BORROW SITE EXCAVATION IMPACTS ON SEDIMENT TRANSPORT ALONG THE GULFSTREAM PIPELINE, PETIT BOIS PASS, ALABAMA

Sean W. Kelley, P.E.[1] and John S. Ramsey, P.E.[1]

Two borrow sites offshore of Petit Bois Pass in coastal Alabama had been identified as a source of 12.2 million cubic meters (mcm) of sand for the restoration of Ship Island (Mississippi). After preliminary design of the borrow sites, a natural gas pipeline was found to pass through the area of planned excavation. Rather than abandon the plans for the affected site altogether, it was decided to investigate the viability of modifying the original plan by leaving an undredged buffer along the path of the pipeline. A 2D sediment transport analysis was performed to estimate the magnitude of impacts to the pipeline from dredging at both borrow sites using a modified dredging plan that includes this buffer.

Keywords: Borrow site impacts, pipeline buffers, offshore sand mining

INTRODUCTION

Two borrow sites located offshore of Petit Bois Pass, near the Alabama border with Mississippi, were designed for use in the presently ongoing Ship Island restoration project. The sites, designated as Petit Bois East (PBE) and West (PBW) (Figure 1), were intended to supply 12.2 million cubic meters (mcm) of the total 17 mcm needed to fill Camille Cut at Ship Island (USACE, 2016). PBW, as originally specified, had a total extraction volume of 3.3 mcm with an average cut depth of 1.8 m. PBE was designed to have an 8.9 MCM extraction volume and an average cut depth of 3.0 m. The average water depth at the two sites is approximately 10 m (Figure 2).

Subsequent to the initial design of the excavation plan, it was realized that the Gulfstream pipeline passes across the eastern half of PBW. This 1.4 m diameter pipeline is a major offshore conduit of natural gas between Alabama and central Florida, delivering 37 million cubic meters of gas per day (Gulfstream, 2018).

In the effort to reconciling the design of PBW to account for pipeline's presence, the goal was to modify the plan in order to maximize the extraction volume while ensuring that the pipeline would not be disturbed, rather than abandoning plans for the site altogether. Since U.S. federal law (30 CFR 250.1003) requires that a minimum 3 ft (0.9 m) cover over a buried pipeline for water depths of less than 200 feet (61 m), it was necessary to consider the effects of dredging not only to the pipe, but also to the cover layer over the pipe. Bathymetry change along the pipe route would occur even without dredging, so it was considered adequate to design a buffer that resulted in a magnitude of change equivalent to pre-dredge conditions at the borrow site.

DREDGING BUFFERS

Initially, an undisturbed buffer zone on both sides of the pipe was proposed. A buffer width of 300 m was specified based on information provided in Nairn, *et al*. (2004). In this study for the U.S. Minerals Management Service (MMS, now BOEM), pipeline buffer widths are provided for sites in Louisiana. The 300 m buffer is described as being the upper limit of widths that would be required, based on a survey of dredging contractors. A 1:100 (v:h) slope between the top of cover over the pipeline and the bottom elevation of the dredged pit at the edge of the buffer is described as being not overly conservative. Using the recommended maximum slope would allow up to a 3 m excavation with a 300 m buffer.

In subsequent work (Nairn, 2005), more general dredging guidelines were developed that indicate that a buffer width as narrow as 50 m could be adequate in areas within a sandy setting. In the case of multiple sandy borrow sites in the vicinity of a pipeline, Nairn (2005) cautions that a site-specific evaluation is warranted, and that a buffer width greater than 50 m could be required.

Based on the available guidance, the delineation of a 300 m buffer along the pipeline route through PBW would satisfy the maximum slope recommendations, and protect the pipeline from erosion caused by the dredging of PBW. Applying this buffer, the extraction volume of PBW is reduced by 1.1 mcm (30%) of the original planned volume, and would allow areas of PBW on both sides of the pipeline to be dredged.

---

[1] Applied Coastal Research and Engineering, Inc., Mashpee, Massachusetts

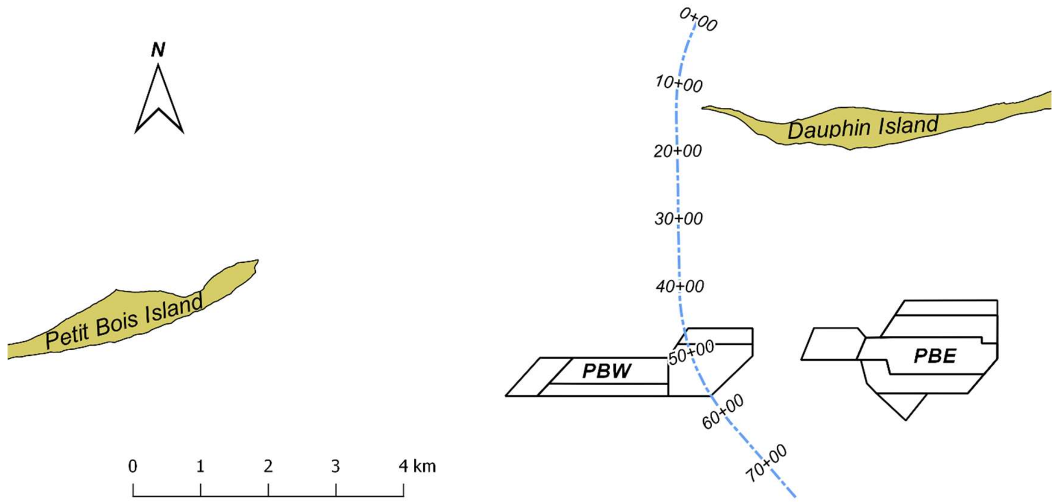

Figure 1. Original PBW and PBE borrow site delineation with sub-areas at Petit Bois Pass with a segment of the Gulfstream pipeline and reference stationing in meters.

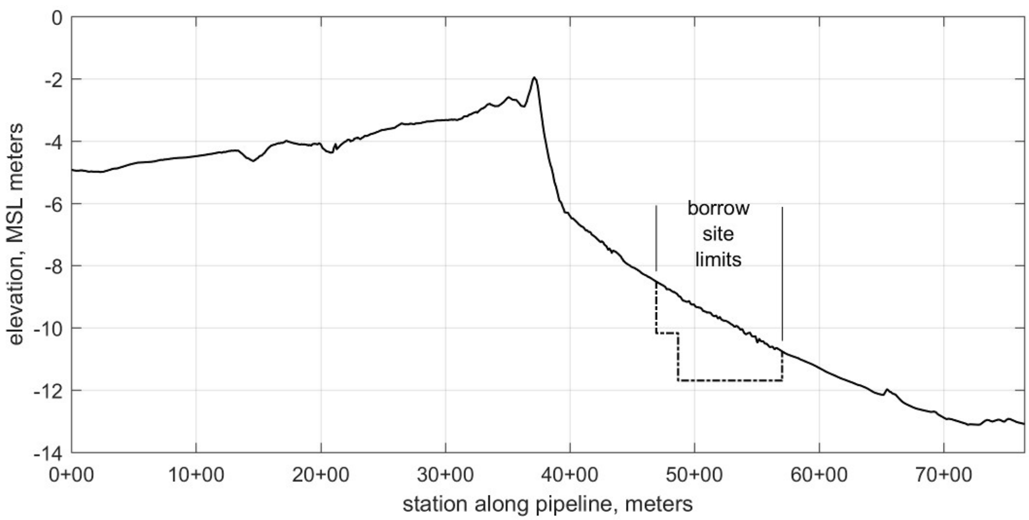

Figure 2. Bottom elevation along the Gulfstream pipeline transect, with the excavated profile along the pipeline. Stationing of profile corresponds to Figure 1.

RECONFIGURING THE PETIT BOIS DREDGE PLAN

Though the addition of the 300 m buffer to the borrow site design of PBW was considered to be conservative based on the available general guidance, it was necessary to demonstrate the adequacy of the buffer for this particular plan using a site-specific analysis. Historical shoreline and bathymetric change of the Petit Bois Pass region (Byrnes, *et al.*, 2012) between Dauphin and Petit Bois Islands showed that the area is very dynamic, even within the areas designated for the borrow sites. The pass has moved about 8 km to the west since circa 1850. Some areas of PBE experienced over 1.5 meters of erosion between 1970 and 2011 as the ebb shoal complex has evolved along with the pass.

In order to assess the performance of the proposed buffer, a 2D coastal model analysis was developed using the USACE Coastal Modeling System (CMS) suite to test the buffer performance under typical annual conditions and extreme storm events.

Development of Modeled Conditions

At the time the study was undertaken, the USACE Wave Information Study (WIS) hindcast records for the Gulf of Mexico included the 20-year span from January 1980 through December 1999. Interest in simulating the performance of the buffer under the extreme conditions of Hurricane Katrina lead to the use of hindcast data from Oceanweather, Inc. (OWI). 29-year wave hindcast datasets from OWI are available at grid points spaced 7 km (3.8 NM) covering the entire Gulf of Mexico. Complete 2-dimensional wave spectra are available from a subset of the 7 km grid, at 14 km intervals. The closest OWI station to Petit Bois Pass with spectral data is located 23.0km from PBW and 28.6 km due south of Dauphin Island (Figure 3). The data provided for each storm simulation includes wave parameters, wind speed and ocean surface elevation from all 7 km grid points in the Gulf of Mexico at 15-minute time step.

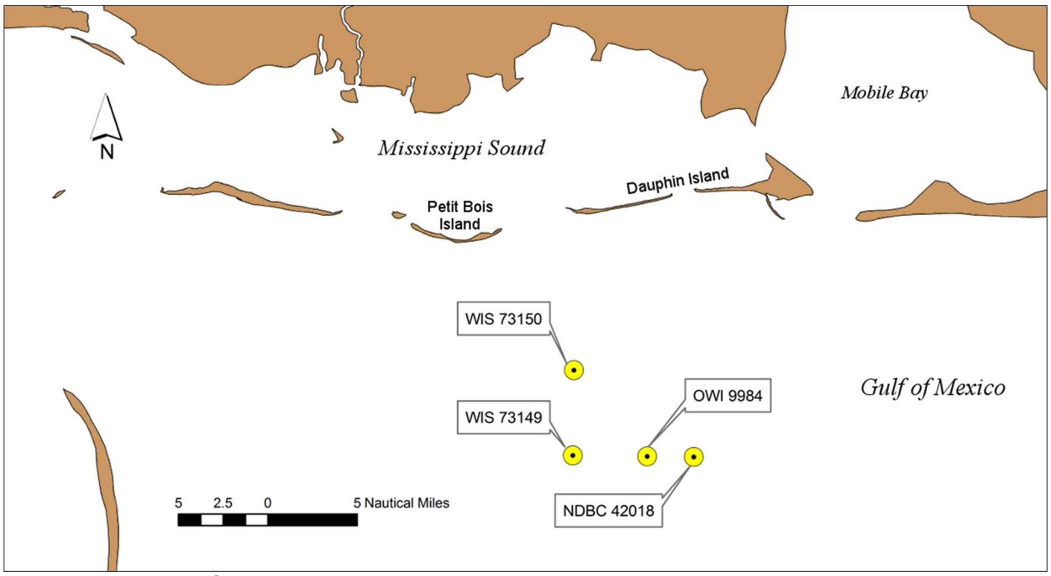

Figure 3. Locations of available wave data sets.

<u>Modeled Annual Conditions.</u> One objective of this analysis was to run pre- and post-dredge conditions at the Petit Bois borrow sites for a complete year. The single year chosen to model from the complete 29-year OWI hindcast was selected based on how well it represented average conditions from the complete record. This was accomplished by comparing the energy distribution of all waves approaching Petit Bois Pass (the compass sector between 90 and 270 degrees) for the entire length of the record to each separate year. Mean wave energy was calculated for each of nine 22.5-degree direction bins (East through West) for all 29 years in the OWI hindcast. These separate annual distributions of wave energy where compared to the distribution calculated for the same direction bins using the entire 29 year of data. A plot of wave energy by compass sector for all years and the annual average is presented in Figure 4. For the SSE sector (the predominant wave direction), annual wave energy varies between one-half to two-times the average energy of complete hindcast. The year that best represents wave conditions of the whole record is 1984, which has the distribution with the minimum RMS difference (2% of total average wave energy of E through W sectors) and best R2 correlation (0.94). The distribution of energy for the year 1984 is also shown in Figure 2. At the peak SSE sector, the average annual wave energy content is essentially equal to the peak in the 1984 distribution.

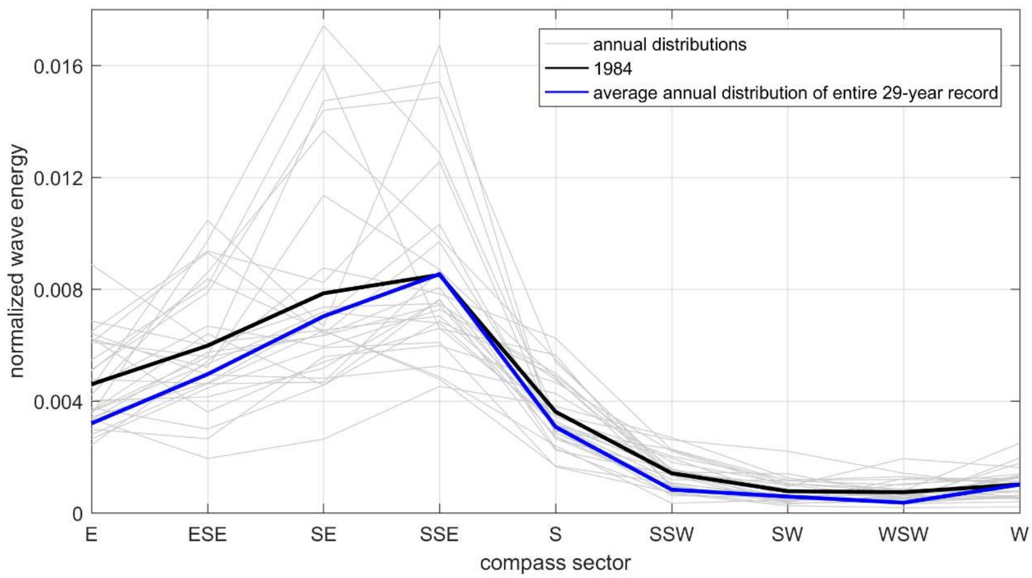

Figure 4. Distribution of normailized wave energy by compass sector from the OWI 29-year hindcast. Annual wave energy ditributions (grey lines) are compared to the average for the entire record by sector (blue line). The year with the best comparison to the entire record (1984) is indicated using a black line.

__Modeled Storm Conditions.__ In addition to the year-long period of waves that were run at Petit Bois Pass, a separate storm simulation was used to gauge how the morphology of the borrow sites would be affected by a major storm event compared to more typical conditions. A simple method was developed to select which storm event in the 29 years covered by the OWI hindcast based on the magnitude of bottom orbital velocities that would be generated at the borrow sites by waves. By this method, waves are shoaled from the offshore location of the OWI hindcast station to a depth of 10.5 m, which approximates the mean depth of water that the borrow sites. Water surface elevations from in the OWI hindcast were added to the mean depth to account for tidal and storm surge variations of the total water depth. Orbital velocities at the borrow sites are then computed using linear wave theory.

Because the largest waves in the 29-year record approaching the borrow sites are depth limited, the top 10 annual events in the record produce mean velocities that occur within the narrow range of 1.7 and 2.1 m/sec (5.7 and 7.1 ft/s). The top five mean velocities occurred during hurricanes Georges (September, 1998), Gustav (September, 2008), Opal (October, 1995), Ivan (September, 2004) and Katrina (September, 2005), listed in increasing order.

An extremal analysis of the calculated maximum bottom orbital velocities was performed to provide further insight into how waves during extreme storm events affect sediment mobility at the borrow sites. Based on this analysis of extreme bottom velocities, Hurricane Katrina has a return period of between 33 and 52 years, using Weibull (k=1.0) and Fisher–Tippett I probability distribution plotting functions, respectively (USACE, 2002). The five top storms have return periods of between 7 and 52 years based on bottom velocities. This indicates that events that generate mean bottom velocities at the Petit Bois borrow areas that are equal to or greater than 2 m/sec occur on average once every 8 years.

Because large bottom velocities occur relatively frequently, it was decided that Hurricane Katrina would be a useful storm to simulate using CMS. Though this storm produced the greatest bottom velocities in this quick analysis, the magnitude of the velocities are not that much larger than more commonly occurring events. With regard to maximum wave orbital velocities at the borrow sites, Katrina well represents more commonly occurring events at this site, even though it is the most extreme, by most measures in the record.

Model Development

CMS-Flow was used in this study to simulate hydrodynamics and sediment transport in the vicinity of the borrow sites, including Petit Bois Pass. Tidal flows through the Pass influence the movement of sediment and morphology change across the planform of the Pass and at the ends of Petit Bois and Dauphin Islands. The extent of the CMS-Flow grid was designed with a focus on the borrow sites and to include the Pass and a portion of the islands that demark the boundary of Mississippi Sound and the Gulf of Mexico (GOM).

ADCIRC. Because the study area is located more than 8 NM from the mainland along the barrier islands of Mississippi Sound, it is necessary to create a model mesh that has open boundaries on both the Sound and Gulf sides of the grid. The hydrodynamic boundary conditions for both grid open boundaries were extracted from a simulation of tides for the entire Gulf of Mexico computed using ADCIRC.

The GOM model was calibrated using a month-long period of predicted tides from three active NOAA tide stations: 1) Dauphin Island, AL at the entrance to Mobile Bay; 2) Galveston Island, TX; and 3) Clearwater Beach, FL. Predicted tides from NOAA were used because the measured tide data include non-tidal fluctuations in water level caused by atmospheric forcing or warm-water eddies shed from the Loop Current, which are not included in the GOM model. 2007 was selected because it is recent enough that NOAA tide gauge data are available from stations across the Gulf that can be used to calibrate the model and because this year was relatively quiet with regard to storm activity in the area around Petit Bois Pass. For the Dauphin Island NOAA tide station, the non-tidal variance (a measure of energy content) of water level fluctuations amounts to 49% of the total variance of the measured tide for the whole of 2007. For the modeled month of November 2007, the non-tidal variance is 28% of the measured tide. Tidal constituent amplitudes at each station were computed and compared, with amplitude errors of less than 3 cm for the M_2 and 1 cm for all other constituents.

In addition to the tidal calibration, available ADCP data were used to corroborate maximum ebb and flood velocities in the Pass. During maximum flood, the average velocity is calculated to be 46 cm/sec. Maximum model flood velocities are 34 cm/sec, during a flooding tide with a similar range as the tide measured during the survey and averaged across Petit Bois Pass. Though the ADCP data did not allow a precise comparison, this check shows that the ADCP measurements and model output compare well.

CMS. Output from the ADCIRC GOM simulation was used to drive the open boundaries of the CMS-Flow grid developed to model annual wave and tidally driven sediment transport at the borrow sites and the general area of Petit Bois Pass. The CMS-Flow mesh is shown in Figure 5. This telescoping grid has a total of 37,475 cells, with a cell size that varies between 31 and 496 meters. The finest grid resolution was used primarily in the area around the borrow sites. The greatest depths in the grid occur along the southern open boundary (approximately 17 meters) near the point where the Gulfstream pipeline exits the grid domain to the south.

The most recent available ship track bathymetry was utilized in the development of this grid, including the 2011 survey of the borrow sites. The 2010 shoreline conditions for Dauphin and Petit Bois Island were also incorporated into the grid.

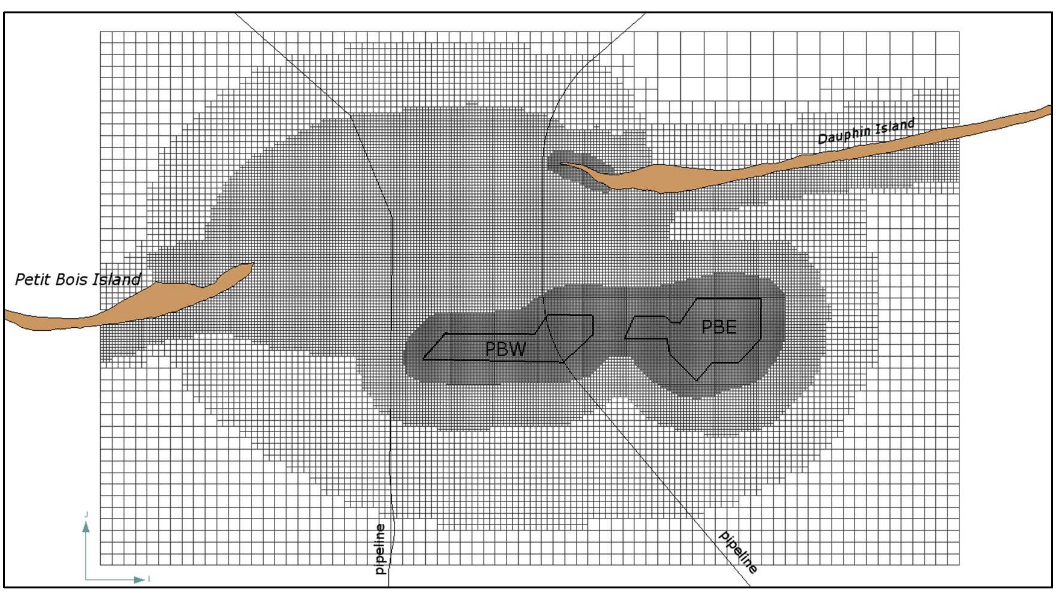

Figure 5. CMS-Flow telescoping mesh of Petit Bois Pass.

The Flow model was run using a 10-minute time step for an entire year (1984) and for the modeled storm. This time step is the same specified as the output interval of the GOM ADCIRC model. The implicit formulation of the model was used. This formulation was made available in the latest versions of CMS and allows the user to specify time steps of the order of one to ten minutes. The explicit formulation is generally much less numerically robust when used with time steps that are this large. For the simulation of Hurricane Katrina, water levels from the OWI hindcast of the storm were applied to both open boundaries. The storm simulation runs for 122 hours, beginning at 0000h UTC August 26, 2005. The same time step and model parameters used for the annual simulation were utilized for the storm run.

Sediment transport and morphology change also were modeled using CMS-Flow. The same telescoping mesh used for hydrodynamic is used for morphology change. The same 10-minute model time step used with the hydrodynamic computations was used for morphology change. The Lund-CIRP transport capacity formula was selected as the basis of sediment transport computations. A sediment density of 2650 kg/m3 was specified. A median grain size of 0.32 mm was applied to the whole model domain based on available sediment core data at the borrow sites from a recent USACE geotechnical investigation of the area (Byrnes, *et al*., 2010).

Initially, the full morphological model including waves and tidal currents was run using NDBC spectral wave data from to compare measured trends in bathymetric change with model results. This check is intended to provide a qualitative comparison based on observed trends. Trends in computed bathymetric change (Figure 6) compare well with trends in the most recent period of measured bathymetric data (Figure 7). Because the measured change is calculated using a much longer time period than even the year-long simulation, it is difficult to make an exact comparison.

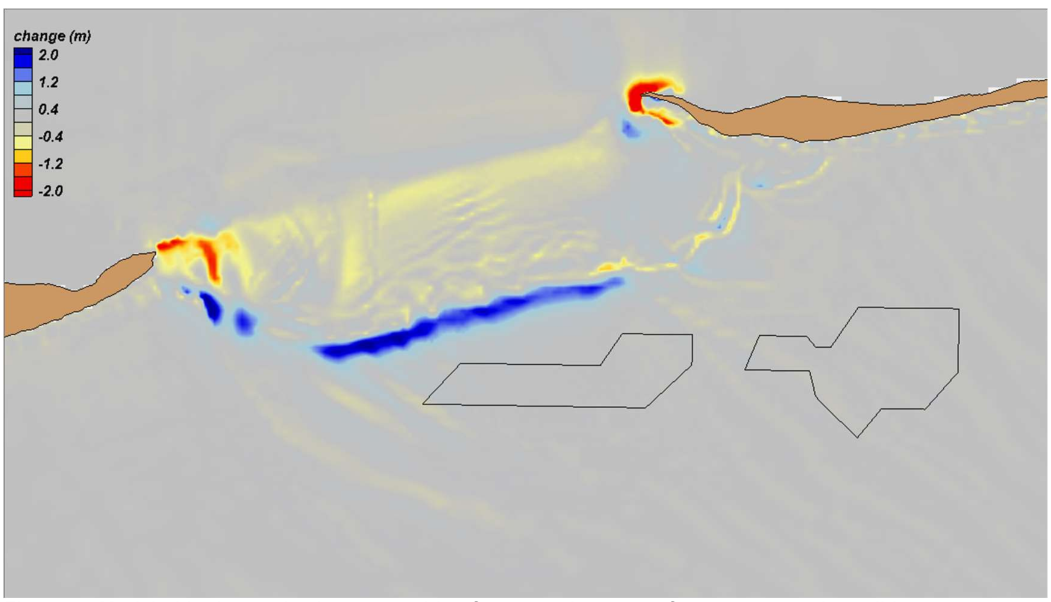

Figure 6. Modeled bathymetric change resulting from year-long run of average annual conditions.

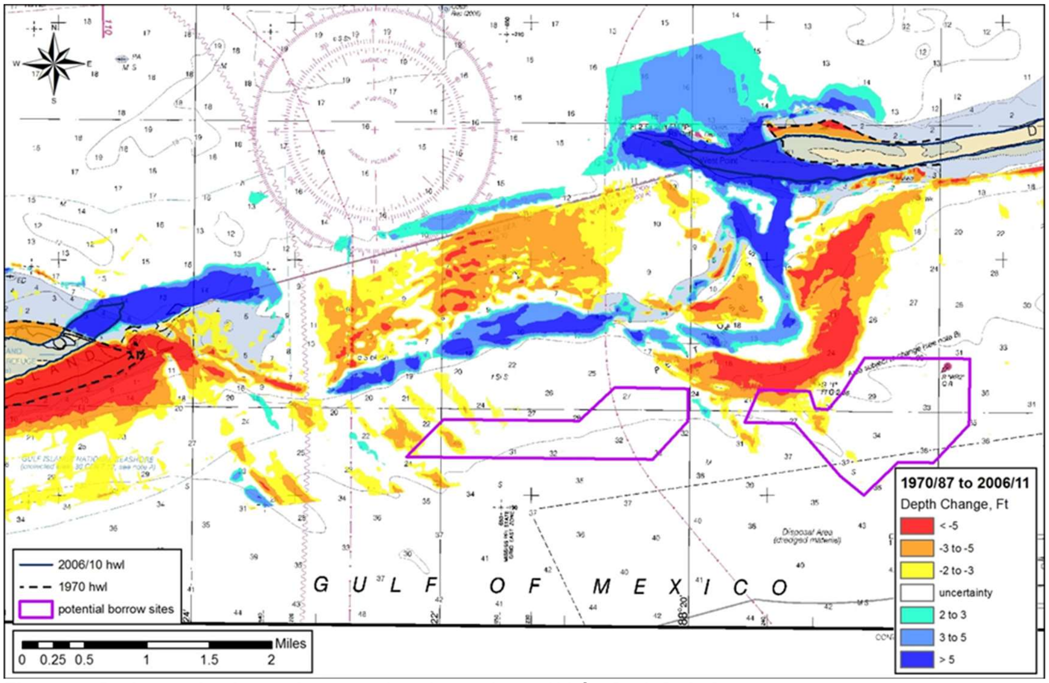

Figure 7. Bathymetric change between 1970/87 and 2006/11 for Petit Bois Pass.

Evaluation of Modified Dredge Plan

With the completion of the model development, the proposed modification of the PBW dredge plan with the 300m buffer around the pipeline was run. The modified plan was evaluated using both typical annual conditions and the extreme storm conditions of Katrina. The storm run produced greater amounts of change compared to typical annual conditions. Because sediment movement and bathymetric change at the borrow sites is much greater for relatively frequent storm events due to the water depths of the sites, the modeled extreme storm was seen a more useful gauge of comparison in the ability of the borrow site design to avoid pipeline impacts. The bathymetric change resulting from the run of Hurricane Katrina for existing conditions was subtracted from the same storm run with the 300-meter pipeline buffer in order to determine the change directly attributed to the borrow sites. This difference in bathymetric change between the two simulations is presented in Figure 8. It can be seen in this plot that the buffer erodes by almost 0.3 meters over existing conditions along the pipeline. Cumulative runs of the storm show that the buffer area continues to erode into a deepening saddle shape, with each subsequent storm causing a further 0.3 meter lowering of the bottom surface over the pipeline.

The results of the modified PBW plan with the 300-meter buffer demonstrated that the buffer would not be adequately protective of the pipeline. A further modification to PBW was made with the aim of reducing the resulting impacts of the plan with the buffer. The plan for PBW was reconfigured (referred to as PBW-2) so that no dredging would occur within the two sub sections of the original plan that the pipeline crosses. This adjustment of the design reduces the total volume available from PBW by 1.8 mcm, which is a 50% reduction from the extraction volume of the original plan, but is only a 20% reduction from PBW with the 300m buffer removed.

The difference in bathymetric change between existing conditions and the updated dredge plan is shown in Figure 9 for the run of Hurricane Katrina. Along the alignment of the pipeline, bathymetric change difference from existing conditions is about 5 cm. Additional cumulative runs of the extreme storm result in further changes of this magnitude. The PBW-2 dredge plan causes bathymetric change along the pipeline that is almost an order of magnitude smaller than the change resulting from the originally proposed design modification with the 300m buffer (Figure 10). With three cumulative storm runs, the mean difference between change along the pipeline section within the original PBW limits resulting from existing and dredged conditions is reduced from 18 cm for the 300m buffer to 1cm for the final PBW-2 plan. The standard deviation of change difference along the pipeline is also reduced from

32 cm with the 300m buffer to 4 cm with the PBW-2 plan. This indicates that with the PBW-2 plan, bottom changes are of the same magnitude as changes that occur for the undredged bottom, and therefore would not impact the pipeline differently than the existing conditions.

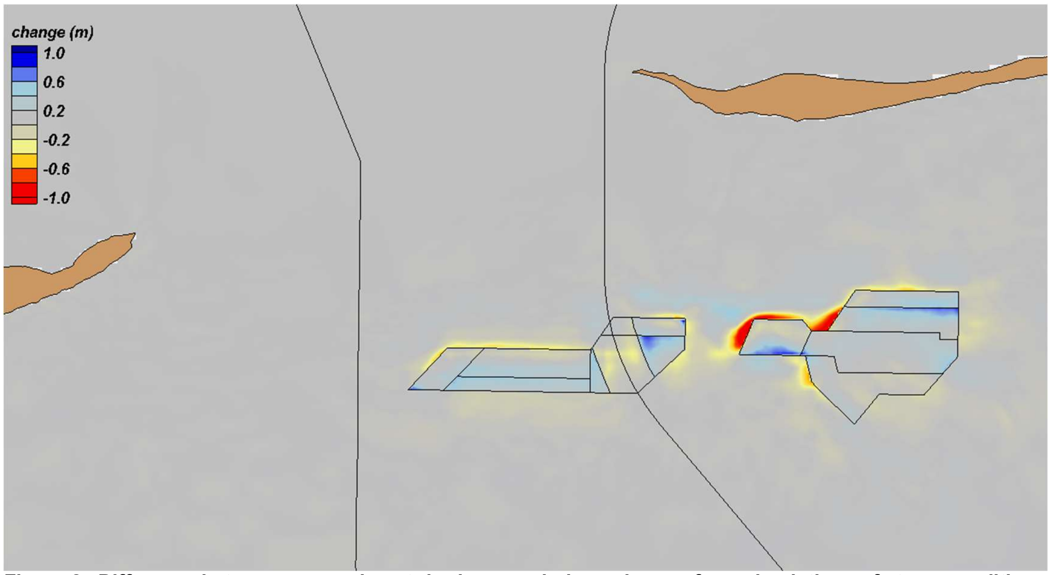

Figure 8. Difference between pre- and post-dredge morphology change, from simulations of storm conditions of the original plan to modify PBW using a 300m buffer around the pipeline, which permits dredging on both sides of the buffer.

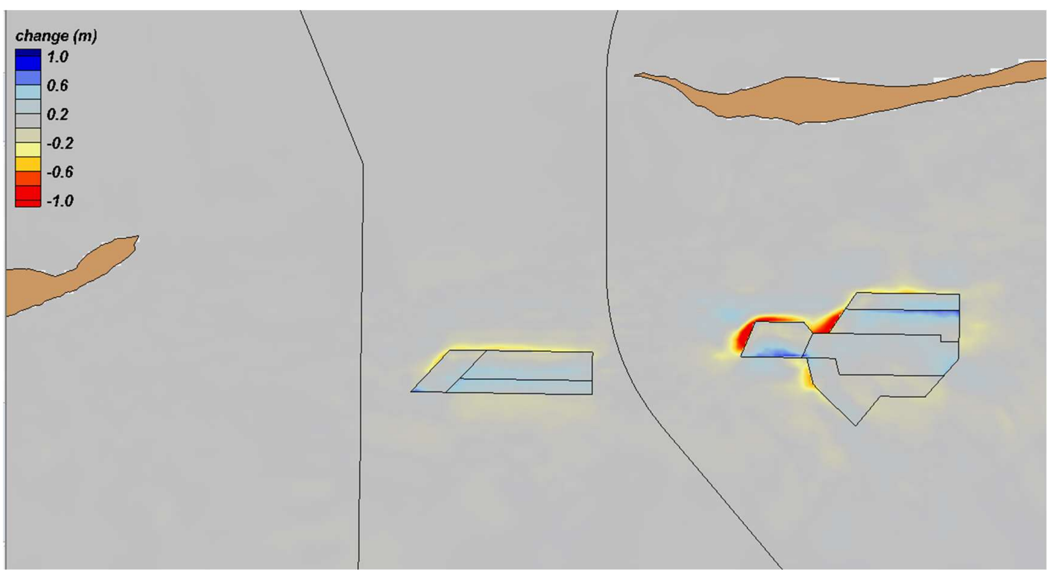

Figure 9. Difference between pre- and post-dredge morphology change, from simulations of storm conditions of the final modified dredge plan, with no dredging in the two eastern-most subsections of PBW (PBW-2 plan).

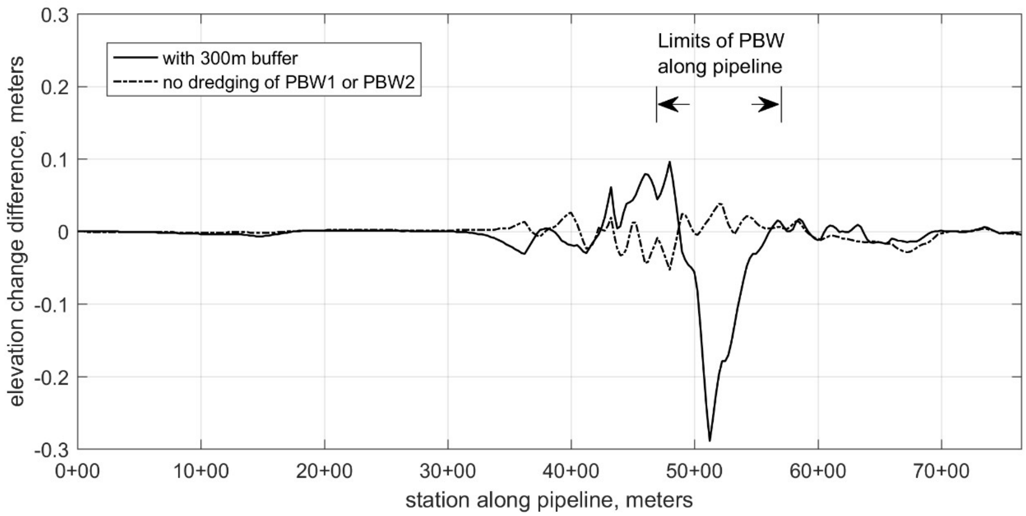

Figure 10. Comparison of bottom change difference (compared to pre-dredge conditions) between original PBW design with the original 300m pipeline buffer and the further-modified design with no dredging of the two eastern-most subsections of PBW.

CONCLUSIONS

The final modified recommended dredge plan for the Petit Bois sites (PBW-2) was permitted and is planned to be used for the Ship Island restoration. The portion of Petit Bois West in Mississippi will be used in the first phase of the project. As of July 2018, 2.8 mcm of sand has been placed in Camille Cut of a total of 5.4 mcm planned for 2018. The volume remaining within Petit Bois West and East after the first phase is scheduled to be used in future phases of the project.

ACKNOWLEDGMENTS

The authors would like to acknowledge Justin McDonald and Elizabeth Godsey at the Mobile District of the Army Corps of Engineers that funded this study. The authors also acknowledge co-workers Mark Byrnes and Sarah Griffee at Applied Coastal for their analysis of historical data.

REFERENCES

Byrnes, M.R., S.F. Griffee, and M.S. Osler, 2010. Channel Dredging and Geomorphic Response at and Adjacent to Mobile Pass, Alabama. Technical Report ERDC/CHL TR-10-8, U.S. Army Engineer Research and Development Center, Vicksburg, MS, 309 pp.

Byrnes, M.R., J.D. Rosati, S.F. Griffee, J.L. Berlinghoff. 2012. Littoral Sediment Budget for the Mississippi Sound Barrier Islands, ERDC/CHL TR-12-9. U.S. Army Corps of Engineers Coastal and Hydraulic Laboratory, Vicksburg, MS. 184 pp.

Gulfstream. 2018. "About Gulfstream." < http://wp.gulfstreamgas.com> (Sep. 19,2018).

Nairn, R., S. Langendyk, J. Michel. 2004. 2004. Preliminary Infrastructure Stability Study, Offshore Louisiana, OCS Report MMS 2004-019. U.S. Department of the Interior Mineral Management Service, Herndon, VA. 30 pp.

Nairn, R., Q. Lu, S. Langendyk. 2005. A Study to Address the Issue of Seafloor Stability and the Impact on Oil and Gass Infrastructure in the Gulf of Mexico, OCS Report MMS 2005-043. U.S. Department of the Interior Mineral Management Service, Herndon, VA. 201 pp.

USACE. 2002. Coastal Engineering Manual (CEM). USACE Coastal and Hydraulics Laboratory, Vicksburg, MS.

USACE. 2016. Mississippi Coastal Improvements Program (MsCIP) Comprehensive Barrier Island Restoration, Hancock, Harrison, and Jackson Counties, Mississippi, Final Supplemental Environmental Impact Statement. U.S. Army Corps of Engineers Mobile District, Mobile, AL.