BENEFICIAL USE OF DREDGED MATERIAL AND FATE OF PLACED SAND USING A HYBRID COSMOS-XBEACH SEDIMENT BUDGET MODEL

Rebecca Quan, Baird, rquan@baird.com
Mohammad Dibajnia, Baird, mdibajnia@baird.com
Larry Wise, Baird, lwise@baird.com
Himangshu S. Das, U.S. Army Corps of Engineers Galveston District, himangshu.s.das@usace.army.mil

The Corpus Christi Ship Channel in Texas connects the Port of Corpus Christi to the Gulf of Mexico. The Port is seeking to deepen the channel to allow fully loaded very large crude carriers to access proposed terminals within the port complex. Dredge material from the channel deepening is to be used as beach nourishment and to create offshore berms along Mustang Island and San Jose Island.

The fate of the beach nourishment and offshore berms was assessed using the Hybrid C-X (COSMOS-XBeach) Sediment Budget Model. Longshore and cross-shore transport processes were incorporated in the model using COSMOS (longshore) and XBeach (cross-shore) models. Multi-year simulation of the fate of placed material using process-based two-dimensional horizontal (2DH) models requires long CPU times which are often impractical. A hybrid sediment budget model using process-based cross-shore profile models was thus developed.

Four representative profiles were used to represent the Hybrid C-X Sediment Budget Model domain: nourished profile with and without an offshore berm, and the pre-project unnourished profile with and without an offshore berm. While the actual profiles along the domain can vary, the representative profiles were used in combinations to approximate defining features in the model domain. These approximations allow the sediment budget model to execute quickly as cross-shore and longshore transport rates are pre-computed for four profiles only. Each profile is divided into six cross-shore cells that represent the offshore, offshore berm (if present), deep nearshore, shallow nearshore, beach/nourishment (if present), and backdune areas (Figure 1).

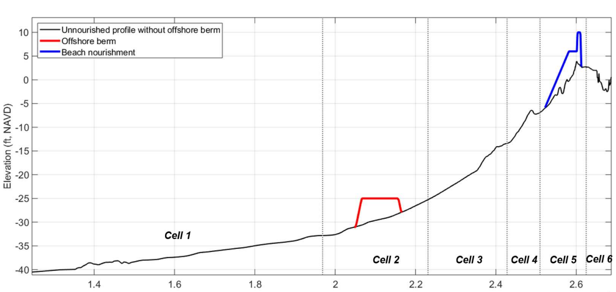

Figure 1 - Cross-shore cells of the representative beach profile; beach nourishment and offshore berm shown

A matrix of offshore wave conditions was selected for COSMOS and XBeach model runs from which any wave condition can be interpolated. Model results were post-processed to determine the longshore and cross-shore transport rates for each of the profile cells and saved to a MATLAB MAT-file.

Prediction of the onshore transport of sediment remains a challenge for existing beach profile change models including XBeach. The beach building process due to onshore sediment movement was included in the model using an algorithm developed based on the criterion C_s, proposed by Sunamura and Horikawa (1974). Additionally, the impact of wave diffraction around jetties on longshore transport is represented by a long shore scaling factor that varies with time and space, depending on the incoming wave direction.

Maximum and minimum cell volumes were also specified in the Hybrid C-X Sediment Budget Model. Minimum volumes prevent erosion of the profile beyond the historic low while maximum volumes are set to prevent excessive accretion in cells. For example, in the cells adjacent to the jetties, when the maximum volume is reached, the excess material will move offshore until the maximums are no longer exceeded. This condition approximates the process in which the sediment will move offshore along the jetty by rip currents.

Two Hybrid C-X Sediment Budget Models were developed to predict the fate of beach nourishment and offshore berms along Mustang Island and San Jose Island, Texas. The model domains are shown in Figure 2.

Figure 2 - Beach nourishment (orange) and offshore berm (green) placement cells within the model domains

Offshore wave conditions for the 1980 to 2019 period were obtained from WIS Station 73040. In total, 269 wave conditions (nine wave heights, seven wave periods, and seven wave directions; see Figure 3) with three water levels (representing zero, moderate, and extreme storm surge levels) were simulated for the four representative profiles resulting in a total of 3,228 individual runs for both COSMOS and XBeach models.

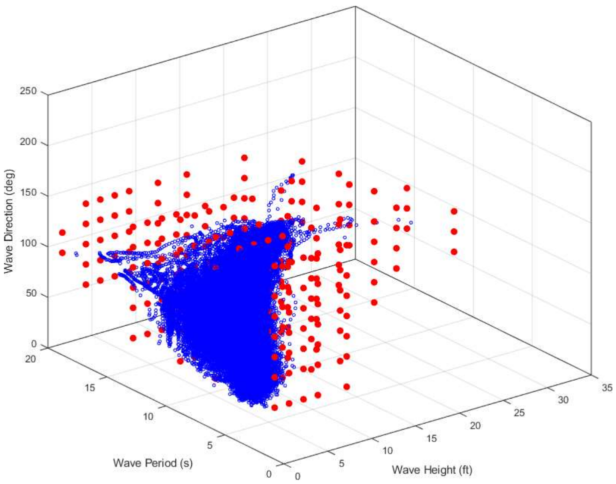

Figure 3 - Matrix of modeled wave conditions (red points) and all wave conditions measured at WIS Station 73040 from 1980 to 2019 (blue points)

Simulation of annual variations of the alongshore transport from 1980 to 2019 using COSMOS indicated that the net longshore transport is towards the northeast on average. Exceptional years where the transport is towards the southwest coincide with significant hurricanes where the counterclockwise winds generate easterly waves that move nearshore sediment towards the west. Significant hurricanes included Hurricanes Allen (1980), Gilbert (1988), Katrina (2005), Ike (2008), and Harvey (2017). Two modeling periods were thus selected for the Sediment Budget model runs: 1992 to 2002 - eleven-year run with no major hurricane events (net eastward longshore transport); and 2000 to 2019 - 20-year run that includes several significant hurricanes that can move sediment back towards the west.

The shoreline along the Mustang Island and San Jose Island domains are relatively stable. The shoreline change analysis from Paine et al., 2021 estimated ±2 feet/year (±0.6 meters/year) of shoreline change from 1950-2019. Due to the lack of definitive accretion and/or erosion trends to calibrate the model against, the objective of the sediment budget model calibration was to simulate a long-term existing conditions (unnourished, no offshore berms) scenario that would produce relatively small changes along the shoreline cells. Calibration of the model primarily focused on the San Jose Island domain and the calibrated parameters were extended to the Mustang Island domain for validation. The 1992 to 2002 period was chosen for calibration as it is a calmer period with no major hurricanes with an overall net easterly alongshore transport.

The calibrated model result is shown in Figure 4. The colorization of the cells in the figure is intended to visualize the trends in the domain only and the thickness value should not be taken literally. Cells with warm colors (positive thickness) represent volume gain above the initial elevation while cool colors (negative thickness) indicate that volume has been lost/eroded below the initial elevation.

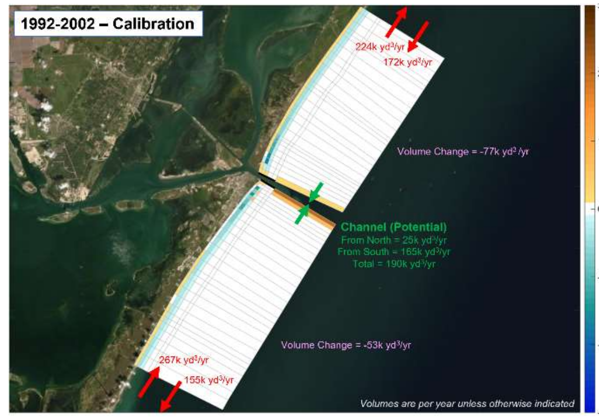

Figure 4 - Sediment budget model results for the 1992 to 2002 calibration period

Figure 4 shows that erosion generally occurs on the beach and in the nearshore area while sediment is overwashed to the backdune area. Cells along the shoreline (Cell 5) generally lose 1 cubic yard/foot/year (3 cubic meters/meter/year). This loss rate corresponds to a lateral shift of approximately 1 foot/year (0.3 meters/year) of the existing conditions profile, measured between the depth of closure and the top of the dune, which is within the range reported by Paine et al., 2021. Most of the lost sediment is redistributed across the domain through overwashing to the backdune area and also moved offshore. Sediment that is moved offshore may be transported to the channel area, where it is assumed to be trapped by the deep navigation channel.

The Hybrid C-X Sediment Budget Model predicts that the average nourishment loss rate is approximately 29,000 to 112,000 cubic yards/year (22,000 to 86,000 m^3/year, 1 to 5% of the total volume per year) in the Mustang Island domain; the lost sediment is generally transported to the northeast towards the jetties. In the San Jose Island domain, the average nourishment erosion rate is approximately 0 to 80,000 cubic yards per year (0 to 62,000 m^3/year, 0 to 2% of the total volume per year); the lost sediment is generally redistributed over the model domain. The range in nourishment loss rates correspond to years with hurricanes (high loss) and calm years (low loss).

Figure 5 shows the cumulative change in beach nourishment volume and potential channel infilling volumes for the two model domains for the period from 2000 to 2019. Sharp decreases in beach nourishment volumes in 2005, 2008, and 2017 correspond to Hurricanes Katrina, Ike, and Harvey, respectively. The volume of sediment entering the channel from the San Jose Island domain is increased during this period as the hurricanes push sediment to the southwest.

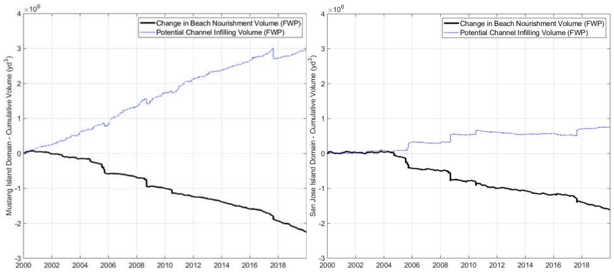

Figure 5 – Cumulative change in beach nourishment volume and potential channel infilling volumes for the Mustang Island (left) and San Jose Island (right) domains for the period from 2000 to 2019

The impact of beach nourishment and offshore berms on channel sedimentation was predicted to be small by the Hybrid C-X Sediment Budget Model. The larger footprint of the beach nourishment on San Jose Island allows the sediment to move back and forth along the nourishment footprint while staying within the nourishment footprint over time. The nourishment along San Jose Island is also fronted by offshore berms to a greater extent than the Mustang Island nourishment, adding additional stability to the beach. The offshore berms provide protection to the beach under the waves with long periods and relatively low surge. Waves with longer wave periods have a deeper wave base (maximum depth at which a wave causes significant water motion) and can be impacted by morphological features in deeper water, like the offshore berm.

REFERENCES

Paine, J. G., Caudle, T., and Andrews, J. R., 2021, Shoreline movement and beach and dune volumetrics along the Texas Gulf Coast, 1930s to 2019: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the General Land Office under contract no. 16-201-000, 101 p.

Sunamura, T., & Horikawa, K. (1974). TWO-DIMENSIONAL BEACH TRANSFORMATION DUE TO WAVES. Coastal Engineering Proceedings, 1(14), 53. https://doi.org/10.9753/icce.v14.53