IMPACT MODELING OF SEWAGE DISCHARGE FROM GEORGETOWN OF PENANG, MALAYSIA ON COASTAL WATER QUALITY

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Abstract. Currently about 200,000 persons of the Penang Georgetown population is served by a sewerage system which conveys the raw sewage to an open channel flume in Jelutong for discharge into the Western Channel. This has resulted in the degradation of coastal water quality in the affected areas. Therefore, there exists an urgent need to look for other alternatives for sewage treatment and disposal. This paper presents the results of computer simulations on the impacts of sewage discharge on Penang coastal waters under two treatment and disposal options. The preferred option is a conventional activated sludge treatment system capable of treating the sewage to secondary level with a submerged outfall to the Western Channel for the disposal of the treated effluent. The results of computer simulations show that the quality of coastal waters, other than in the immediate vicinity of the discharge point, would be able to achieve the Malaysian proposed criterion for recreational waters up to year 2020.

1. Introduction

The present sewerage system serving an estimated two hundred thousand people in the Georgetown area of Penang, Malaysia is antiquated. This is so because raw sewage is conveyed by sewer lines to an open channel flume in Jelutong and discharged without any form of treatment into the Western Channel (Figure 1). A recent study (Koh and Lim, 1989) concluded that the dispersive capacity of the Western Channel is inadequate to cope with the present loading from the Jelutong outfall. This has resulted in the poor water quality status of the Western Channel (Owens, 1978; Lim *et al.*, 1984; Koh *et al.*, 1987).

In view of the rapid economic growth and population increase in the Georgetown area, projected to reach 657,700 in year 2020 (Biwater, 1992), the sewage flow is anticipated to reach 148,000 m^3/day based on the sewage generation rate of 225 ℓ/capita/day as recommended by the Malaysian Standard (MS) 1228. If the sewage is not properly treated and disposed of, this is bound to put more stress on the coastal environment.

The major part of the eastern foreshore of Penang Island has been earmarked to be developed into a high quality business, residential and recreational area. A prerequisite to the success of this development is a good water quality in the coastal environment commensurate with the planned beneficial uses. This can only be achieved if the proper mode of treatment and disposal for sewage are implemented.

Various treatment and disposal options have been explored of which two are selected for further analysis. Option A involves building a conventional activated sludge treatment system capable of providing secondary treatment with a submerged outfall to discharge the treated sewage into the Western Channel. Option B involves building a long submerged outfall to convey primary treated sewage to the Southern Channel (Figure 1) for disposal. This paper presents the results of computer simulations on the impacts of

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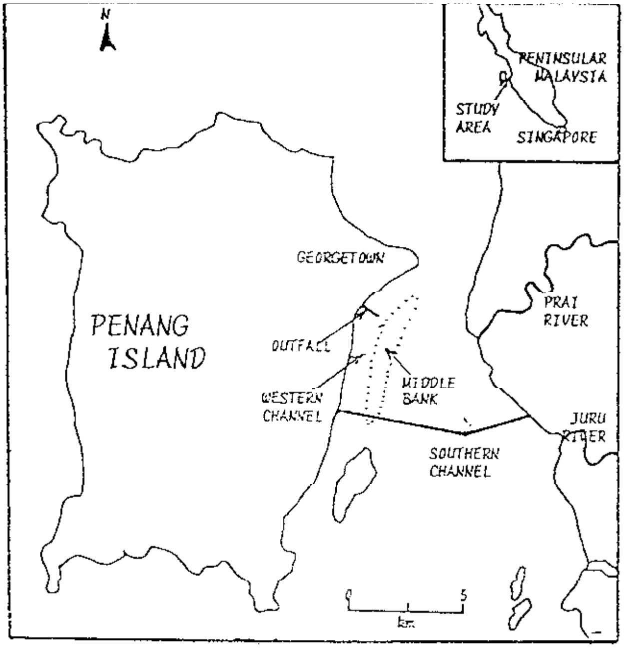

Fig.1. Location map of Western and Southern Channels and Jelutong outfall.

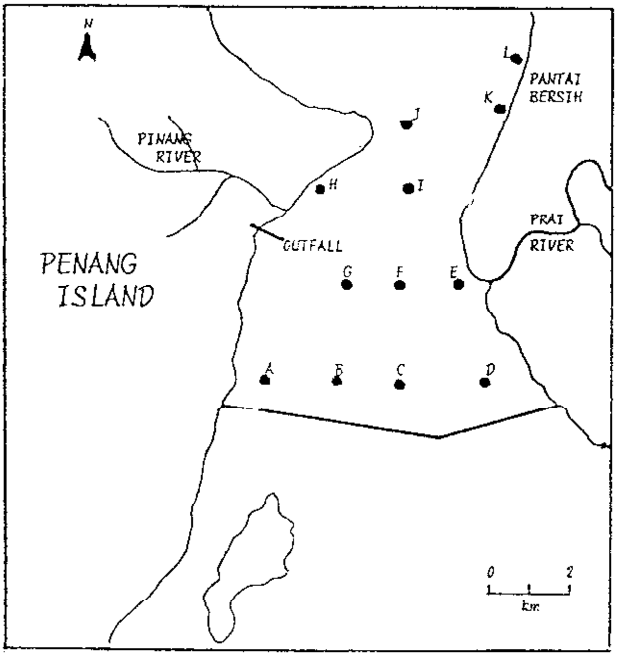

Fig.2. Locations of sampling stations in Penang Straits.

sewage discharge on the water quality of the Western and Southern Channels respectively under these two options.

2. Current Water Quality Status in Western and Southern Channels

When sewage is discharged into sea water through properly designed diffuser systems, initial dilution of 100 to 1 is achievable. Therefore, sewage constituents such as BOD, suspended solids, dissolved oxygen and nutrients are of little significance to the marine environment as a result of the dilution effect. The microbial parameters particularly faecal coliform (FC) concentration remains the best pollution indicator for coastal waters.

The FC concentrations in the Western Channel which had been extensively determined in earlier studies (Owens, 1978; Lim *et al.*, 1984; Koh *et al.*, 1987) consistently vary within the range of $10^3 - 10^5$ MPN/100 ml depending on the distances from the sewage outfall. This indicates that none of the sites along the Western Channel satisfies the proposed Malaysian criterion of 200 MPN/100 ml for bathing waters (DOE-UM, 1986).

This study has extended the determination of FC levels to the Southern Channel. The locations of sampling stations and the mean FC concentrations are shown in Figure 2 and Table I respectively. The primary source of FC bacteria in the Penang Straits is the raw sewage discharged at the Jelutong outfall. The results indicate that the Middle Bank, a low lying sand bank, plays an important role in partially restricting the distribution of the bacterial load to the waters of Western Channel. This is supported by the observation that much higher FC counts were detected at Stations A and H located in the Western Channel. The background FC concentrations detected in the Southern Channel reflect bacterial input from the Jelutong outfall and other unidentified sources. Stations L off Pantai Bersih is the only location where the Malaysian criterion for bathing waters has been satisfied.

TABLE I

Mean faecal coliform (FC) concentrations in Penang Straits

Samping station	FC concentration (MPN/100 ml)
A	1.1×10^3
B	2.5×10^2
C	3.8×10^2
D	5.9×10^2
E	3.2×10^2
F	4.3×10^2
G	4.6×10^2
H	2.6×10^3
I	1.6×10^3
J	2.6×10^2
K	2.2×10^2
L	9.1×10

3. Mathematical Models

Data on water temperature and salinity in the Penang Straits, namely the Southern and Western Channels, indicate that the water column is essentially vertically well-mixed. Hence vertically-integrated two dimensional models are adequate and appropriate. Two models were used. Firstly, a hydrodynamic model was used to simulate current flows in the Straits subject to tidal inputs, and other environmental parameters. Then an advection-diffusion model was used to simulate the transport and decay of pollutants such as faecal coliform with computed current flows as input.

3.1. HYDRODYNAMIC MODEL

For vertically-integrated model, the pressure is assumed to be hydrostatic and the two horizontal velocity components u and v are vertically integrated. The model consists, then, of a conservation of mass Equation (1) and two horizontal momentum Equations (2) and (3).

$$\frac{\partial H}{\partial t}+\frac{\partial (Hu)}{\partial x}+\frac{\partial (Hv)}{\partial y}=0 \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}+g\frac{\partial \zeta}{\partial x}-fv+\frac{gu\sqrt{u^2+v^2}}{c^2H}-\frac{\zeta^x}{H}=0 \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\frac{\partial \zeta}{\partial y}+fu+\frac{gv\sqrt{u^2+v^2}}{c^2H}-\frac{\zeta^y}{H}=0. \tag{3}$$

Here x is positive eastward (m), y is positive northward (m), u is the eastward velocity (m/s), v is the northward velocity (m/s), g is the gravity (m/s^2).

Further h is the distance from mean sea level to the bottom of the estuary (m), ζ is the distance from mean sea level to the water surface (m), H is total depth, $h+\zeta$ (m), f is the Coriolis parameter $\left(s^{-1}\right)$, and c is the Chezy coefficient (m$^{1/2}$/s).

In the tropics, f may be set to zero. The second last term in Equations (2) and (3) accounts for frictional losses at the bottom of the estuary. The last term refers to the wind stress conceived to act as a body force throughout the water column.

Details regarding the finite element numerical schemes used to solve the above hydrodynamic model as well as computational results for the Penang Straits are available in Koh (1986, 1988). It should be noted that the computed current flow regimes closely resemble those obtained in another study (DHI, 1992), and are in general agreement with theoretical results (Koh, 1991).

3.2. ADVECTION DIFFUSION MODEL

We consider a single neutrally buoyant pollutant and its transport in an estuarine or coastal environment as follows.

$$\frac{\partial c}{\partial t}+u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}-\frac{1}{H}\frac{\partial}{\partial x}\left(H.k_x\frac{\partial c}{\partial x}\right)-\frac{1}{H}\frac{\partial}{\partial y}\left(H.k_y\frac{\partial c}{\partial y}\right)+\alpha c-R=0 \tag{4}$$

where k_x, k_y are diffusion coefficients in the x, y directions respectively, α the decay rate and R is the source-sink term. Here c is the vertically averaged concentration of pollutant.

The above equation has previously been numerically solved by the eight-node quadrilateral finite element method and applied to the Johore Straits of Malaysia (Koh *et al.*, 1991). However, recently a three-node lumped parameter finite element technique has been developed (Koh and Lee, 1993) with the purpose to reduce computer memory requirement and is used in the present study. The two methods yield comparable results.

4. Simulated Tidal Regimes

The Penang Straits has a width that varies from 1.4 km to 14 km and a length of 22 km. The tidal regimes are generated by tides in the Straits of Malacca and are driven primarily by the astronomical semidiurnal tide entering and leaving the Straits at the two north-south entrances. The mean spring tide has an amplitude of about 1 m and a maximum current speed of 1.05 m/s while the corresponding values for a mean neap tide are 0.25 m and 0.30 m/s respectively. The semidiurnal tide has a tidal period of 12.42 hours, and is used in this study.

Figure 3 illustrates some computed flow regimes in the Penang Straits and the Western Channel which is inside the Penang Straits. Figures 3(a) and 3(b) refer respectively, to flood and ebb tides during a mean tidal cycle with an amplitude of 0.5 m in the Western Channel while 3(c) and 3(d) are the velocity plots during flood and ebb tide within a spring tide cycle in the Penang Straits.

5. Simulated Input Parameters

This section briefly discusses some critical parameters that form part of the input to the FC simulation model, which were obtained in two previous studies (Koh *et al.*, 1987; 1989).

The cross-flow diffusion coefficient k_x and the along-flow diffusion coefficient k_y were found to have the range $k_x \in (0.1, 1)$ m^2/s and $k_y \in (10, 30)$ m^2/s. These values agree in general with values compiled by Okubo (1971), which are based upon the concept of length scale of diffusion. For Southern and Western Channels, it is reasonable to take the diffusive scale for k_x and k_y to be 1 km and 10 km respectively, based upon

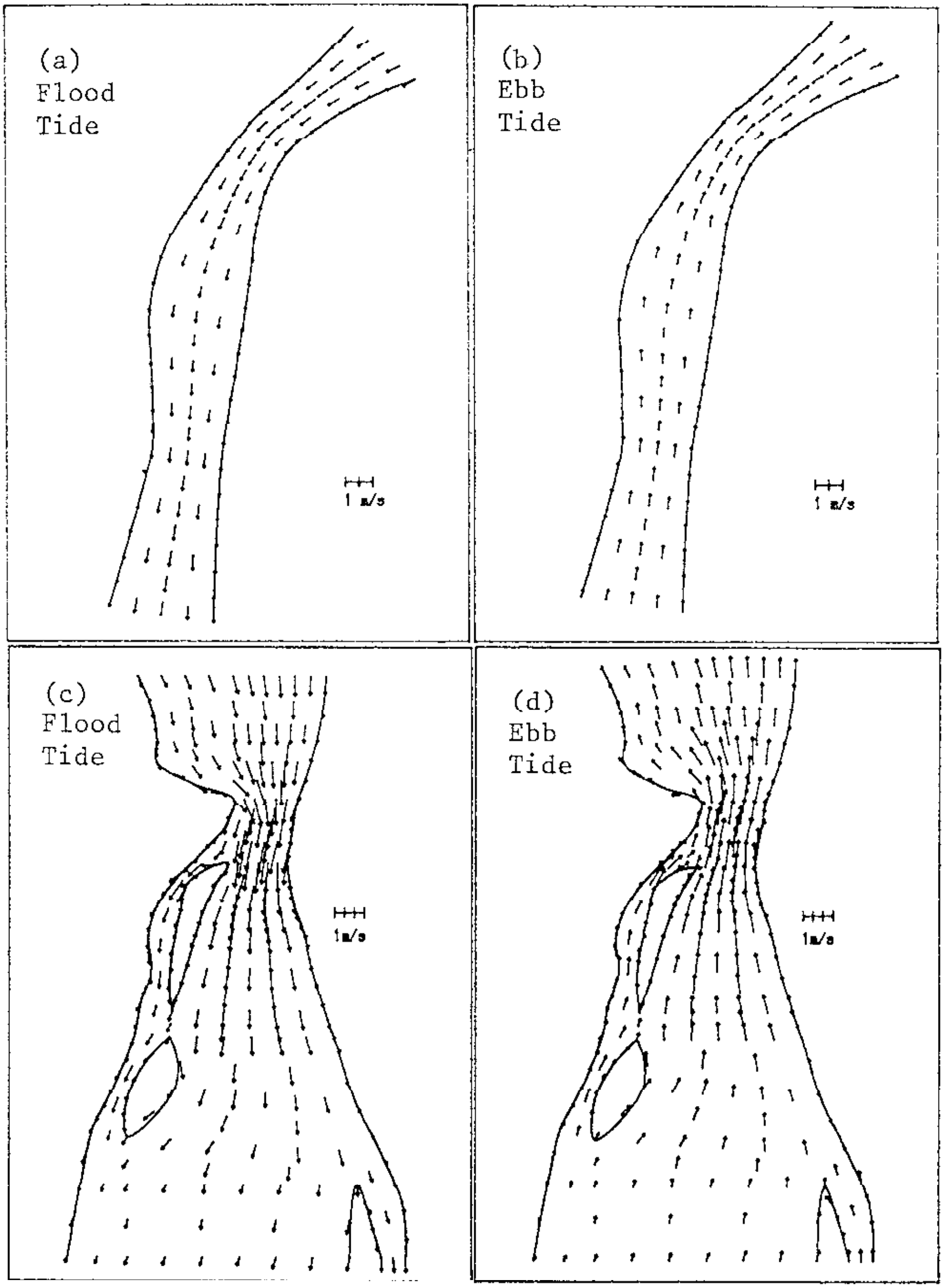

Fig. 3. Current velocity plots: (a), (b) refer to Western Channel during a mean tide; (c), (d) refer to Southern Channel during a spring tide.

observations of dye tracing previously conducted in the study area. These give rise to k_x= 0.5 m^2/s and k_y=10 m^2/s. In the present paper, for Western Channel k_x= 0.5 m^2/s, k_y=10 m^2/s, and for Southern Channel, the values of the two coefficients are doubled to reflect the larger length scales in the Southern Channel.

The semidiurnal tide with period of 12.42 hours is used. Current flow regimes during the mean tide which has a tidal height amplitude of about 0.5 m and a velocity amplitude of about 0.5 m/s are used as inputs to the advection-diffusion model. Faecal coliform (FC) die-off rate has the value of T_{90} = 3 hours, i.e., it takes 3 hours for 90% die-off, which agrees reasonably well with values compiled by Ludwig (1988). Sensitivity analysis indicates that variations in diffusion coefficients, tidal regimes and FC die-off rates within the ranges encountered in the study area to result in variations in simulation results within a factor of 5. The following section summarises simulation results based upon a fixed set of input parameters as given above, without any further reference to sensitivity analysis. This is deemed appropriate since FC counts and interpretations should be based upon order of magnitude, and not absolute number (WHO, 1975).

The raw sewage flow rate is projected to increase from 68,000 m^3/day in 1996 to 148,000 m^3/day by year 2020 (Biwater, 1992). Based on analyses of raw sewage samples, a FC concentration of 8×10^7 MPN/100 ml of raw sewage was adopted. The percentages of FC removal using primary (sedimentation) and secondary (activated sludge and chlorination) processes were estimated to be 75% and 99% respectively which are within the ranges quoted by Metcalf and Eddy (1979). This implies that the primary and secondary treated effluents would achieve FC concentrations of 2×10^7 and 8×10^5 MPN/100 ml respectively.

6. FC Simulation Results

Several treatment and disposal options were evaluated in terms of FC pollution in receiving waters subject to environmental parameters briefly described in the previous section. Option A involves treating the sewage to a FC concentration of 8×10^5 MPN/100 ml with a flow of 148,000 m^3/day to be discharged into the Western Channel via a short submerged outfall. Option B involves treating the sewage to a FC concentration of 2×10^7 MPN/100 ml with a flow of 68,000 m^3/day to be conveyed by a long submerged outfall beyond the Middle Bank and discharged into the Southern Channel. Two other options involve extending the outfall in Option B further into the Southern Channel, with the same loading as in Option B.

6.1. OPTION A: DISCHARGING SECONDARY EFFLUENT INTO WESTERN CHANNEL

This section presents the scenario in year 2020 when secondary effluent were to be discharged into the Western Channel. Figure 4 shows tidally averaged FC contours in Western Channel during a mean tide with a maximum current of 0.5 m/s. In the immediate vicinity of the outfall, FC concentration is expected to reach 4000 MPN/100 ml, decreasing to 200 MPN/100 ml at a distance of about 1 km south of

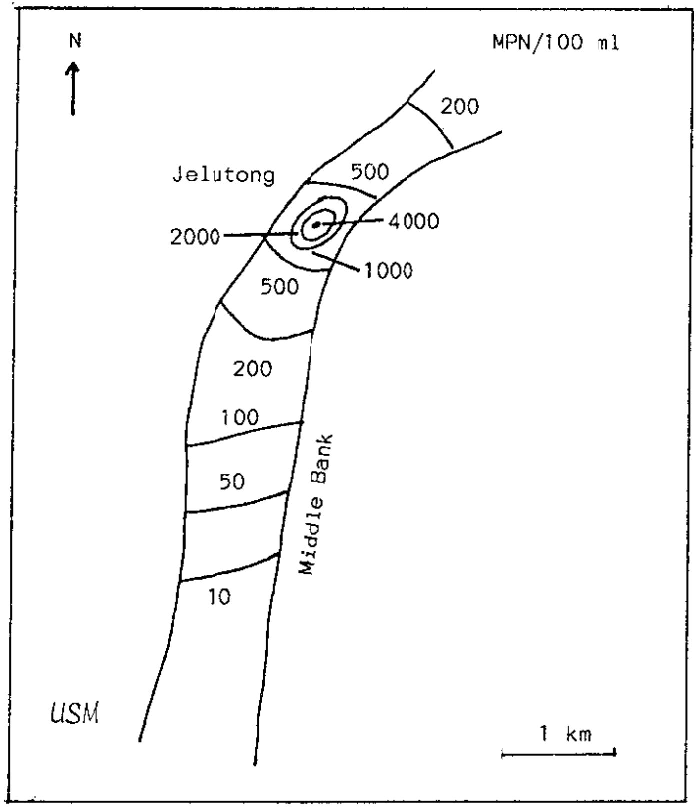

Fig. 4. Tidally averaged FC contours during mean tide for sewage flow of 148,000 m^3/d, treated to 8×10^5 MPN/100 ml in Western Channel

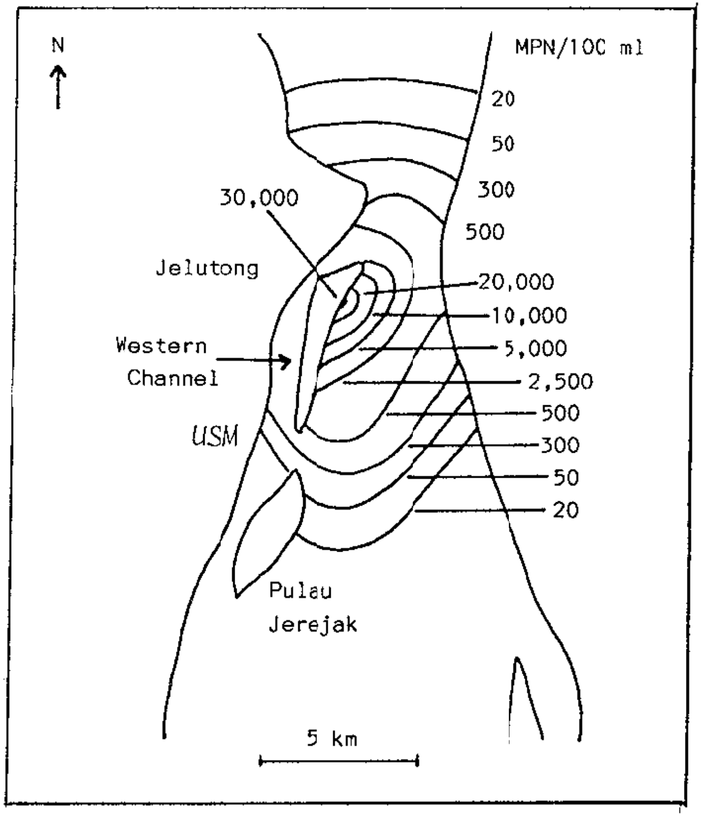

Fig. 5. Tidally averaged FC contours during mean tide for sewage flow of 68,000 m^3/d, treated to 2×10^7 MPN/100 ml in Southern Channel.

the outfall. Hence for a considerable stretch of the Channel south of the outfall, the coastal waters is suitable for bathing and contact sports based on the Malaysian proposed criterion of 200 MPN/100 ml FC for such activities. In addition, the water quality of the Southern Channel is anticipated to improve in view of the significant reduction in the bacterial load being discharged into the Western Channel as compared to the present situation. Although almost the entire channel is unsuitable for shellfish harvesting based on the water quality criterion of 14 MPN/100 ml (USEPA, 1979), this will not have adverse impact on the planned development of the eastern foreshore as it is planned for business, residential and recreational activities.

6.2. OPTION B: DISCHARGING PRIMARY EFFLUENT INTO SOUTHERN CHANNEL

This section presents the scenario in year 1996 when primary effluent were to be discharged into the Southern Channel which is primarily used for navigation. Only two locations demand good water quality: one off Pantai Bersih, a beach resort north of Butterworth and the other at the Juru River estuary where cockle rearing activities are presently found. Figure 5 shows that FC concentration may reach 30,000 MPN/100 ml in the immediate vicinity of the outfall, just beyond the Middle Bank. Even at this relatively low sewage flow, the water quality will not be able to satisfy the criterion for bathing waters in Pantai Bersih and also the criterion for shellfish harvesting at the Juru estuary. Further, the Middle Bank may not be an effective barrier to prevent bacterial pollution from reaching the Western Channel especially during high tide conditions. The scenario will certainly be worse under the projected flow of 148,000 m^3/day in year 2020.

6.3. OTHER OPTIONS EVALUATED

In addition to the two options considered above, several other treatment and disposal options were also evaluated, of which two will be briefly discussed. One option involves extending the outfall in Option B another 1.5 km eastward into the middle of Southern Channel. The peak FC density would reach 12,000 MPN/100 ml, decreasing to 600 and 300 MPN/100 ml around Pantai Bersih and Juru estuary respectively. Hence Pantai Bersih is unsuitable for bathing activities while Juru estuary is unsuitable for shellfish cultivation. The other option considers extending the outfall some 3 km south-east into the Southern Channel. The peak FC density would decline to 9,000 MPN/100 ml, decreasing to 600 around Juru estuary, rendering it unsuitable for shellfish harvesting. Pantai Bersih, however, would be suitable for bathing activities.

These two options are not considered for implementation because these two options would create additional cost and engineering problem in view of the need to construct submerged outfall in a major navigational water course.

7. Conclusion

Environmental impact evaluation of the two options shows clearly that Option A is the preferred alternative as it represents the most optimal compromise among the various conflicting conditions imposed. Further, the anticipated cost and engineering problem of constructing a submerged outfall pipe across the Western Channel needed for Option B, an important water course would add credence to the rejection of Option B as a viable alternative.

It should be noted that currently the sewage discharge from Pinang River contributes about 25% of that of the Jelutong outfall in terms of FC loading (Koh *et al.*, 1987). Thus, improvement in the water quality of the Western Channel also demands further improvement of water quality of Pinang River.

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