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Research paper

Determining the maximum sediment dispersion in an ocean disposal site for dredged material in Buenaventura, Colombia

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Abstract

This paper presents an analysis of the affected area at an ocean disposal site, in terms of sediment dispersion, as a consequence of the disposal of dredged material from the approach channel for Buenaventura´s Port. The analysis was carried out at three points within Buenaventura´s Bay, one located at the authorized disposal site, a second point at a proposed future disposal site and a third point at the Bocana Sector, where the highest tidal velocities are identified. The PTM (Particle Tracking Model) mathematical model was used for this investigation, showing that due to the hydrodynamic conditions, a sediment particle can reach a longer dispersion distance from its original disposal point. Finally, sediment dispersion at the three analysis points were compared in terms of current velocity and maximum displacement.

Keywords: *Disposal Site; Dredged Material; Sediment Dispersion; Tidal Velocity.*

1. Introduction

Buenaventura´s port is the main port of Colombia; it is located along the Pacific Coast and it handles an import/export cargo of nearly 15 million tons per year. The port has an approach channel of nearly 34 km in length, divide in two sections: Inner Channel (from K0 to K15) and Outer Channel (from K15 to K34).[1]

The approach channel is maintained annually by the execution of a maintenance dredge work in order to keep the navigation channel in its design conditions, both in width and depth. These maintenance dredge works remove a volume of approximately 2.2 million m^3 of sediments along the navigation channel and take approximately 2 months to be fully executed. Since it is a high volume of sediment material, there is an authorized disposal area located at open sea at nearly 35 km from Buenaventura's Port.

It is of vital importance to quantify the effects generated by the disposal of this great volume of sediments in the disposal area; therefore, the sediment dispersion when the dredge disposes the material was studied. A wide dispersion of sediments can lead to undesired environmental effects, affecting microorganisms and the general environmental dynamic of the area. [2]

In this investigation, the sediment dispersion distance within the authorized disposal area was analyzed through numeric 2D modelling. Two other points within the bay area were analyzed as well; one corresponding to a proposed future disposal site located at a greater depth than the current disposal area, and another point located at the Bocana Sector where the highest current velocity magnitudes are identified. This last point served as a control point for this investigation.

2. Background

The impacts caused by dredging works, including the disposal of dredged material, can be simulated by different numerical models. Models used by other investigations relate the marine dynamics with the sedimentological behaviour, Coastal Modeling System SMC [3] [4], MIKE21 [5] Short-Term FATE STFATE [6]; however, this models tend to be highly complex and require a lot of information in order to be applied.

The majority of numeric models are based in the relationship between environmental impact and the sediment plume, such is the case of the PTM numeric model [7]

None of these models have been designed with the capacity of choosing both the method and area for the final disposal site, however, they allow to determine the disturbance in terms of sediment transport. [8]

3. Problem conceptualization

Due to the imminent insufficiency of the current disposal site for dredged material, it is necessary to select a new disposal site that has the capacity to receive the high volume of sea bottom material that will be dredged from the approach channel in Buenaventura's Port. In accordance to the environmental criteria, it is required to check the effects that the disposal of dredged material would have [9], in terms of maximum sediment displacement, in the different oceanic sites where the dredged material may be finally disposed [10]. Figure 1 shows a general location of the current disposal site and the new proposed disposal site within Buenaventura's Bay Area.

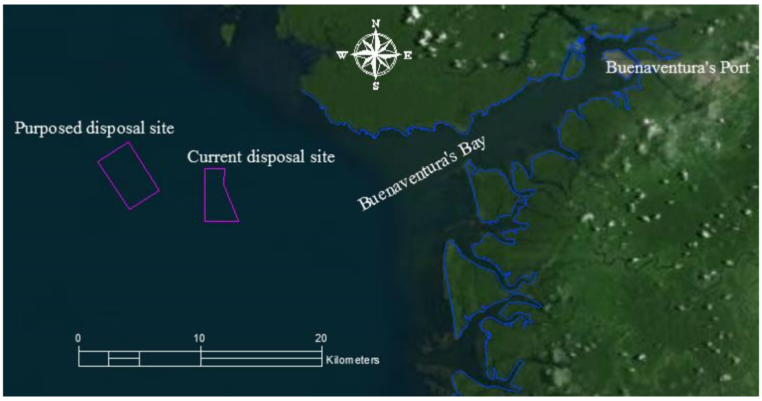

Fig. 1: Current Disposal Site and Proposed Disposal Site at Buenaventura's Bay Area.

The sediment displacement was analyzed in three different sediment discharge points; as shown in Figure 2. The first discharge point serves for illustrative purposes, as it allows to observe how sediments move back and forth due to the hydrodynamic conditions of a point where the maximum tidal velocities occur (P1); in this case, the purpose is to analyze the paths traveled by the sediment particles using the PTM numeric model. The other two discharge points will simulate the sediment displacement due to tidal velocities at the current disposal site (P2) and at the new proposed disposal site (P3). [11]

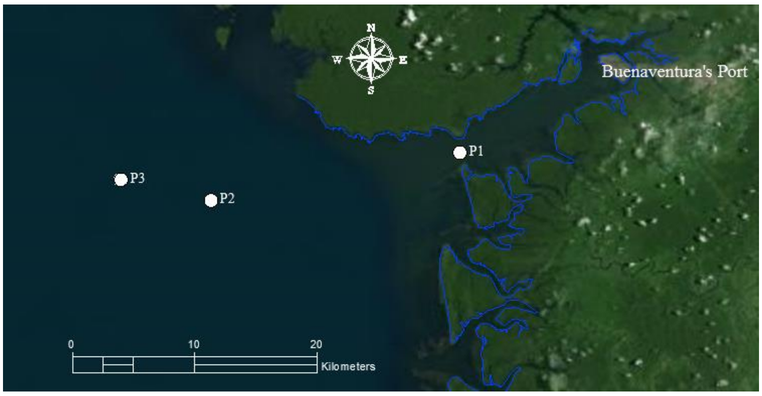

Fig. 2: Location of the Three Sediment Discharge Points for PTM Numeric Model.

4. PTM numeric model

PTM (Particle Tracking Model) is a numeric model attached to the SMS (Surface-water Modelling System) developed by Aquaveo; it serves as computational program that models different transport processes (advection, diffusion, settling, deposition and resuspension) for a determined source, such as: sediments, pollutants and biological elements. [12]

PTM is not hydrodynamic software, on the contrary, it feeds from the hydrodynamic results of other models and determines the sediments' position in terms of its X, Y position and time. PTM offers three calculation options, which are: 2D, quasi-3D and 3D. As of its latest version, the model shows the particle's movement based on hydrodynamic conditions that are vertically integrated (i.e. 2D). PTM has two basic components, the first one named "Eulerian Transport Calculations", which describes the processes affecting bed particles. And the second component named "Lagrangian Transport Calculations", verifies the direction of the processes that determine the particle's movement, such as: mobility, advection, dispersion and settling.

Within the component of "Eulerian Transport Calculations", the model carries out the following calculations:

Roughness characterization: Calculated from the D50 and D90 diameters of sediment particles.

Shear stress: Calculated as a function of the bed flow velocity. PTM applies methods described by Van Rijn (1993) to calculate the bed shear stress, as shown in the following equation.

$$T_c^{'} = \frac{\rho U}{C''^2} \tag{1}$$

Where, ρ stands for the water density, U is the depth-averaged velocity, and C is the dimensionless Chezy's coefficient, which, for turbulent flow, is approximately equal to:

$$C^{"} = 2.5ln\left(11\frac{h}{ks}\right) \quad (2)$$

Where, h is the water depth and ks is the roughness height.
Initiation of movement: Based on the dimensionless Shields parameter, as shown in the following equation:

$$\theta_{cr} = \frac{\tau_{cr}}{\rho g(S-1)D} \quad (3)$$

Where, $\square_{cr}$ is the dimensionless critical Shields parameter, $\square_{cr}$ is the critical shear stress, g is the gravitational acceleration, S is the relative density ratio of the particle and D is the characteristic grain size.

Mobility: The particle´s mobility is a dimensionless parameter that relates both the acting bed shear stress and the critical shear stress to generate movement, as shown in the following equation.

$$M = \frac{\theta}{\theta_{cr}} \quad (4)$$

Where, $\square$ is the dimensionless Shields parameter and M is the dimensionless mobility.
In addition, the model calculates the position of sediment particles with the following equation:

$$X' = xn + \frac{1}{2}(u_a dt + u_d dt) \quad (5)$$

Where, x is the particle's position one-half time-step into the future, x_n is the particles location at time-step n, u_a is the advection velocity and u_d is the diffusion velocity. [7]

5. Results and discussion

5.1. Sediment dispersion

The simulations using the PTM were done based on the characteristics from the sediments located in the study area, which were determined by particle size analysis of soil samples from the ocean bed. The particle sizes used for this research are shown in Table 1.

Table 1: Particle Size Distribution of Sediments Used for Numeric Modelling

Distribution	Diameter
D30	0.23 mm
D50	0.43 mm
D90	3.43 mm

Punctual discharges of sediments were simulated over the three evaluation points along the bay. The sediments discharge combined with hydrodynamic results of water velocity, were simulated until the model showed that the sediment particles reached a spot where they were no longer moving due to current velocity.
Figure 3 shows the results of the particles' movement for the three points evaluated, as well as the diameter distribution of the particles and their distance travelled from the starting point of sediment discharge.

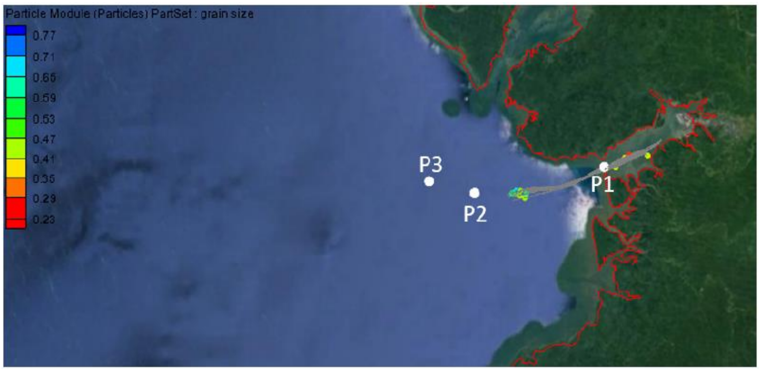

Fig. 3: Results for Movement of Sediment Particles.

As shown in Figure 3, once the sediments are disposed in point P1, the tidal currents displace the particules in an occilating pattern 15 km towards the inner bay area and then 15 km towards the outter bay area. The sediment particles that have a diameter of up to 0.6 mm are carried by the tidal currents towards the outter bay area. Results at P1 were as expected, due to the high tidal velocities in that point, it served to verify that the model was correctly reproducing the particle´s movement.
Meanwhile, sediments that are disposed over points P2 and P3 don´t show mayor displacement or motion, because the tidal currents in these two points are extremely low. For a disposal site located at point P2 the maximum distance of sediment dispersion is 45 m; meanwhile for disposal site at P3 the sediment dispersion was of up to 4 m from its starting point of discharge.
Figure 4 shows the maximum sediment dispersion for the smallest size particle in the currently authorized disposal site (point P2) and in the proposed disposal site for future dredge works (point P3).

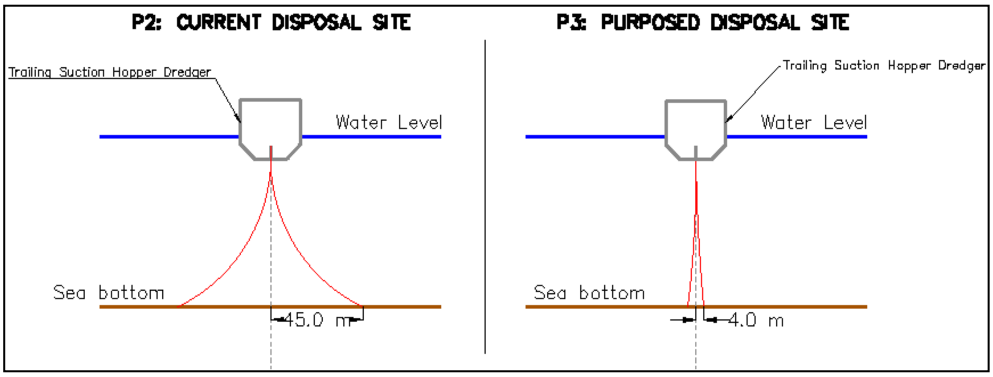

Fig. 4: Maximum Sediment Dispersion for Current Disposal Site (P2 = 45.0 M) and Proposed Disposal Sited (P3 = 4.0m).

5.2. Tidal velocities

Figure 5 shows the velocity map for the highest tidal velocity simulated by 2D modelling of Buenaventura´s bay area, whereas Figure 6 displays the velocity time series for the analysis points P1, P2 and P3 for a two months simulation period. Both figures show that the areas corresponding to the current and proposed disposal sites, have very low tidal velocities which leads to a low sediment dispersion once the dredged material is discharged. However, point P1, located at the Bocana Sector, is exposed to high tidal velocities throughout the simulation, explaining its extremely high sediment dispersion (up to 15 km).

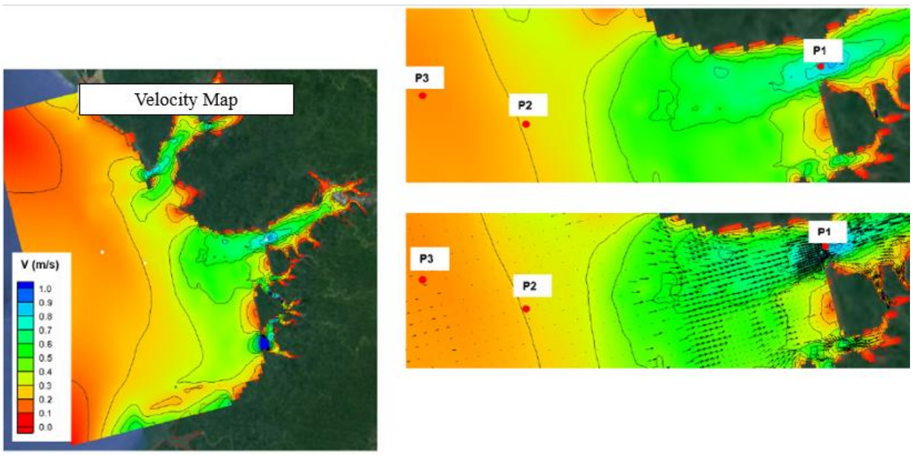

Fig. 5: Velocity Map (Magnitude and Vectors) at the Analysis Points P1, P2 and P3 In Buenaventura´S Bay Area.

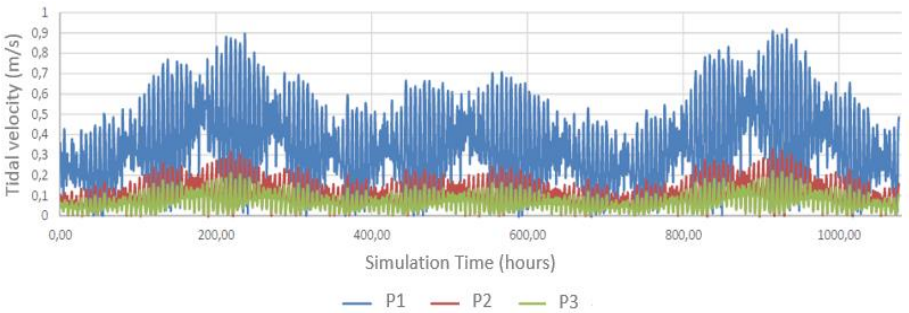

Fig. 6: Velocity Time Series for Analysis Points P1, P2 and P3.

6. Conclusion

The PTM numeric model can be applied to estimate de maximum sediment displacement at a particular discharge point within a bay area. It applies the hydrodynamic conditions, such as tides and currents, and calculates the particles movement based on its critical shear stress, critical velocity and particle size.

For this investigation the PTM was applied as a tool to determine whether or not the disposal of dredged material at an oceanic disposal site, causes the sediment particles to spread at high distances from its original point. Results showed that for the current disposal site at Buenaventura’s Bay Area, once the dredged material is disposed the sediments can have a displacement of up to 45.0 m from its original disposal point. In this current disposal site, tidal velocities are of much lower magnitude as those shown at the Inner Bay Area.

As for the proposed disposal site, since the tidal velocities are even lower than those shown at the current disposal site, the maximum sediment displacement calculate is 4.0 m. Based on these results, the sediment dispersion within a bay area is higher for points where tidal velocities are higher.

Therefore, the dredged material from an approach channel must be disposed at an area of low tidal velocities in order to assure a low sediment displacement, this would translate in lower environmental impacts and will assure that sediments will not be transported back to the approach channel.

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