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Coastal Sediment Transport and Environmental Management Analysis of the Dredging Activity of Maloma River in San Felipe, Zambales, Philippines

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Abstract **-** Maloma River is one of the three major rivers of Zambales that has been clogged by lahar since the eruption of Mt. Pinatubo. To mitigate the risks of flooding, the government has embarked on a rehabilitation of the river through a 60-hectare dredging project. However, the project needed more support from the local populace due to the potential environmental and social (E&S) risks of dredging that they have previously seen in the dredging of the Bucao River, another of the three major river basins. To address the concerns regarding potential coastal erosion, the researchers investigated the sediment transport for the assessment of coastal erosion of the Maloma River Rehabilitation Project. The study aimed to comprehensively analyze the dredging-influenced sediment dynamics of the Maloma River using Delft3D and recommend effective management strategies. To supplement the data from the EIA of the project, third-party data were sourced from corresponding institutions for oceanographic, meteorological, and sediment characteristics. In Delft3D-FLOW, one of the modules of Delft3D, the initial conditions used were applied to run simulations with a baseline bathymetry and another with a dredged bathymetry generated via ArcGIS. Among the six (6) observation points, sediment activities were apparent in the Maloma Bridge. The peak of cumulative erosion/sedimentation (m) from the baseline simulation coincided with the Habagat season. While for the dredged simulation, the cum. erosion/sedimentation sky rocketed suggesting Maloma Bridge was a dredging-induced hazard area. However, it must be noted that for both simulations, a persistent error of water level that was too high was prompted by the predetermined limitations of the study. As such, the researchers recommend further research including project-specific surveys to aid the model's accuracy.

Keywords**:** River, dredging, Sediment, Coastal erosion, Environmental and social risks

1. Introduction

In 1991, the historic eruption of Mount Pinatubo deposited about six (6) cubic kilometers of pyroclastic materials on the volcano's slopes – two-thirds of which was funneled in the western side through the Bucao, Santo Tomas, and Maloma River Systems in Zambales (Scott et al., 1991). While three (3) decades have passed since the world's second-largest eruption of the 20th century, its impact is still felt through the lahar left congesting the riverbeds of the aforementioned. To mitigate the risks of flooding, the government has embarked on a rehabilitation of the river through a 60-hectare dredging project.

In July 2023, the Zambales Ecological Network (ZEN) and ZEN San Felipe released a statement on their "strong condemnation" of the Maloma River Dredging that is feared to negatively impact the well-being of their marine ecosystem, fishing industry, tourism areas, and livelihoods. ZEN stated that numerous typhoons have crossed the province, but no "catastrophic doomsday scenario" has occurred contrary to the claim that calls for the project's execution. They believe that the "purported river rehabilitation project is merely a pretext to extract seabed sediments for the completion of the Manila Bay Reclamation," where 23 out of the 52 ongoing reclamation projects in the country are (Philippine Reclamation Authority, 2023). Ultimately, with the absence of transparency and meaningful public consultation in the decision-making process, the community is concerned about the possibility of repeating in Maloma the disastrous similar project in the neighbouring town – the dredging of Bucao River, Botolan – where barangays were washed out, 400 houses were swallowed by the sea due to coastal erosion, and the marine ecology was annihilated affecting livelihoods (ZEN, 2023).

With the worsened effects of climate change becoming more evident, more so in the archipelagic Philippines, coastal vulnerabilities must be taken into consideration. A Sediment Transport Analysis can aid in understanding how the dredging may change the Maloma River morphology, particularly at its estuary, which can impact erosion rates, flooding risks, and the health of aquatic ecosystems (N. Joshi et al., 2019). As such, the study focused on the investigation of sediment transport for the assessment of coastal erosion of the Maloma River Rehabilitation Project, contributing valuable insights to the field of river restoration and management.

2. Methods

2.1. Data Collection and Curation

Baseline data refers to information that is collected before any intervention or change is implemented. To establish a starting point for measuring the impact of the Maloma River Dredging, the researchers shall collect baseline data as the first stage of the methodology. The parameters to be considered are bathymetry, sediment characteristics, current velocity and direction, wave height, wind speed and direction, water level/tide heights, and sediment discharge of the river. The procedures and instruments for data gathering are further discussed later in this chapter.

On top of the baseline data, information regarding the dredging shall be obtained from the project EIA. Data from the dredging project shall be used to generate the immediate bathymetry of the area right after dredging. The generation of the updated bathymetry was done through ArcGIS and was used for Phase 2 among other collected data.

2.2. Hydrodynamic Analysis

To create a hydrodynamic analysis the researchers used Delft3D. This software creates a multidimensional hydrodynamic simulation that calculates the non-steady flow and transport phenomena from tidal and meteorological forcing on a curvilinear, boundary-fitted grid. Furthermore, the application applies a sigma coordinate transformation in the vertical, resulting in a smooth representation of the bottom topography.

For this phase, data parameters mentioned in Phase 1 were dealt into the software. The model parameters of stages 5 & 6 specified the boundary conditions, grid geometry, govern equations to be solved, and the coordinates of the monitoring observation points. Input data, or in this case data gathered from Phase 1, projected the hydrodynamic state of the estuary of the Maloma River. Recalibration and simulation were repeated if necessary.

2.3. Coastal Erosion Analysis

To create an analysis of the coastal erosion of the estuary of Maloma River, the coastal erosion data were taken from data gathered in Phase 2, particularly Stage 6. The generation of the coastal erosion map along with the analysis of sediment transport is based on the output of the hydrodynamic analysis of phase 2. The data gathered were fed into Delft3D to create a simulation of the coastal area. This phase is heavily reliant on the data projection of phase 2 since coastal erosion is dependent on the hydrodynamic analysis of the river.

2.4. Conclusion and Recommendation

With the output from coastal erosion analysis, the researchers shall conclude with the identified intensity of the sediment transport impact, whether or not there will be coastal erosion, as well as when and where it could occur. Furthermore, the study can provide recommendations for mitigation measures based on the qualitative review of documents, particularly of the EIA, and the results of the coastal erosion analysis.

3. Results and Discussion

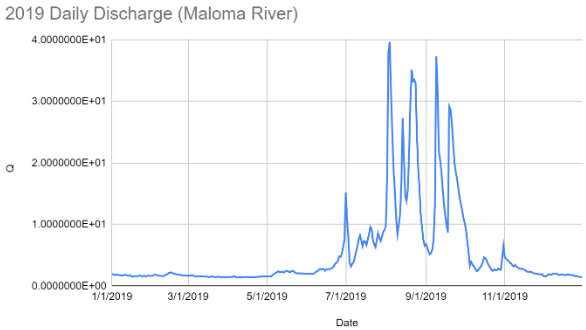

Figure 1 Water Flow Data in 2019

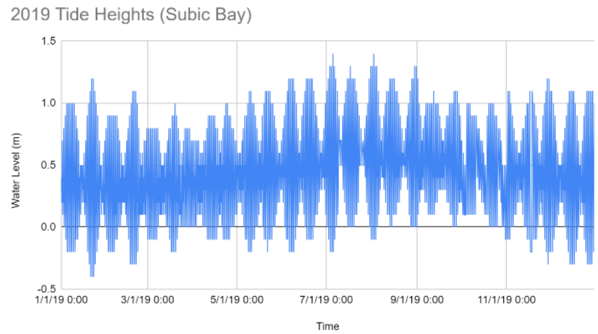

Figure 2. Water Level 2019

Figure 1 shows the water flow data in 2019. As shown in the figure, water flow levels remain stagnant until they fluctuate in July and peak in August. It can be observed that in the months to follow, water flow increases and decreases until plummeting in October, and after fluctuating in November, it stagnates. Figure 2 shows the water level data for 2019. As shown in the figure, there is a steady increase and decrease in water level. The water level peaks in August at a height of approximately 1.4m, and steadily increases and decreases thereafter. It is also evident that the decrease in water level is shown in February.

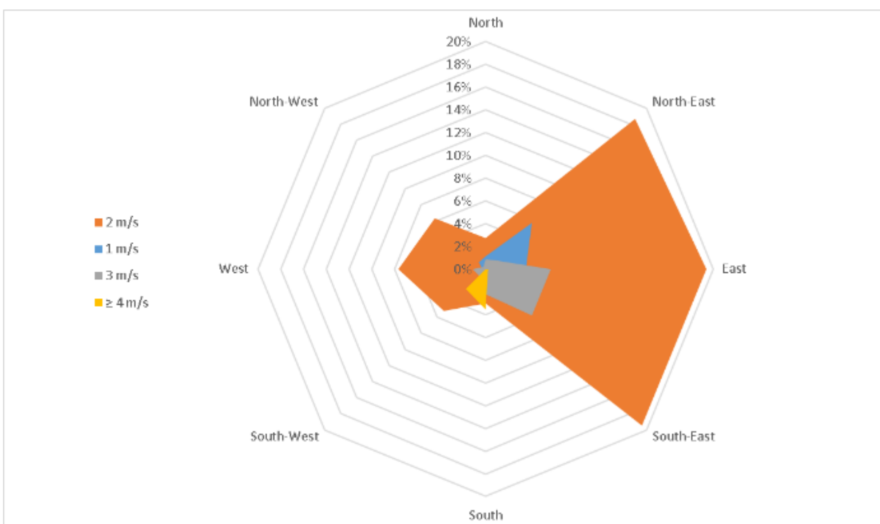

Figure 3. Wind Speed & Direction 2019

Figure 3 shows the wind speed and direction for 2019. As seen in the figure, the direction of the wind is blowing relative to the North towards the East. Additionally, the wind speed is also shown in the figure with 4 m/s being the strongest and 1 m/s being the weakest.

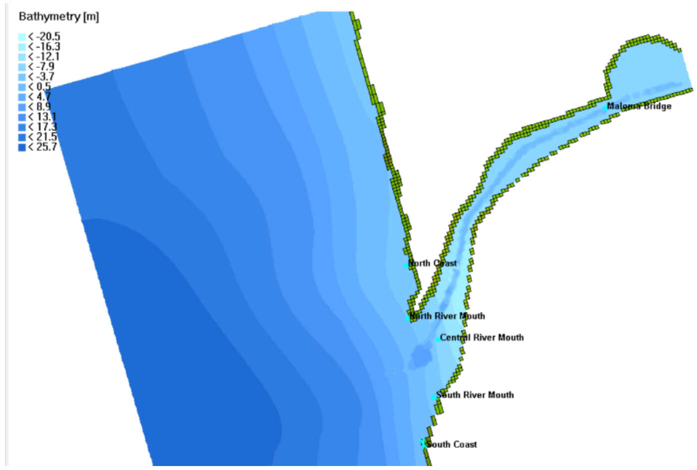

Figure 4 Observation Points

The researchers plotted a total of six (6) observation points within the project area as shown in figure 4. The first observation point is the central river mouth located near the silt basin. The second and third observation points are also in the estuary – the North and South River Mouth. The researchers also added observation points along the coast approximately 250 m away from the North and South River Mouths. Lastly, an observation point was placed about the Maloma Bridge as an additional point of interest.

In the simulation for both baseline bathymetry and dredged bathymetry, only the Maloma Bridge observation point yielded non-zero values for cumulative erosion/sedimentation; the observation points along the coastline and within the estuary displayed a constant zero. However, sediments in equilibrium may only be expected to have net zero value but not linear zero considering their very dynamic nature. Possible reasons for such results include the locations of said points being in areas unreached by flow changes, and/or the predetermined limitations of the study.

3.1 BASELINE DATA

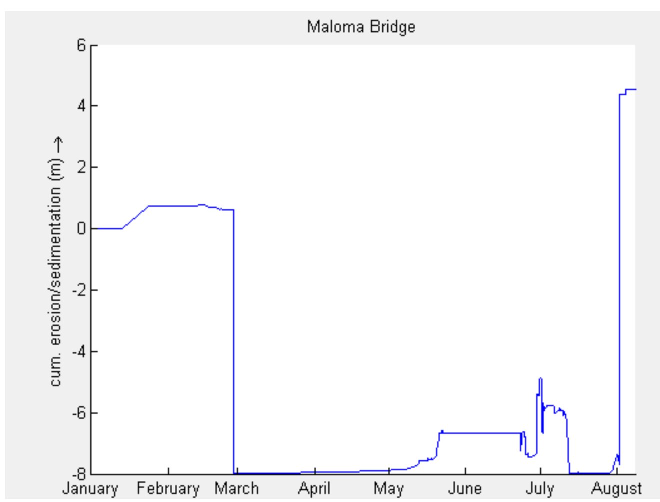

Figure 5. Baseline Erosion/Sedimentation (Maloma Bridge)

Figure 5 shows the baseline data for the accumulation and movement of sediments/erosion at the Maloma Bridge observation point from January to August. It can be seen that in the last week of February, there was a sudden drop in cumulative erosion/sedimentation to -8 meters. From March, a somewhat slow-and-steady increase was observed through May where it then fluctuated until a drop back in July. However, by August, the cumulative erosion/sedimentation surged up to 4.55 meters before the simulation ended.

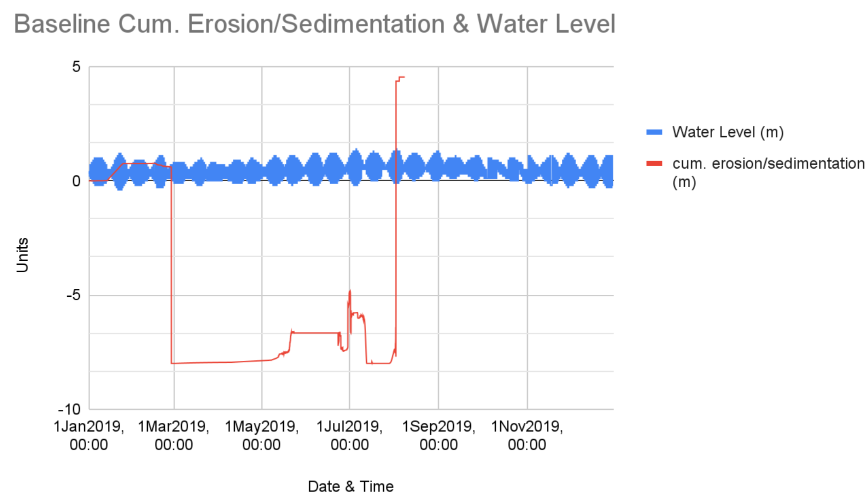

Figure 6. Baseline Erosion/Sedimentation with Respect to Water Level

It was observed that an increase in water level occurred at roughly the same time as cumulative erosion/sediment started increasing. It can be hypothesized that water level is directly correlated to the accumulation of erosion/sediments.

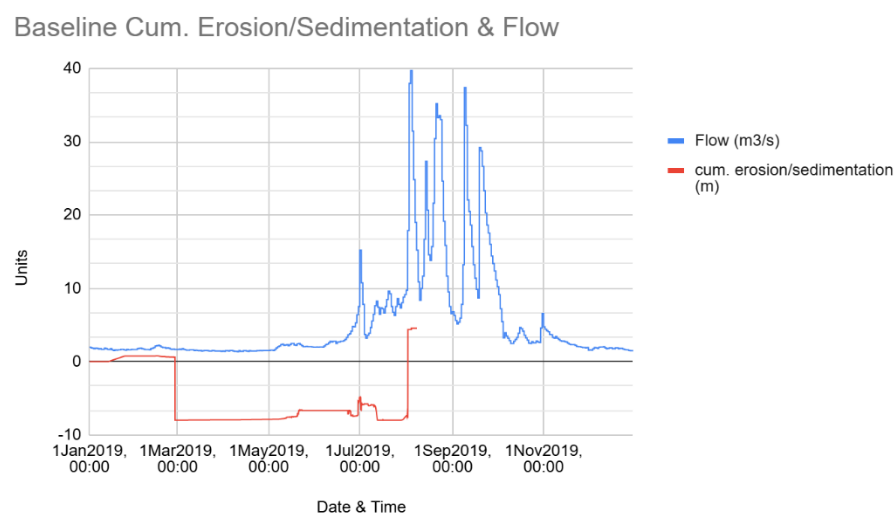

Figure 7. Baseline Erosion/Sedimentation with Respect to Water Flow

With respect to water flow, it is evident in the figure that there is a direct correlation between the cumulative erosion/sediment date for water flow data. The sudden drop in sediment collection is evident when water flow shows signs of dipping from March to April and steadily increases in the succeeding months. The spike in sediment buildup in August is attributed to an increase in water flow.

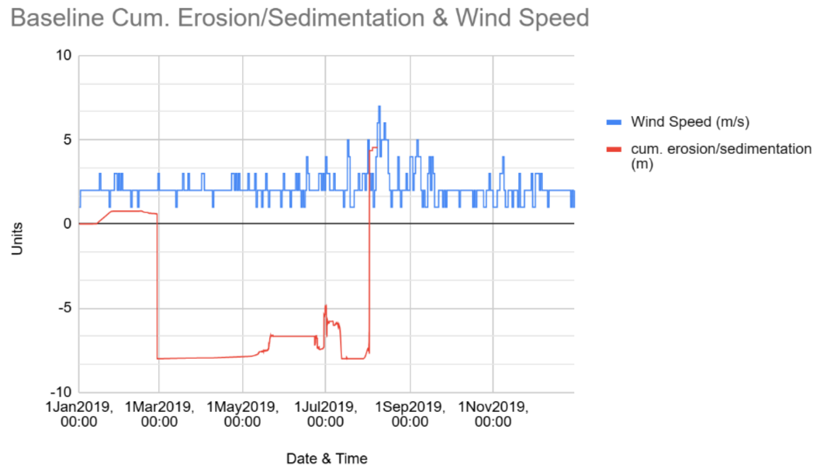

Figure 8. Baseline Erosion/Sedimentation with Respect to Wind Speed

Figure 8 shows the baseline data for the cumulative erosion/sediments by the Maloma Bridge with respect to wind speed. The figure shows that there is a direct correlation between the accumulation of erosion/sediments with the number of wind speed intervals. This is evident between March and April when the number of wind speed intervals are lesser, compared to later months. In addition, as the number and heights of intervals increase, so does cumulative erosion/sediment. This is apparent from late May to mid-August.

3.2 Dredged Data

It can be observed that for the dredged results, there is no movement of sediments until its peak in August, wherein it shows no movement thereafter.

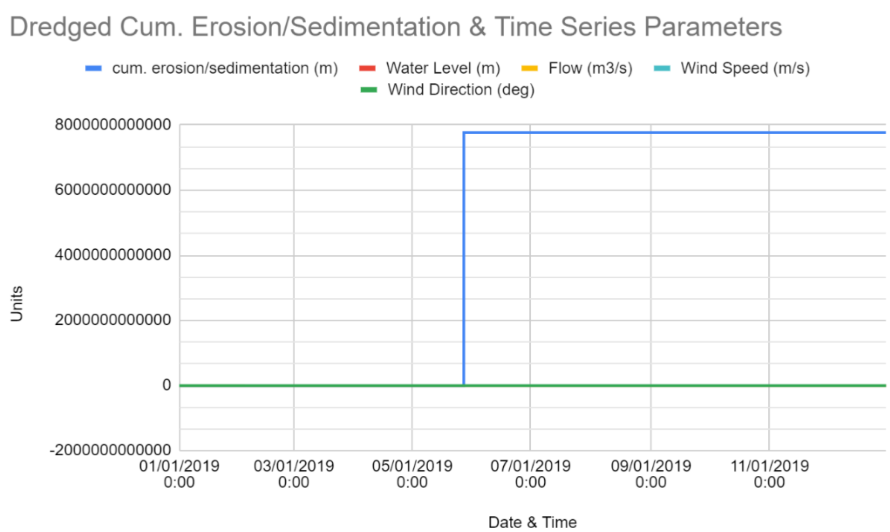

Figure 10. Dredged Erosion, Wind Speed, Wind Direction, Flow and Water Level (Maloma Bridge)

Compared to the time series parameters such as wind speed, wind direction, flow, and water level, it can be observed that the sudden increase of sediments/erosion occurs in August when water flow peaks as seen in Figure 10. However, this increase resulted in values that far exceed water level, flow, and wind speed data.

4. Conclusion

Data gathered from both baseline and dredged data showed that there is a correlation with water flow and level data with cumulative erosion/sediment data. It was observed that in the months where water flow and level increased and decreased, there is a notable change in the accumulation of erosion/sediment data. Factors such as wind speed and direction affected these because as winds moved westward, erosion/sediment data fluctuated as well. This is more evident in the baseline data compared to the dredged data because of the difference in y-values.

As stated in the project EIA, “Maloma River is a natural drainage feature serving the Municipality of San Felipe”; this is evident in the results analyzed by the researchers, particularly in the Maloma Bridge observation point where most of the data gathered varied as compared to other observation points. Results indicated that the majority of the sediments discharged came from the Maloma Bridge, which spread throughout the river and into the ocean towards the end of the year. It was also mentioned in the project EIA, that the dredging area is considered “environmentally critical” due to its vulnerability to geologic hazards and typhoons. The river’s critical state will only be amplified as a result of the dredging process, causing increased turbidity and change in the water’s chemical composition; increased turbidity in water will not be confined to the dredging zones, the pilot channel and the dredging basin, as the mentioned in the project EIA, but will thoroughly affect the entirety of Maloma River. The project EIA’s risk analysis of the effects of this project towards the environment, particularly with respect to pollution control, does not highlight the severity of the project on the natural environment. The EIA’s findings also suggest that the likelihood of the project affecting the environment is either “unlikely” or “rare”, however, based on the results that the researchers gathered, the environmental impact of this project is highly likely to occur and affect the environment and livelihood of all living organisms in the area.

The findings revealed that the cumulative erosion/sediment data of the dredging project heavily affects the Maloma River in terms of flow, morphological evolution, and erosion and deposition processes due to high sediment output. The dredging project of Maloma River produced 81012 m erosion/sediments, which can be a problem for the surrounding environment. Such influx can lead to habitat degradation, increased turbidity, and the release of pollutants such as metals and other organic compounds that were once settled on the river bed. These effects can be monitored and predicted through 3D hydrodynamic modeling. However, it must be noted that data accuracy will vary due to the distance between weather and tide stations from San Felipe, Zambales.

While Subic is geographically close to San Felipe, the bathymetric and water level conditions in Subic Bay might not well-represent that of Maloma’s coast. Such may have caused the error: Water level too high >25m, which was persistent, especially in simulating the baseline bathymetry. Monitoring and predicting the effects of dredging on sediment dynamics in rivers like the Maloma River can be achieved through 3D numerical modeling. These models integrate hydrodynamics and sediment transport, allowing us to assess environmental impacts and predict sediment fate. Such models provide valuable insights for efficient dredging planning and environmental management. However, the success of such monitoring and projecting lies in the accuracy of the model which is heavily dependent on the input data. It is recommended that future researchers have the necessary equipment such as measuring tools to collect accurate data to improve the efficiency of the simulation. Furthermore, incorporating oceanographic forcing parameters such as tides, winds, freshwater, discharges, and other factors (e.g. temperature, salinity, wave) will simulate complete ocean dynamics.

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