected either through retention or retention and mixing. Retention inhibits reaeration and increases the residence time of a pollutant in the water column. This in-turn promotes decay/transformation of non-conservative constituents such as organics [1]. Tidal mixing results in dilution and may also contribute to increase of certain constituents, including dissolved oxygen (DO) [2].

Table 1

Coordinates of sampling stations

River	Latitude (N)	Longitude (E)
Terumpah	1°27.761'	104°17.036'
Che Minah	1°32.176'	104°16.104'
Semangar	1°33.459'	104°13.175'
Beluntu	1°27.330'	104°17.303'
Penawar Besar	1°28.949'	104°16.301'
Mertang Besar	1°32.960'	104°15.569'

Water sampling, *in*-situ (temperature, DO, salinity, conductivity) and hydraulic (depth, width and velocity) measurements were done at rivers and streams anticipated to be affected by pollution input from the proposed development. Samples were analyzed for parameters listed in Table 2.

Table 2

Parameters under laboratory analyses
and corresponding test methods [3]

Parameter	Test method
pH	APHA 4500 H^+B
Biochemical oxygen demand (BOD_5)	APHA 5210 B
Chemical oxygen demand (COD)	APHA 5220 B
Total suspended solids	APHA 2540 D
Iron	APHA 3112 B
Sulphides	APHA 4500 S^{2-}C
Oil and grease	APHA 5520 B
Ammoniacal nitrogen (NH_4^+ + NH_3 as N)	APHA 4500 NH_3B
Phosphorus	APHA 4500 PC
Nitrates (NO_3^- as N)	APHA 4500 NO_3 B
E. coli	APHA 9221 E&B
Conductivity	APHA 2510 B
Turbidity	APHA 2130 B
Salinity	APHA 2520 A

3. ESTIMATION OF POLLUTION LOAD

It is difficult to determine the exact amount of pollution load C_iQ_i, where C_i is the pollutant concentration and Q_i is its flowrate, that will be generated from the proposed development due to unavailability of primary data. A different approach was therefore employed, where the amount of pollution load per area was derived based on a study conducted by DOE, 2010 [4] for commercial and mixed land-use within the Kuantan basin. The three respective land-uses comprise the following activities (Table 3).

Table 3

Activities for each land-use

Commercial	Sewage treatment plant	Mixed
Restaurant Food court Carwash Laundry	proposed stps within development region based on design pe (not modelled)	individual sewage treatment systems sullage (greywater)

To be conservative, only pollution loads from urbanized basins were chosen in the calculation. The final pollution load per area is shown in Table 4.

Table 4

Pollution load [4] [kg/(day·km^2)]

Land-use	BOD_5	COD	NH_3-N	TSS
Commercial	9.27	19.70	0.06	11.81
Mixed	7.21	22.72	0.92	7.16

Using the total development area for each basin, the pollution load contribution for each river was approximated as depicted in Table 5. The values below include an additional safety margin of 20% for commercial and mixed land-use [5]. The proposed development region is expected to bring in another 492 kg/day of BOD_5 and 80 kg/day of NH_3-N, which will be distributed to various rivers and streams within the development area. The high loading value is meant to represent peak loading conditions (worst case scenario) such as during the holiday season, when there would be an influx of tourists.

Table 5

Estimated total pollution load contribution

River	Total development area [km^2]	Loading (kg/day)			
		BOD_5	COD	TSS	NH_3-N
Terumpah	–	–	–	–	–
Che Minah	3.93	172.03	597.16	204.82	30.04
Semangar	0.89	28.77	74.09	20.91	1.71
Beluntu	2.06	33.29	85.74	24.20	1.97
Penawar Besar	2.60	118.54	423.44	147.33	22.24
Mertang Besar	3.20	139.44	482.39	165.17	24.14
Total		492.07	1662.82	562.43	80.1

Six sewage treatment plants (STPs) have been identified for construction in the region. However, design specifications for these plants are still pending and therefore they will be negated from the modelling exercise. The impact assessment modeling exercise will center on the Semangar and Beluntu Rivers. Once the STP design specifications are obtained, the pollution load then can be derived from the design population equivalent (PE), assuming 0.225 m^3/day PE [4].

3.1. DEVELOPMENT OF A SIMPLE MIXING MODEL

The model to be used is based on the Streeter–Phelps formulation which forms the core of many more advanced water quality modeling tools [6]. It is an algebraic equation derived by integrating the differential equation governing the oxygen sag. When a pollutant is introduced into a water source, the dissolved oxygen (DO) typically decreases to a minimum before gradually recovering. There are two competing processes in this interaction. reaeration (k_r) and deoxygenation (decay) (k_d). Reaeration adds molecular oxygen to the stream from the atmosphere whereas decay/transformation depletes the oxygen [7]. The Streeter–Phelps equation models the amount of DO and BOD in a stream after wastewater is discharged into it. This model follows the BOD pollutant downstream as it travels at stream velocity [8]:

$$D = \frac{k_d L_0}{k_r - k_d}(\mathrm{e}^{-k_d t} - \mathrm{e}^{-k_r t}) + D_0 \mathrm{e}^{-k_r t} \tag{1}$$

where: D – final DO deficit (mg/dm^3) at spatial point x, D_0 – initial DO deficit (mg/dm^3) at point x_0, L_0 – initial UBOD (ultimate BOD) after mixing (mg/dm^3) at point x_0, k_d – decay rate (1/day), k_r – reaeration rate (1/day), t – travel time to point x.

The minimum of the DO sag curve, which occurs at the sag time, is the time when the oxygen deficit is greatest (minimum DO) and represents the time of greatest stress to aquatic macroorganisms in the stream [7]. When a river or stream system receives mass loading input from either tributary confluences or wastewater input, the general mass balance equation at location $l = 0$ km and $t = 0$ can be written as.

$$C_0 = \frac{C_r Q_r - C_i Q}{Q_r + Q_i} \tag{2}$$

where: C_0 – initial constituent concentration in the stream after mixing (mg/dm^3), C_r – initial constituent concentration in the stream at spatial before mixing (mg/dm^3), Q_r – stream discharge (m^3/s), C_i – influent concentration (mg/dm^3), Q_i – influent flowrate (m^3/s).

For UBOD, denoting C as L, for consistency with the Streeter–Phelps formulation, L, at any spatial point, x and time, t can be represented by

$$L = L_0 - (k_d)(L_0) \tag{3}$$

The above equation assumes no losses in oxygen demand due to, settling, k_s, of organic constituents particularly in terms of particulate organic carbon [6]. Streams are also assumed to be well mixed and generally homogenous with an evenly distributed concentration pattern, vertically and laterally. This is coherent to one-dimensional water quality modeling [9].

The same equation can also be used to approximate residual concentrations of other constituents such as COD, NH_3-N, and TSS. The residual COD present in the water column can be determined by accounting for the amount of UBOD removed in the water column and subtracting that value with the initial COD [10]. For TSS, a similar procedure is also applied though, instead of k_d being the predominant removal factor, k_s, is more prevalent, assuming that majority of the TSS consists of inorganics (sometimes referred to as inorganic suspended solids, a conservative constituent) [6].

The above approach should give a good representation of the impact of pollutants towards receiving streams. It should be noted, that the modeling proceedings do not incorporate tidal accumulation which warrants a dynamic water quality modeling exercise. Tidal retention, which inhibits reaeration potential, hence compromising the waste assimilative capacity (WAC), was also captured in the modeling proceedings. Hence, the effects of the organic contribution affecting the DO balance were also conservatively represented.

For this study, the class II and class III designations of the national water quality standards (NWQS) for Malaysia [11] was adopted as the WAC benchmark. Once the baseline model was developed, each reach was scrutinized to determine its corresponding WAC. Depending on the current condition of the stream, whether it is still within or beyond the desired water quality status (usually measured in terms of concentration), the total amount of pollution load (or total maximum daily load (TMDL)) the river can sustain or needs to reduce (in kg/day) was determined [12].

Table 6

Results of sampling water quality

Parameter	River					
	Terumpah	Che Minah	Semangar	Beluntu	Penawar Besar	Mertang Besar
pH at 25 °C	6.20	5.08	6.10	6.56	5.12	5.37
Temperature, °C	27.4	29.3	27.3	27.9	28.3	31.2
DO, mg/dm^3	5.1	5.5	4.9	4.8	5.7	5.7
DO_{sat}, %	64.5	71.9	61.8	61.2	73.2	77.0
BOD_5, mg/dm^3	6	4	2	2	2	5
COD, mg/dm^3	22	41	3	38	6	7
TSS, mg/dm^3	6	12	8	12	12	16
Iron as Fe, mg/dm^3	1.83	23.72	2.31	2.26	0.80	0.62
Sulphide as S^{2-}, mg/dm^3	2.63	nd (<0.1)	2.03	0.30	1.22	3.34
Oil and grease, mg/dm^3	2	nd (<0.1)	1	nd (<0.1)	nd (<0.1)	nd (<0.1)
NH_3-N, mg/dm^3	nd (<0.005)	nd (<0.005)	0.245	nd (<0.005)	nd (<0.005)	3.358
Phosphorus, mg/dm^3	0.45	0.98	0.38	0.63	0.15	0.40
NO_3-N	3.61	1.82	2.72	1.55	0.87	0.87
E. coli	3500	4200	2100	3700	500	330
Conductivity	488.0	67.9	136.8	1139.0	6050.0	8900.0
Turbidity	18.20	97.70	27	7.46	5.17	4.35
WQI score	83	79	85	82	87	72
WQI class	II	II	II	II	II	III
WQI status	C	SP	C	C	C	SP

Referring to Table 6, the water quality for most rivers within the region was good, between class II and III of the NWQS. Non-anthropogenic sources may have contributed to the elevation of organic matter in the Terumpah River, whereas sullage sources may have resulted in NH_3-N elevation in the Semangar River to 0.245 mg/dm^3. The NH_3-N increment in the Mertang Besar River (to 3.358 mg/dm^3) on the other hand, was rather anomalous and may have been due to tidal mixing. DO levels were also moderate, reflective of the low organic levels and tidal mixing. *E. coli* count in the Terumpah (3500 cfu/100 cm^3), Che Minah (4200 cfu/100 cm^3), Semangar (2100 cfu/100 cm^3) and Beluntu (3700 cfu/100 cm^3) Rivers were on the higher side; indicative of fecal contamination. For the Che Minah River, the origin of the contamination may have been anthropogenic, as there is a nearby oxidation pond that dislodges its effluent into the river. Likewise, the Semangar River, which passes through Bandar Penawar is susceptible to bacterial input such as from greywater sources. The water quality index (WQI) analysis [11] was reflective of the above discussion, registering between class II and class III; where the rivers were designated to be either clean (C) or slightly polluted (SP).

3.2. RESULTS OF A SIMPLE MIXING MODEL AND WASTE ASSIMILATIVE CAPACITY

The results of modeling below discuss the assessment of modeling impact proceedings for the Semangar and Beluntu Rivers. Although the pollution load data for other rivers (Mertang Besar, Che Minah, Pawang Kecil, Penawar Besar and Terumpah) were available, the impact assessment modeling was not carried out at these rivers. This was because the design specifications for the STPs were still pending. Thus at this point in time, modeling of these rivers would not give an acceptable representation of the cumulative impact of all pollution sources [13]. Instead, the WAC for each of river system was derived and discussed below.

3.3. IMPACT ASSESSMENT MODELING OF THE SEMANGAR RIVER AND BELUNTU

The Semangar River is the only river potentially affected by the proposed development that does not flow directly into the South China Sea. Instead, the river flows to the west, through Bandar Penawar before confluence with Johor. On its upper reaches, the river is relatively small. Downstream, tributary confluences result in the river becoming deeper and wider, hence also increasing its WAC.

Referring to Figure 1, the results of spatial modeling the Semangar River did not show significant deterioration of constituents of water quality, with TSS and DO remaining within the class II denotation. An NWQS class change however, was predicted for BOD_5 and NH_3-N as levels went beyond the class III denotation at 4 mg/dm^3 and 0.34 mg/dm^3, respectively. This indicated that sullage sources would inevitably be the main pollution source propagating the change in ambient water quality.

From Table 7, to maintain the current class II BOD_5 NWQS classification, an incoming TMDL of no more than 17 kg/day must be achieved, whereas for NH_3-N, the TMDL should not be more than 1 kg/day. Such a low value (for NH_3-N) indicated that the class II threshold was very close to being breached. Current pollution sources in the

Semangar River include sewage and sullage sources that primarily originate from Bandar Penawar.

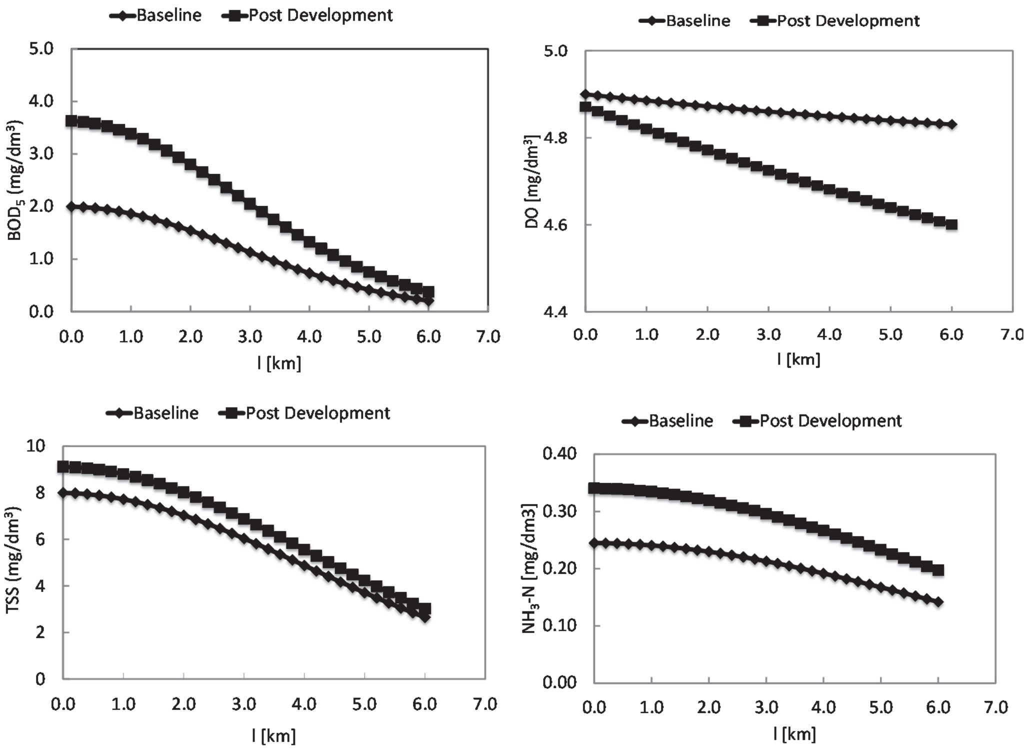

Fig. 1. Results of spatial modeling of the Semangar River

Table 7

WAC [kg/day] of the Semangar River (relative to class II and III)

Parameter	Current	Class II	TMDL Class II	Class III	TMDL Class III
BOD_5	35	52	17	104	69
COD	52	432	380	864	812
TSS	138	864	726	2592	2454
NH_3-N	4	5	1	16	11

The Beluntu River is the most southern river located within the development region. It has limited WAC as well. The river is already in a grotesque state due to debris and other floatables. The river is not expected to receive any sewage effluent from the proposed development. Despite so, pollution loading from other sources was enough to compromise water quality.

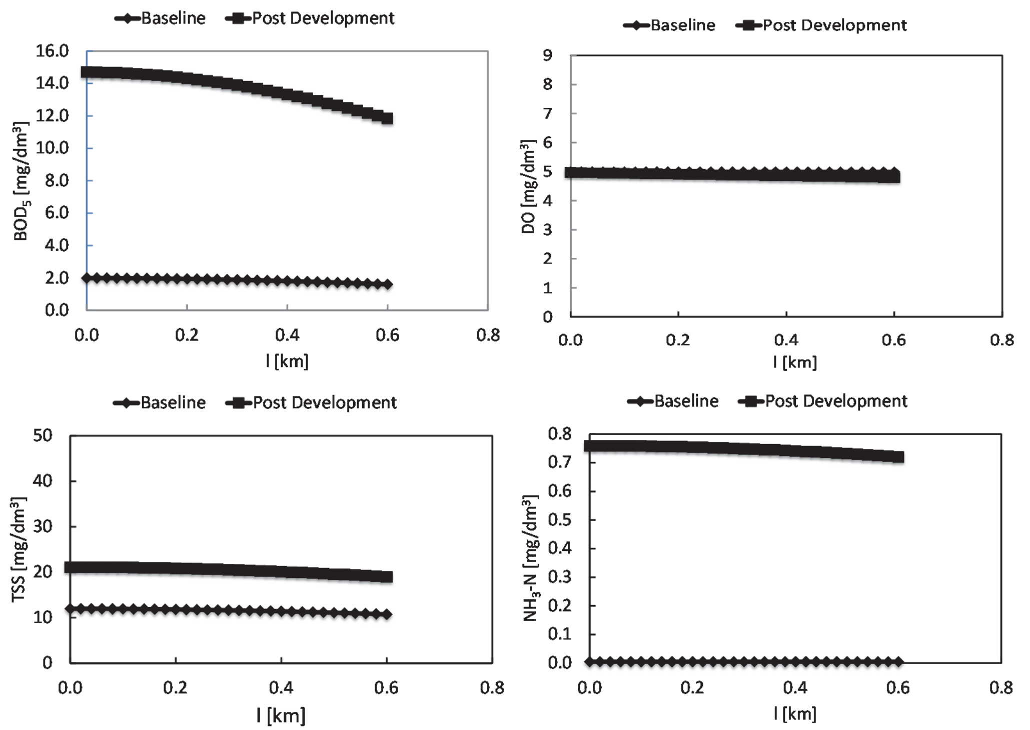

Fig. 2. Results of spatial modeling of the Beluntu River

Referring to Figure 2, post-development, the BOD_5 levels in the Beluntu River were predicted to increase to above class V, at about 14 mg/dm^3, whereas NH_3-N levels would be at class III (0.8 mg/dm^3). This was a stark contrast to the class II baseline denotation. Interestingly, the DO levels remained relatively unperturbed. This was likely due to the reaeration coefficient and its relation to shallow stream conditions (which enhances surface oxygen transfer [14]). The ambient TSS was also predicted to increase from 12 mg/dm^3 to about 20 mg/dm^3 (Table 8).

Table 8

WAC [kg/day] of the Beluntu River (relative to class II and III)

Parameter	Current	Class II	TMDL Class II	Class III	TMDL Class III
BOD_5	5	8	3	16	10
COD	98	65	–34	130	31
TSS	31	130	98	389	358
NH_3-N	0	1	1	2	2

3.4. WAC ANALYSIS FOR MERTANG BESAR, CHE MINAH, PENAWAR BESAR RIVER AND TERUMPAH

The Mertang Besar, is a medium sized river, ca. 3–5 m wide. Tidal retention means the velocity of the river (hence also flowrate) is limited, which in turn also limits its WAC [15]. Referring to Table 9, to maintain the current BOD_5 class III denotation, no more than 15 kg/day of the constituent can enter the river. Therefore, in order to maintain the current water quality status, other discharge options should be considered.

Table 9

WAC [kg/day] of the Mertang Besar River (relative to class II and III)

Parameter	Current	Class II	TMDL Class II	Class III	TMDL Class III
BOD_5	76	45	–30	91	15
COD	106	378	272	756	650
TSS	242	756	514	2268	2026
NH_3-N	51	5	–46	14	–37

The Che Minah river is located not far from the Mertang Besar, near the Desaru Golf and Country Resort. The upstream reaches are quite small and slow flowing; no more than 2 m wide. In terms of WAC, referring to Table 10, only 43 kg/day of BOD_5 can be added to the Che Minah River for it to remain within the class III. For NH_3-N TMDL, a surplus of 6 kg/day is allowable for the river to be within class II, whereas the class III resolution permits 16 kg/day of NH_3-N input.

Table 10

WAC [kg/day] of the Che Minah River (relative to class II and III)

Parameter	Current	Class II	TMDL Class II	Class III	TMDL Class III
BOD_5	86	65	–22	130	43
COD	886	540	–346	1080	194
TSS	259	1080	821	3240	2981
NH_3-N	0	6	6	19	19

The Penawar Besar River is a medium sized river with correspondingly moderate carrying capacity. The water quality here is generally within the class I–II range of the NWQS. Reviewing the WAC (Table 11), revealed that the Penawar Besar River is capable of receiving up to 194 kg/day of BOD_5 and 57 kg/day of NH_3-N before the class II threshold is breached. The class III denotation permits an additional 778 kg/day of BOD_5 and 174 kg/day of NH_3-N load. Good water quality conditions and sufficient hydraulic capacity also enable the river to support fish species [16] such as siakap (barramundi), the primary game fish sourced by local anglers.

Table 11

WAC [kg/day] of the Penawar Besar River (relative to class II and III)

Parameter	Current	Class II	TMDL Class II	Class III	TMDL Class III
BOD_5	389	583	194	1166	778
COD	1166	4860	3694	9720	8554
TSS	2333	9720	7387	29160	26827
NH_3-N	1	58	57	175	174

From Table 12, the Terumpah River has very limited WAC for all constituents modeled, as there was no more room BOD_5 input (with respect to class II). For NH_3-N, the class II TMDL threshold was at about 2 kg/day.

Table 12

WAC [kg/day] of the Terumpah River (relative to class II and III)

Parameter	Current	Class II	TMDL Class II	Class III	TMDL Class III
BOD5	16	8	–8	16	0
COD	57	65	8	130	73
TSS	16	130	114	389	373
NH3-N	0	1	1	2	2

4. SUMMARY AND CONCLUSIONS

The modeling exercise has successfully given several indications on the impact of development towards rivers within the Desaru region. Majority of rivers within the region are affected by tidal intrusion either through retention or retention and mixing. The Semangar and Penawar Besar Rivers still possess considerable WAC margin, hence should be less susceptible to pollution. This was mainly due to the larger size. Pollution input towards the Matang Besar, Che Minah, Terumpah and Beluntu Rivers may result in water quality deterioration particularly in terms of BOD_5 and NH_3-N, as these rivers possessed limited WAC.

Installation of grease traps at restaurants, food courts and other commercial premises will minimize oil and grease input. Gross pollutant traps should also be installed in and around the development region to trap debris and floatables. To further improve the model, sewage contribution also needs to be quantified. Besides this, pollutant accumulation as a consequence of tidal dynamics over a temporal period will also be encapsulated in future models.

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