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PHILIPPINE ENVIRONMENTAL GOVERNANCE 2 PROJECT (EcoGov 2)

DEVELOPMENT OF A DAVAO GULF HYDRODYNAMIC MODEL IN RELATION TO POLLUTION DISPERSAL

May 2009

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by: Cesar L Villanoy

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DEVELOPMENT OF A DAVAO GULF HYDRODYNAMIC MODEL IN RELATION TO POLLUTION DISPERSAL

by

Cesar Villanoy

INTRODUCTION

Davao Gulf is one of the biggest embayments in the country with a total surface area of about 6,600km^2 and depths of more than 2000m near the mouth. The total coastline length is about 500km and is bounded by four different provinces, namely; Compostela Valley, Davao del Norte, Davao del Sur, and Davao Oriental. The large catchment of the rivers that empty into the gulf implies that riverine inputs into the gulf may carry with it significant amounts of pollutants and sediments from the different activities conducted upstream of the rivers. In addition, the regional center, Davao City also lies along Davao Gulf and may contribute to problems of solid waste and sewage discharges into the Gulf. The purpose of this study is to develop a hydrodynamic model for the northern Davao Gulf area, to describe the surface circulation in general terms and to demonstrate the potential fate of pollutants released at different locations around the gulf. This is an initial step in establishing the linkages between the watershed and the coastal waters of Davao Gulf. Models such as these are also useful in assessing the vulnerability of coastal systems to pollution and on longer time scales, climate change. It should be noted however that this simplified model has not been validated with field data. Although the data used to force the model are based on the best available information, actual field data for validation purposes are not available.

METHODS

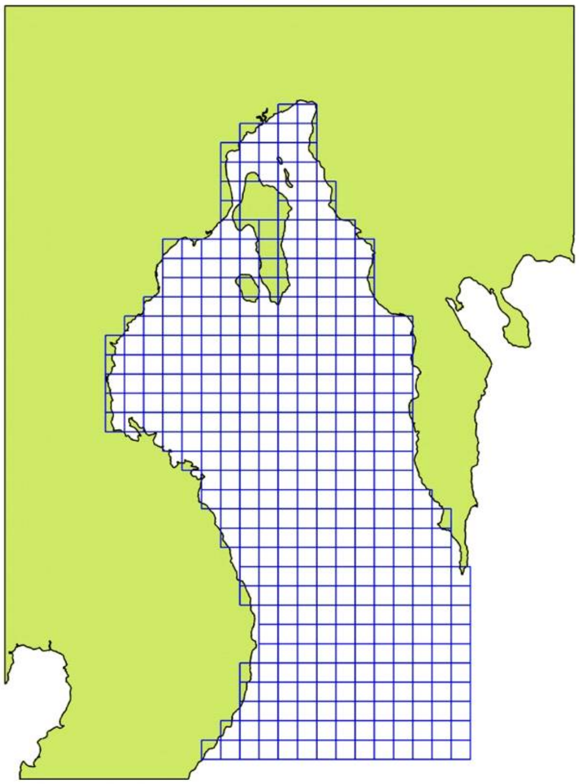

Figure 1. Davao Gulf coarse grid model grid.

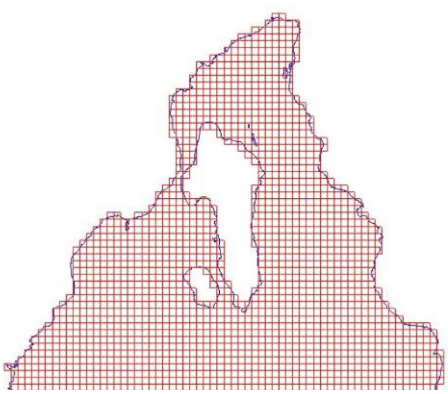

Figure 2. Davao Gulf high resolution nested grid.

Hydrodynamic flow patterns for Davao Gulf were modeled using a nesting scheme. An initial coarse-resolution model, with a grid resolution of 4.5km encompassing the entire gulf, was used to generate the currents for a 1.2km resolution model, which spanned the northernmost part up to the area south of Samal Island (Figure 1). Bathymetric data was obtained by digitizing bathymetric charts. Two types of forcing were used for the coarse-resolution model, namely large scale wind forcing with the use of the Navy Layered Ocean Model (NLOM) model output, and tides, which were modeled using DELFT3D-FLOW.

Runs for the two types of forcing were done separately, and the results were combined to generate a time-series of boundary currents which were applied to the higher resolution model Figure 2), which was also run using DELFT3D-FLOW. This model also included surface wind forcing with data obtained from the Davao, Philippines local weather station (source: http://www.underground.com).

Discharge from Davao River was also considered, with volumetric flow rates, flow velocities, and sediment input data obtained from local monitoring efforts. Figure 4 shows estimates of Davao River discharge data from gauge data. Although the estimates have data gaps, it is fairly obvious that there is a slight seasonal signal with higher discharge on the latter half of the year. In 2003, highest discharge was observed during the southwest monsoon but in 2004, the highest discharges were observed during the start of the northeast monsoon. The average discharge for the entire measurement period was $61m^3s^{-1}$ and this value was used in the hydrodynamic model runs.

No discharge data was available for the other rivers and were not consequently included in the model runs.

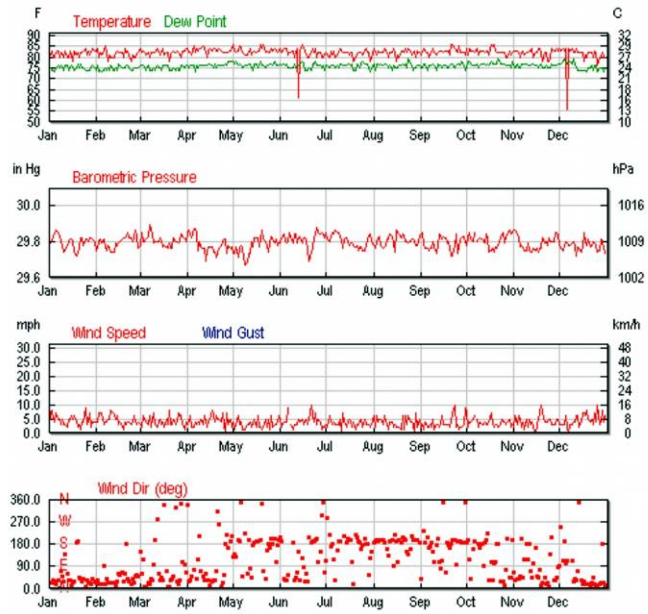

Figure 3. Weather data from Davao City for 2008 (source: www.weatherunderground.com).

With the resulting model output for the high resolution model, three types of dispersal experiments were conducted. For the first type, the Davao River outflow was used as a source point for a conservative tracer in DELFT3D-FLOW. The river was modeled as a continuous source of the tracer with a fixed concentration, and the evolution of the tracer plume over time can then be observed and quantified. The second type involved extracting the hydrodynamic currents from the DELFT3D model for use in the GNOME oil spill model. This particle-tracking model was used to simulate the dispersal of floating solid waste. Although the river may be an important source of solid waste, it is also likely that non-point sources exist along the city coast. As a result, a line source was used in the simulations extending almost across the whole coastline length of Davao City.

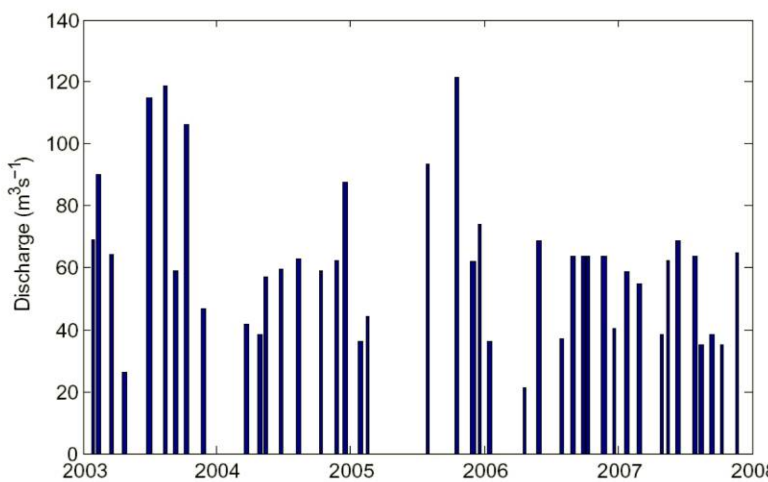

Figure 4. Estimates of Davao River discharge from gauge measurements (data source: DPWH XI).

In the third type of dispersal experiment, the DELFT3D-FLOW model was configured to use the Davao River outflow as a source of sediment input into the gulf. Monitoring data was averaged to determine the sediment concentration for the modeling experiment, which set the river outflow as a fixed-concentration, continuous release point of sediments. Default sediment parameters (settling velocity, non-cohesive nature of sediment, etc.) were used, and background erosion and sedimentation rates were minimized to isolate the effect of the river source. With this model, the dispersal of the sediment plume can be observed over time, and the areas of considerable sediment accumulation can be identified.

RESULTS AND DISCUSSION

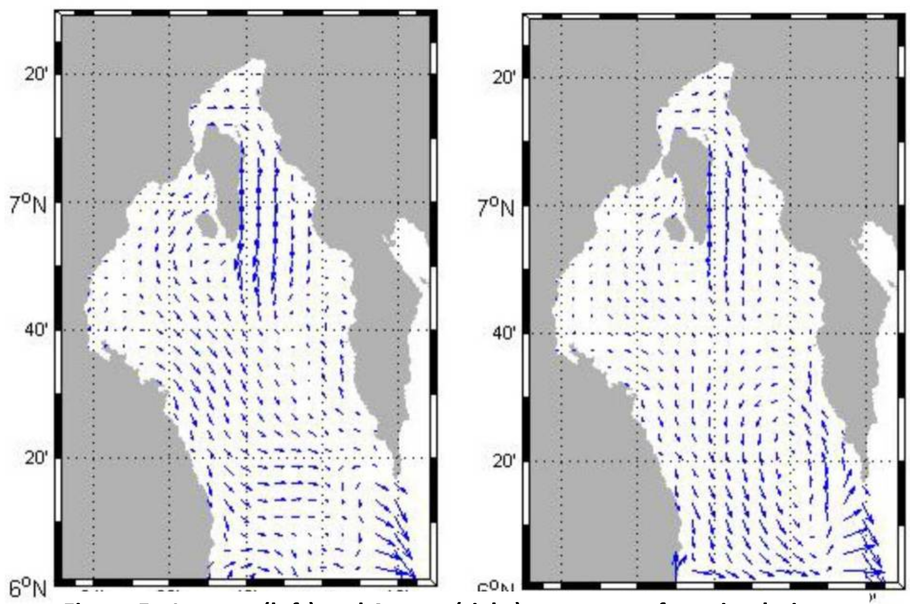

Figure 5. January (left) and August (right) average surface circulation.

The gulf-wide seasonal surface circulation of Davao Gulf is shown in Figure 5. The surface circulation typically contains significant daily variations due to the daily boundary forcing as well as tidal forcing. The plots shown in Figure 5 and Figure 6 represent the 15-day averaged surface velocities, and thus represent the residual flow if the tides are removed. During January, the prevailing northeast monsoon drives a predominantly southward flow throughout most of the Gulf with slight northward flow along the western side of Samal. Net flow around Samal is counterclockwise. During August when the southwest monsoon is blowing, the surface circulation is still predominantly to the south albeit a little weaker. Larger differences occur in the southern portion of the Gulf close to the opening to the Sulawesi Sea. A larger recirculation gyre forms near the mouth during August. During weak wind conditions (e.g., April simulation), the circulation in the northern half of the gulf is very weak with a stronger recirculation in the southern half.

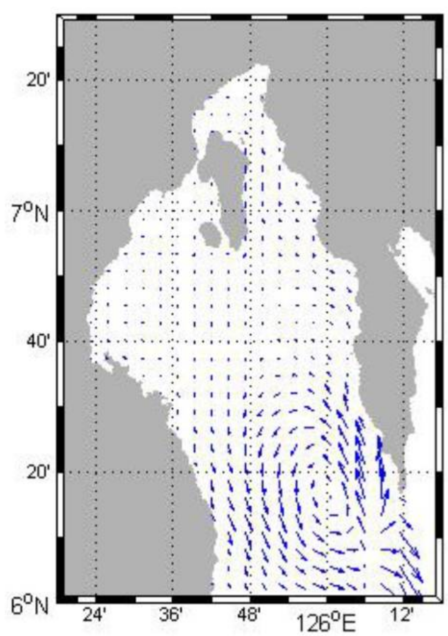

Figure 6. Davao Gulf April average surface circulation.

The velocity plots in Figure 7 to Figure 9 show the residual surface currents using the nested model. Note that much more detail in the circulation patterns are evident because of the higher resolution. There is more variability in the flow in the east of Samal Island where northward flow is evident for January and April. For both monsoons (January for northeast monsoon and August for the Southwest Monsoon), the net flow east of Samal Island is southward. Surface flow along the southern boundary of the model is northward in the eastern and western sides with southward in between. The strongest flow occurs during August and the weakest during April. Note that these figures are based on averaged daily velocity fields for the month and that significant day to day variations can be observed in the model. Animation files of surface circulation are included in this report to show the degree of spatial and temporal variability of the surface current field. Net flow through the narrow channel between Davao city and Samal Island appears to be northward for all the three months considered.

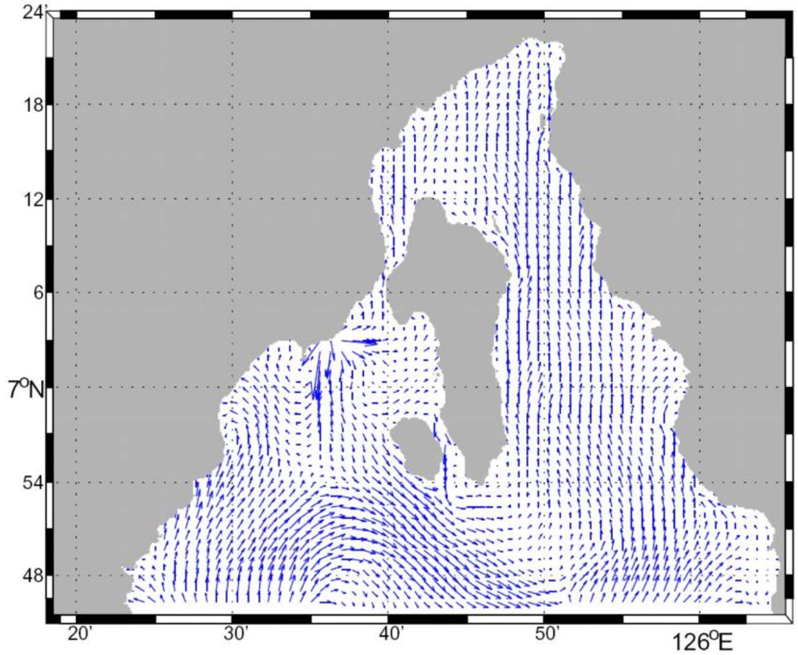

Figure 7. Averaged surface current velocity field for January.

Davao River is one of the greatest contributors of freshwater into the Gulf. The discharge of Davao River can range from 20-120m^3s^{-1} (Figure 4) and drains area of 1700km^2. The average discharge is about 60-70m^3s^{-1}. Along with the freshwater discharge, Davao River also carries with it sediments eroded from the watershed as well as potential pollutants released to its waters as it traverses the watershed to the coast.

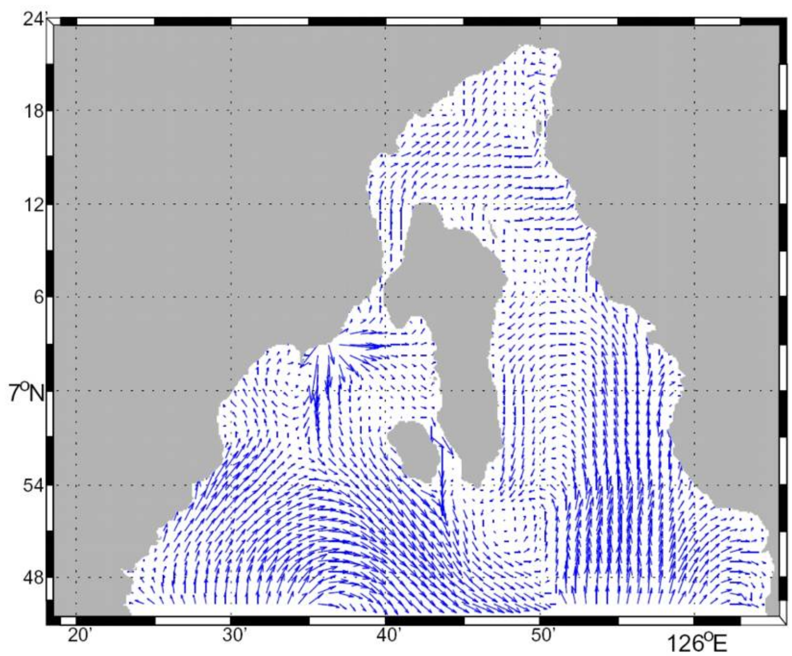

Figure 8. Averaged surface current field for August

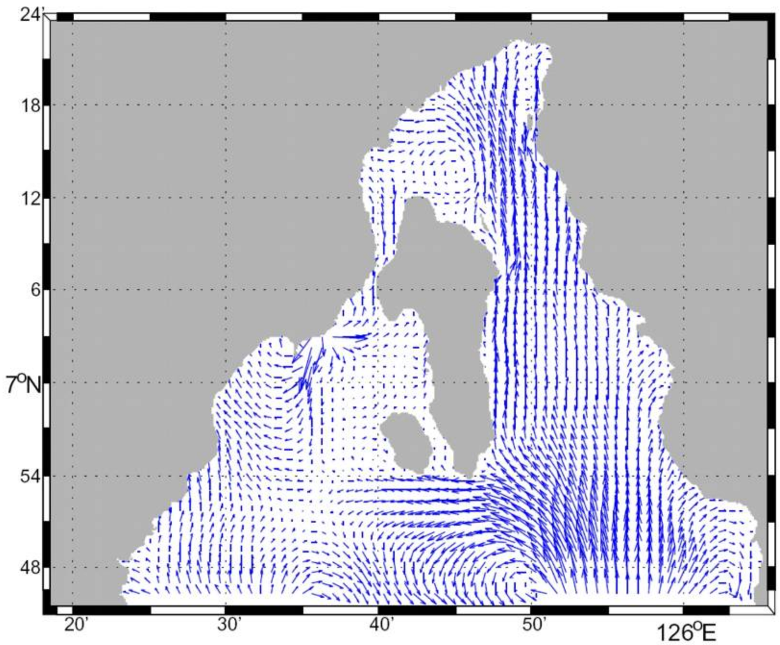

Figure 9. Averaged surface current field for April.

It is easier to visualize how pollutants from the rivers spread out into Davao Gulf by looking at distributions of surface salinity. Salinity in the ocean is a conservative tracer and hence their distribution and transport are based solely on advection by currents and mixing with waters of different salinity. Concentrations of conservative pollutants originating from the rivers follow closely the surface salinity distribution. Compare for instance the salinity distributions in Figure 10 and Figure 11 with the distributions of conservative pollutants released from the rivers in Figure 12 and Figure 13. Dissolved pollutants contained in river waters move towards the western coast of Samal Island during the southwest monsoon while during the northeast monsoon, the river discharge can spread both along the western coast of Samal and along the coast south of Davao City. Animations of the freshwater plume show that traces of river water mixed with gulf waters are even advected towards the eastern part of Samal Island from the south and then move towards the north. Table 1 presents some water quality data of Davao River from the Department of Environment and Natural Resources Monitoring Program.

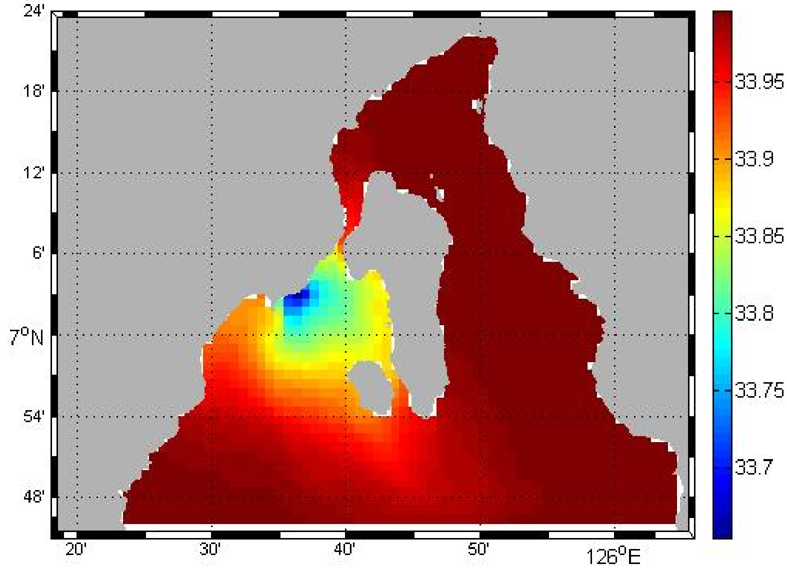

Figure 10. Mean surface salinity during January for model run incorporating freshwater discharge from Davao river.

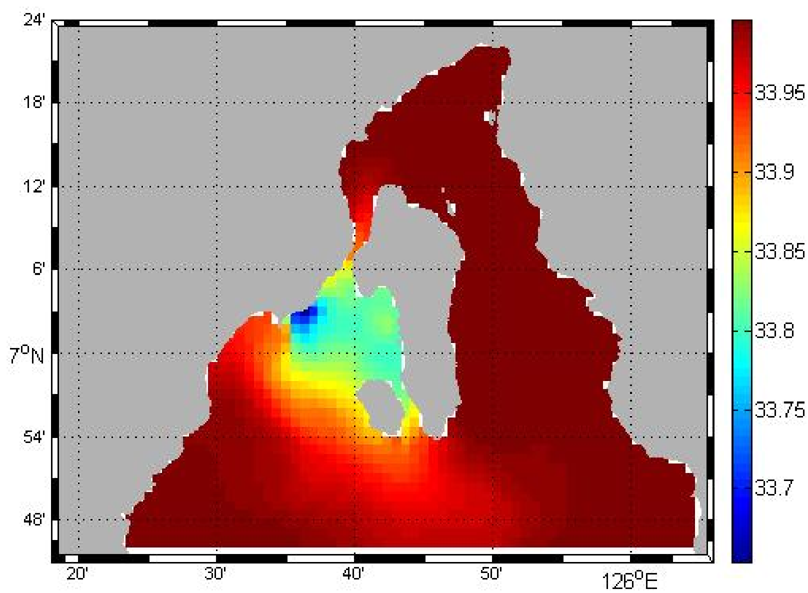

Figure 11. Mean surface salinity during August for model run incorporating freshwater discharge from Davao river.

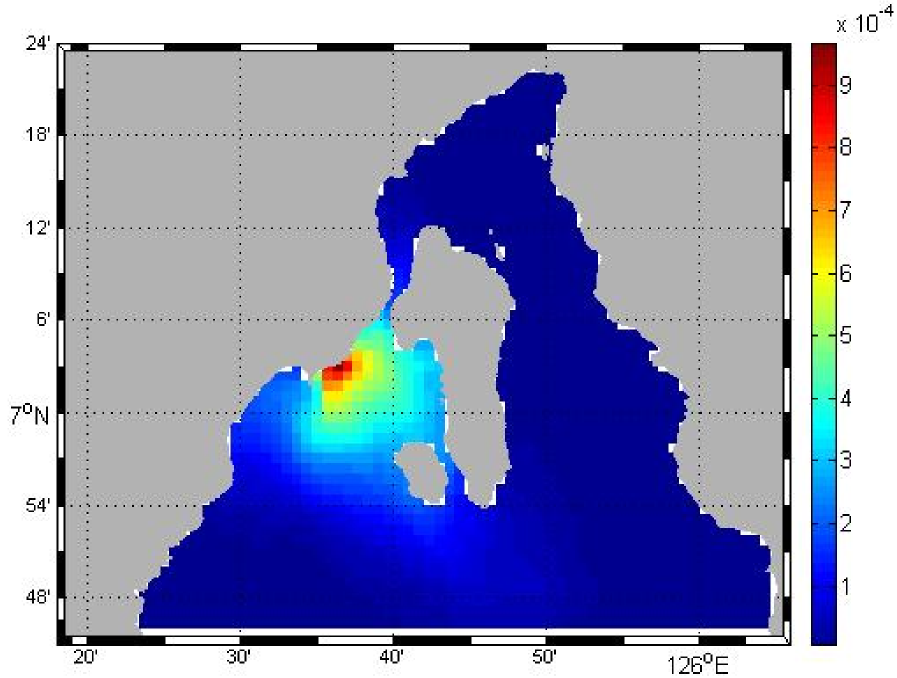

Figure 12. Surface concentration of a conservative tracer discharged from Davao River during January.

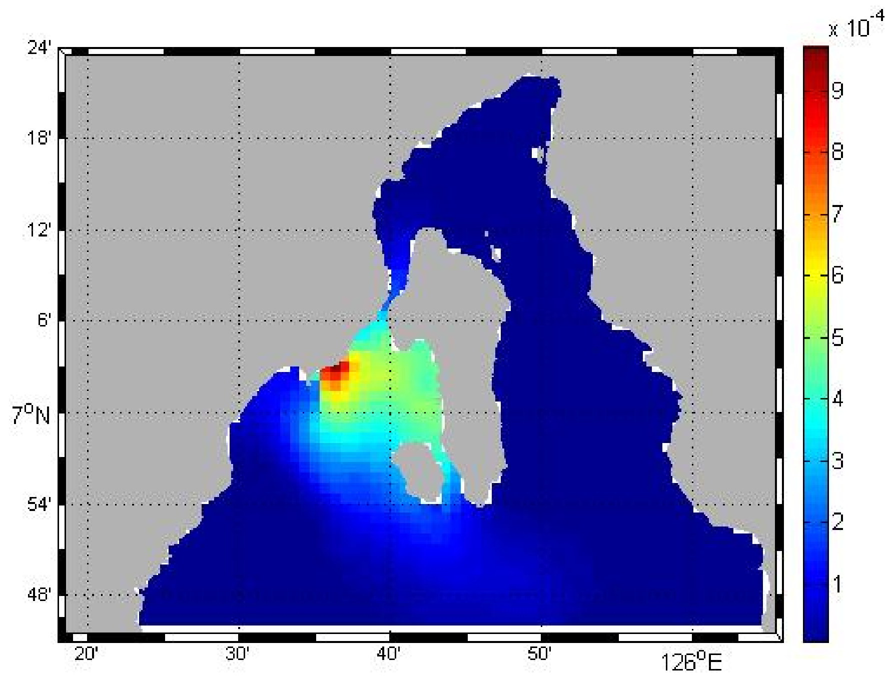

Figure 13. Surface concentration of a conservative tracer discharged from Davao River during August.

Table 1. Summary of water quality monitoring data from Davao River (source: EMB-DENR XI).

Republic of the Philippines
Department of Environment and Natural Resources
ENVIRONMENTAL MANAGEMENT BUREAU
Region XI, Davao City

DAVAO RIVER
(CY 2007)

Table 2a - Summary of Results

Parameter	Sta. 1	Sta. 2	Sta. 3	Sta.4	Min	Max	Ave.	DENR Standard Class B water
Color Units	4	4	4	4	1	10	4	No Abnormal Discoloration
Temperature, C	26	26	26	26	22	28	26	Max. of 3 C rise
pH	7.7	7.8	7.8	7.9	7.2	8.1	7.8	6.5 - 8.5
Dissolved Oxygen, mg/L	6.2	6.2	6.3	7.4	4.8	8.1	6.5	5.0
BOD (5 - day), mg/L	2.9	2.9	2.8	1.1	0.4	6.4	2.4	5
Total Suspended Solids, mg/L	177	169	187	164	7	709	174	Not more than 30 % increase

Simulated solid waste dispersal

For simulating the dispersal of floating solid waste, a Lagrangian model which tracks non-weathering floating virtual particles as it is carried by the currents was used. A line source was used extending along the urbanized coast of Davao City (Figure 14) as no well defined point source can be identified. The surface currents were obtained from the DELFT3D model described in the preceding section.

The areas most prone to receiving solid waste from the coast of Davao City is the western coast of Samal Island for almost all seasons (Figure 15). During the southwest monsoon, a significant part of particles released along the coast also end up in the area north of the narrowest channel between Davao City and Samal Island and even beyond (Figure 16).

Figure 14. Line source (solid black line) of simulated floating solid waste.

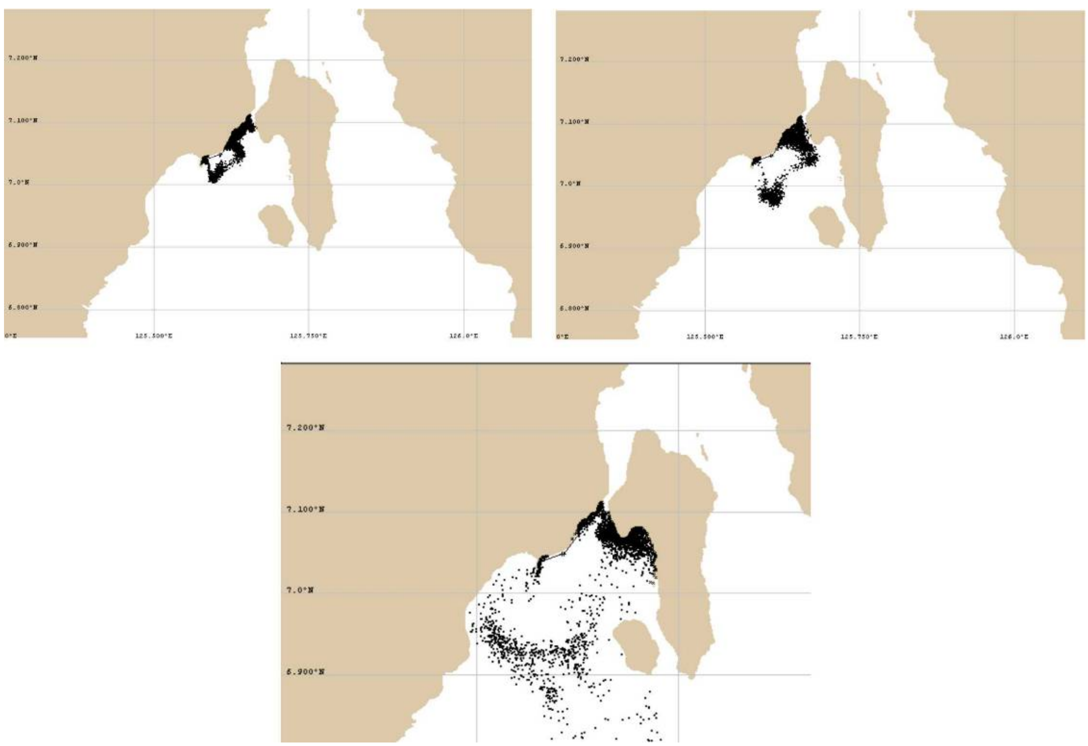

Figure 15. Dispersal of solid waste from the line source during January after 5 hours (top left), 12 hrs (top right) and 3 days (bottom).

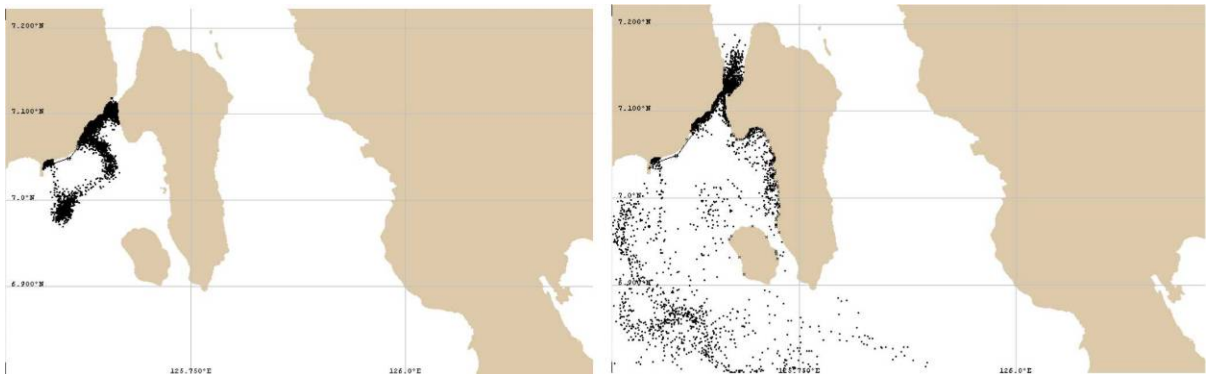

Figure 16. Dispersal of solid waste from the line source during January after 12 hours (left) and 4 days (right).

Sediment transport from Davao River

Davao River drains about 1700km^2 of watershed and together with the rest of the neighboring rivers, provides the sediment supply for the gulf. Estimates of the sediment supply from Davao River are shown in Figure 17. The maximum estimate is almost .07ppm s^{-1} or about 70kg s^{-1} but the average value is closer to 10kgs^{-1}. This is similar to the estimates in Tan and Guanzon (undated) of 5-10kgs^{-1} (Table 2). Using the above estimates for the sediment load of Davvao River, a cohesive sediment transport model also using DELFT3D was used and the sediment accumulation at the bottom after 30 days during January and August are shown in Figure 18 and Figure 19, respectively. The sediment load used for the August simulation was double that of the January simulation. Note that the highest sediment accumulation (6x10^{-3} cm for January and 15x10^{-3} cm for August) was limited to within 2-3 km along the coast adjacent to the river mouth. Traces of sediment deposition can be traced up to the western coast of Samal Island with accumulation of up to 2x10^{-3} cm over a period of 30 days.

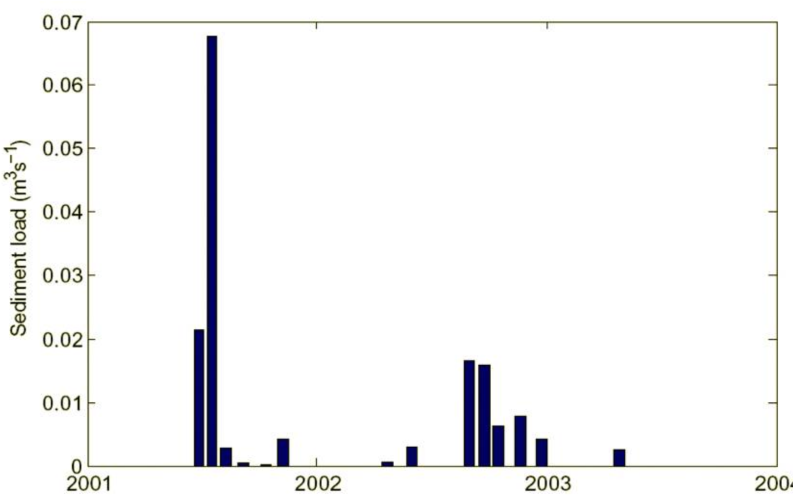

Figure 17. Estimates of Davao River sediment load (data source: DPWH XI).

Hodgson (1989) suggested that sedimentation reefs from 15-200mg cm^{-2} day^{-1} can be damaging to reefs. Tolerance to sedimentation however, is variable depending on the species. The sediment load used in the simulations are based on the average of 10kg s^{-1} and the maximum sediment accumulation shown in Figure 18 and Figure 19 is 0.015cm accumulation over the model time of about 22 days (allowing for sediment model spinup of 1 week). This value translates to a sedimentation rate of 1.8mg cm^{-2} day^{-1} and is significantly less than the suggested sedimentation rates detrimental to coral reefs. On the other hand, the highest Davao River sediment load measured is about 7 times higher that the value used in the model (Figure 17) and can conceivably result in sedimentation rates increasing to almost the lower limit of range suggested by Hodgson (1989) which can impact coral reefs.

Table 2. Annual mean discharge, sediment concentration and sediment load from Davao River from Tan and Guanzon (undated).

Year	Discharge (m^3s^{-1})	Sediment Conc (kg m^{-3})	Sediment Load (kg s^{-1})
2001	274	0.038	10.4
2003	198	0.027	5.3

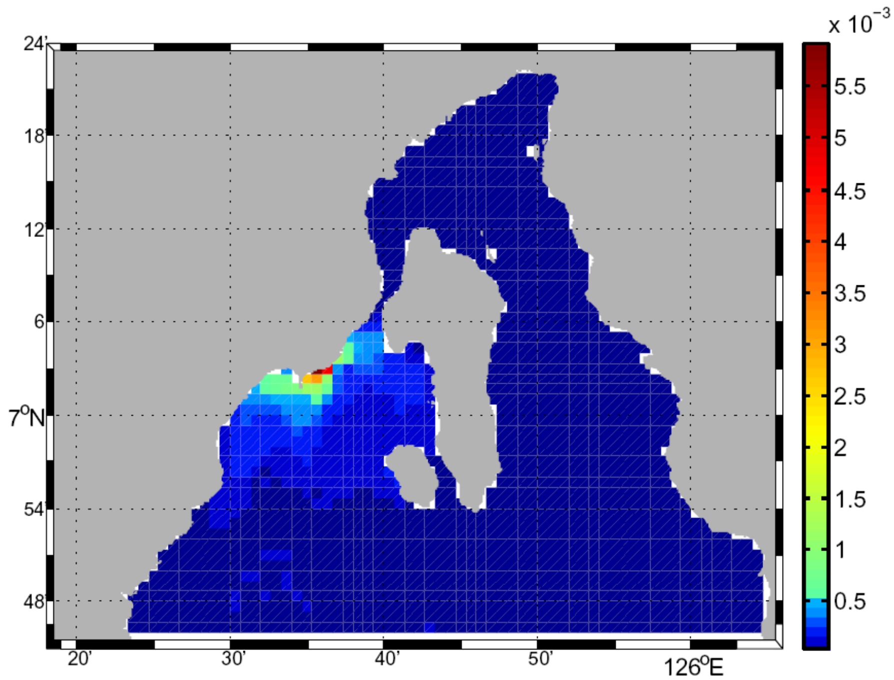

Figure 18. Sediment accumulation (in cm) at the bottom using January conditions with a Davao River sediment load of 10kgs^{-1}.

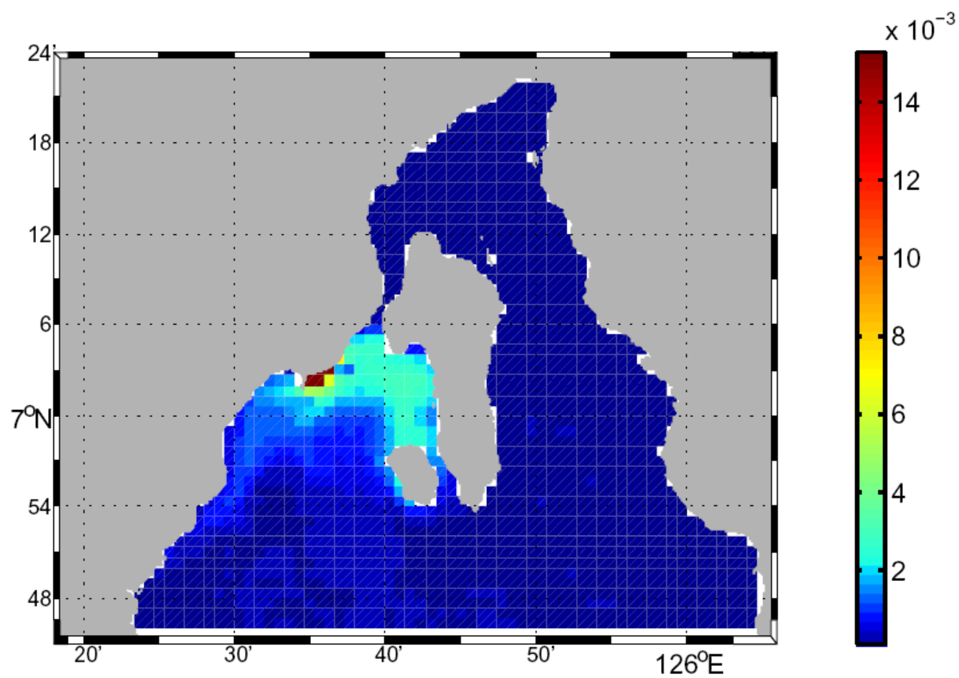

Figure 19. Sediment accumulation (in cm) at the bottom using August conditions with a Davao River sediment load of 20kgs-1.

SUMMARY AND CONCLUSIONS

A hydrodynamic model for Davao gulf using a nested DELFT3D model approach was developed and was used to drive the dispersal of 3 different types of pollutants. The first dispersal model simulates the dispersal of a conservative dissolved pollutant. The second model simulates the dispersal of floating solid waste and the third model is a cohesive sediment transport model. All models show the potential impact areas of waste coming from Davao River and along the coast of Davao City (for solid waste dispersal). The most likely coastal areas which can be affected by pollutants released along the abovementioned sources are the western coast of Samal Island, along the southern coast of Davao City and along the narrow gap between Samal Island and the mainland extending a few kilometers northward along both sides of the Channel. It is apparent that materials released with river discharge can be advected some diatance from the river mouth. In fact traces of river borne material in the model can be traced moving northwards along the eastern side of Samal Island. Perhaps, the important point shown by the model is that river systems and how it is mixed with gulf waters need to be considered in hydrodynamic and pollutant dispersal as pollutant advection can be influenced by river plume behavior. Davao Gulf contains several more rivers were not included in this study simply because no baseline data on discharge, sediment loads and water quality data were available.

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