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Full Length Research Paper

Visual plumes coastal dispersion modeling in south-west Sabah

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The visual plumes model encompassing the DKHW (Davis, Kannberg, Hirst model for Windows) and Update Merge (UM3) sub-models were utilized in the modeling exercise. In theory, the dilution capacity of open waters, particularly coastal areas, straits and oceans are enormous. This means that for surface and sub-merged point source discharges, the effluent concentration (C_e) will cause insignificant change in the overall ambient water quality. Instead, C_e will eventually reach C_a (ambient concentration) over a spatial distance (vertical and horizontal). This distance is of interest with regards to water quality preservation efforts as the macro level distribution effects of the pollutant species in question can be determined. The travel distance (l_t) is a main function of ambient current velocity (m/s) and direction. Prior to the modeling exercise, field data pertaining to ambient water quality, hydraulic characteristics and tide patterns were collected. The modeling results indicated that there was no significant change in ambient concentration for all constituents modeled when the effluent discharge was increased from 1,500 m^3/h to 2,400 m^3/h, as long as the current quality was maintained. The plume travel distance would also not entrain into foreign waters as long as proposed volumetric discharge rate is no violated.

Key words: Visual plumes, coastal, Sabah.

INTRODUCTION

Davis, Kannberg, Hirst model for Windows (DKHW) can be applied to single and multi-port submerged discharges, which can be used in a three-dimensional setting. The program itself is a Fortran executable that is known as VP by demand. The model solves equation for plume size, trajectory, temperature and concentration using the Eulerian integral method, where the distance is considered to be an independent variable, unlike the Lagrangian formulation, where time is considered to be the independent variable (Baumgartner et al., 1994). By utilizing this approach, DKHW is able to provide detailed calculations in fully developed zone, as well as the Zone of Flow Establishment (ZFE) (Baumgartner et al., 1994). The model also considers gradual merging neighboring plumes in its computation proceedings.

UM3 is a Lagrangian model that utilizes the projected-area-entrainment (PAE) hypothesis, which quantifies subjugated entrainment and the rate at which mass, is integrated into the plume. The plume under such circumstances is assumed to be steady state. Under Lagrangian circumstances, this means that the continual elements will also follow a similar trajectory (Baumgartner et al., 1994).

METHODOLOGY

In theory, the dilution capacity of open waters, particularly coastal areas, straits and oceans are assumed to be approaching infinity (ambient concentration) (Davis, 1999). This means that for surface and sub-merged point source discharges, the effluent concentration (C_e) will cause insignificant change in the overall ambient water quality. Instead, C_e will eventually reach C_a (ambient concentration) over a spatial distance (vertical and horizontal). This distance is of interest with regards to water quality preservation efforts so that the macro level distribution characteristics of the pollutant species in question can be determined (Frick and Winiarski, 1976). The travel distance (l_t) is a main function of ambient current velocity (m/s) and direction (Merz, 2004). Prior to the modeling exercise, field data pertaining to ambient water quality, hydraulic characteristics and

Table 1. Variable discharge quality simulated.

BOD (mg/l)	COD (mg/l)	TSS (mg/l)
50, 100, 250, 500	500, 700, 1000, 1500	50, 100, 300, 500

Figure 1. Study area (Sipitang District, Sabah).

tide patterns were collected (Rawn et al., 1960). Several scenarios that were simulated include:

Variable maritime hydraulic conditions

This is variation in ambient velocity to determine maximum plume centerline distance (from diffuser) at 0.108 (field-measurement), 0.216 and 0.500 m/s at a trajectory towards most sensitive receptor (Brunei waters).

Proposed operating conditions

This is submerged discharges (1 diffuser, 40 m port spacing) with variable discharge quality (Table 2) at proposed flow of 0.6667 m^3/s at ambient velocity of 0.5 m/s and low-tide conditions (minimum depth of diffuser).

Worst case scenario

This is submerged discharges (1 diffuser, 40 m port spacing) with variable discharge quality (Table 1) at 5.0 m^3/s with ambient velocity at 0.5 m/s and low-tide conditions (minimum depth of diffuser). The coastal dispersion modeling exercise is based on existing submerged diffuser located parallel to the study area jetty (Figure 1). Modeling assumptions, among others are:

1. Buoyant plume characteristics (in accordance with the DKHW model).
2. The plume is heterogeneously distributed.
3. The plume movement and dispersion is in line with the DKHW and UM-3 mathematical considerations.

RESULTS AND DISCUSSION

Based on the maritime hydrological survey conducted, the following plume distribution pattern was generated from the visual plumes (VP) DKHW modeling exercise. It was observed that even under worst-case-scenario conditions with maximum tidal velocity of 0.500 m/s towards the north-east (Brunei waters), the plume would only travel a maximum distance of about 30 m before hitting the surface (Figure 2). Not surprisingly, an increase in

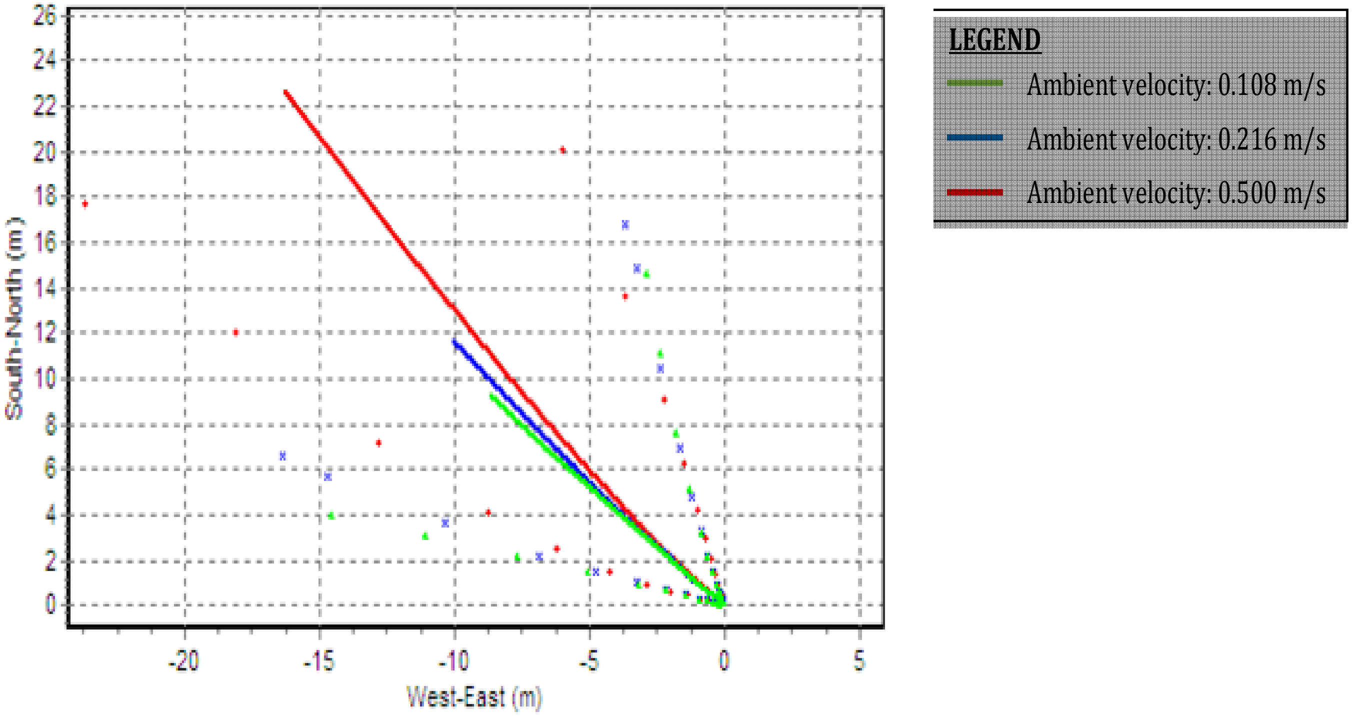

Figure 2. Plume movement from source (DKHW Model).

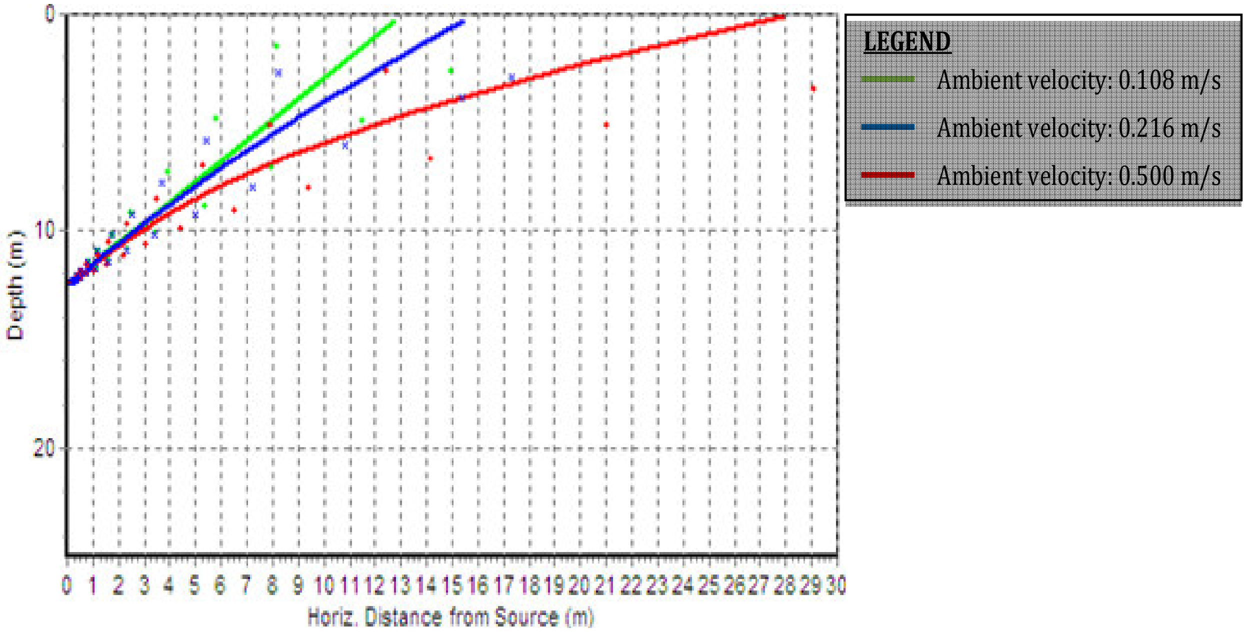

Figure 3. Plume horizontal distance from source (DKHW Model).

ambient velocity resulted in a larger spatial distance prior to hitting of the surface (Figure 3). Although, this may be the case, an increase in plume diameter (boundary) and thus pollutant distribution was observed. The maximum plume diameter was modeled to be at approximately 17.83 m. Comparison with the UM-3 (less conservative model, built more specifically for estuarine conditions) resulted in a similar outcome (Figure 4), albeit a smaller

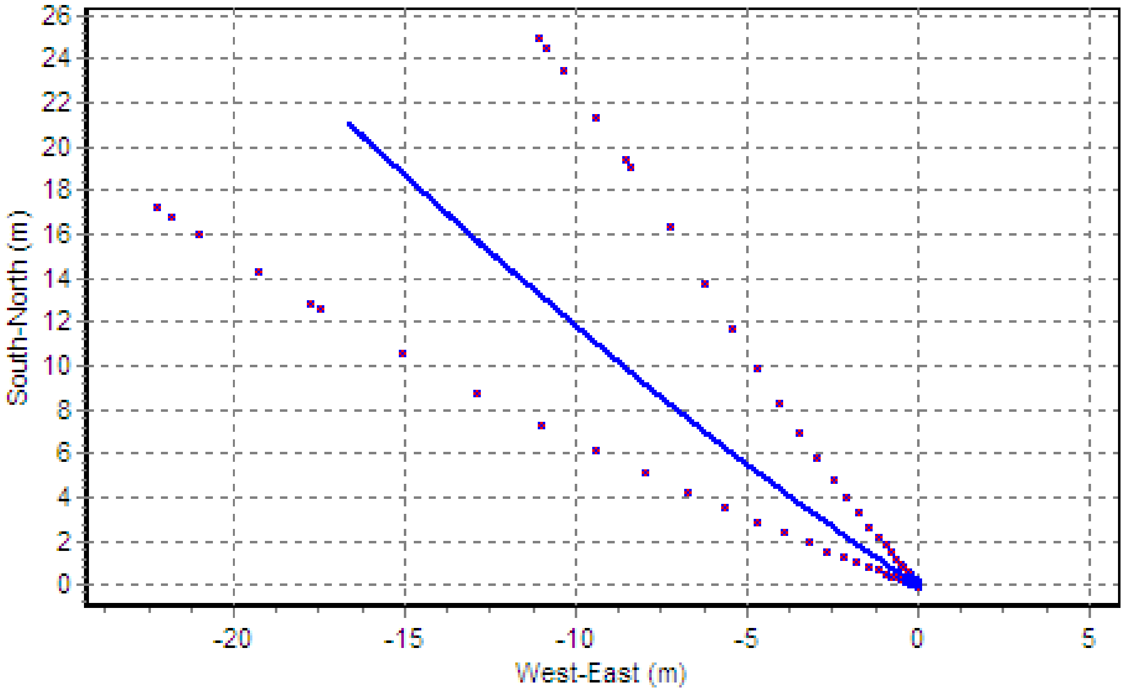

Figure 4. Plume movement from source (ambient velocity = 0.500 m/s, UM-3 Model).

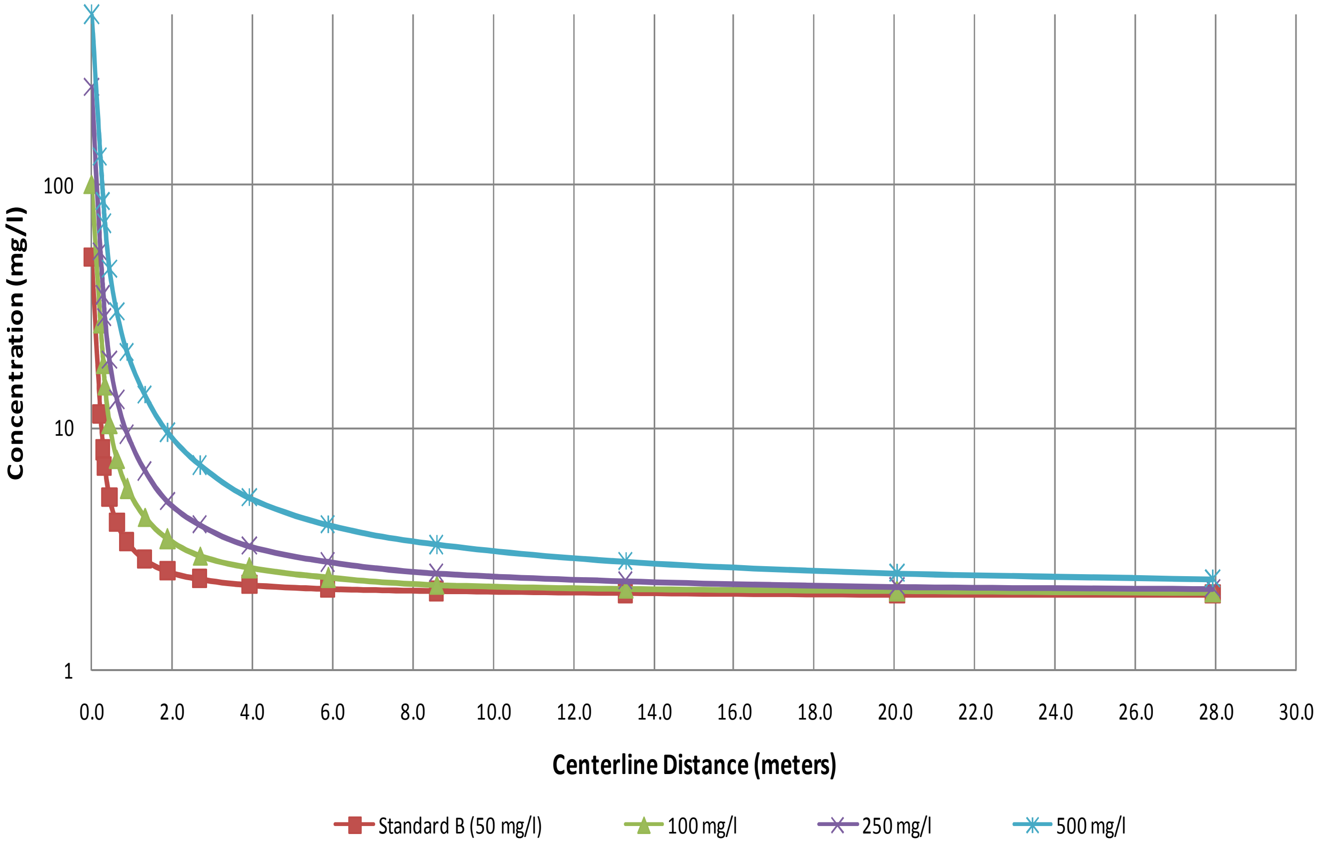

Figure 5. BOD_5 dilution change with centerline distance (proposed discharge flow, Q = 0.6667 m^3/s).

Table 2. Predicted surface BOD_5 concentration for various effluent discharge qualities at normal discharge flow (0.6667 m^3/s).

Centerline distance (m)	Standard B (50 mg/l)	100 (mg/l)	250 (mg/l)	500 (mg/l)
27.93	2.03	2.07	2.14	2.36

plume diameter (13.53 m) was seen.

For BOD_5, the VP modeling results indicated that an increase in operational capacity of the pulp and paper mill would not result in a detrimental increase along the center-line (Figure 5). Only in the event of a failure of the treatment system, with BOD_5 effluent being released at 250 mg/l (and higher) would a significant change along the centre-line be observed, before subsequent surface penetration. This immense dilution potential was consistent with other studies such as by Merz (2004), where dilutions from outfall were predicted at a ratio of 160:1. The ambient BOD_5 near surface concentration increase (ΔC) for this scenario was approximately 0.40 mg/l. This constituent simulation as well as the proceed-ings was based on the worst-case-scenario assumption with a tidal velocity of 0.500 m/s.

Referring to Table 2, even if the effluent BOD_5 was released at 500 mg/l, the effects upon hitting the water surface would be relatively marginal, with no distinctive difference as compared to the Standard B and 100 mg/l scenarios. However, the contemporary effluent quality compliance of 20 mg/l should be maintained, to avoid organic pollutant build-up in the long run and avoid over-nitrification of the bay area (Sawyer et al., 2003).

Conclusions

The modeling results indicated that there would not be a significant change in ambient concentration for all constituents modeled when the effluent discharge is increased from 1,500 m^3/h to 2,400 m^3/h, as long as the current quality is maintained. The plume travel distance would also not entrain into foreign waters as long as proposed volumetric discharge rate is not violated. It is recommended therefore that the BOD_5 discharge quality should not exceed 20 mg/l, COD should not exceed 250 mg/l and TSS should not exceed 50 mg/l to maintain the current ambient quality. Albeit, being the case, the pulp and paper mill is advised to review its current COD discharge quality of about 250 mg/l as is still relatively high. Since COD encapsulates various other chemically oxidizable parameters, decrease of this constituent will no doubt reduce the impact of other constituents not modeled towards the bay area as well as diminish organic build-up and bio-accumulation.

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