LLOYD ENGINEERING, INC.

August 22, 2016

Mr. Tony Galt
Marine Operations Manager
Freeport LNG

Subject: FLNG Marine Basin Sedimentation Study
Freeport, Texas

Dear Tony,

Lloyd Engineering, Inc. (LEI) is pleased to present our findings, in accordance with our proposal, dated 02/18/16, to study the naturally occurring sedimentation within the FLNG marine basin. LEI has evaluated existing (observed) sedimentation patterns, and developed and analyzed existing current diversion structure and/or conceptual dredging solutions that may reduce sedimentation within the basin. The FLNG terminal is located on the Freeport Harbor Channel, at the Lower Turning Basin, approximately 1,500 feet from the Gulf Intracoastal Waterway (GIWW). This study was completed in conjunction with the modeling capabilities of Mott MacDonald.

Figure 1 - Project Location

<u>Assumptions:</u>

The following assumptions were made during the development of this study:

- LEI will utilize existing historical pre and post dredging hydrographic surveys from within the basin and the adjacent channel.
- LEI will utilize historical dredging records within the FLNG basin including volume dredged, date of dredging, and design dredging template.
- LEI will provide a dredging solution on a conceptual level only, as part of this scope.
- No new data will be collected as part of this scope. LEI will use the proposed berth/expansion layout in this study.
- No model validation will be performed. However, sedimentation volumetric rates will be reviewed and compared with the observed rates to ensure the simulations are sufficiently accurate to provide recommendations.

- No vessel maneuverability analysis will be performed related to the current diversion structure as part of this scope of work.

<u>Basin Sedimentation Analysis</u>
A sedimentation analysis of the Freeport LNG basin was conducted by comparing historical hydrographic surveys of the basin collected from May 22, 2009 through October 23, 2015. The surveys were categorized into 5 comparisons (to ideally capture the period from a post-dredge to a pre-dredge event when possible) throughout the survey timeline. The analysis was conducted between each successive survey to determine the average sedimentation between each survey. Table 1 shows the dates of the surveys analyzed.

Table 1: Information on Historical Dredging Activities and Survey Schedules

Year	Month/Day	Purpose of Survey	Comparison
	May 22	Condition	
2009	November 05	Condition	**Comparison 1**
	March 04	**Pre-Dredge**	
2010	October 13	**Post-Dredge**	
	March 08	Condition	
	July 13	Condition	**Comparison 2**
2011	November 02	**Pre-Dredge**	
	November 28	**Post-Dredge**	
	June 07	Condition	
2012	November 14	Condition	
	January 07	Condition	**Comparison 3**
	April 12	**Pre-Dredge**	
2013	May 06	**Post-Dredge**	
	November 01	Condition	
	May 19	Condition	
2014	November 25	Condition	**Comparison 4**
	February 06	**Pre-Dredge**	
	March 03	**Post-Dredge**	
2015	May 19	Condition	**Comparison 5**
	October 23	Condition	

The common overlapping area for all the available surveys was identified and used as the analysis basin area to compute the depth difference between each successive survey. The average depth difference within the basin area was then calculated to determine the average sedimentation within the basin for that time period. Figure 2 shows a contour difference plot of the LNG basin between November 28, 2011 and June 7, 2012.

Figure 2 - contour difference plot of the LNG basin between November 28, 2011 and June 7, 2012

Table 2: Sedimentation Rate Calculations (Existing Basin)

Start Date	End Date	Time Elapsed [yrs]	Average Difference [ft]	Sedimentation Rate [ft/yr]
Comparison 1				
5/22/2009 (Condition)	11/5/2009 (Condition)	0.46	1.2	2.7
11/5/2009 (Condition)	3/4/2010 (Pre-Dredge)	0.33	2.5	7.8
Comparison 2				
10/13/2010 (Post-Dredge)	3/8/2011(Condition)	0.40	0.9	2.3
3/8/2011(Condition)	7/13/2011 (Condition)	0.35	0.8	2.4
7/13/2011 (Condition)	11/2/2011 (Pre-Dredge)	0.31	0.5	1.6
Comparison 3				
11/28/2011 (Post-Dredge)	6/7/2012 (Condition)	0.53	4.1	7.8
6/7/2012 (Condition)	11/14/2012 (Condition)	0.44	3.4	7.7
11/14/2012 (Condition)	1/7/2013 (Condition)	0.15	0.0	-0.1
1/7/2013 (Condition)	4/12/2013 (Pre-Dredge)	0.26	0.2	0.8
Comparison 4				
5/6/2013 (Post-Dredge)	11/1/2013 (Condition)	0.49	2.0	4.0
11/1/2013 (Condition)	5/19/2014 (Condition)	0.54	1.6	2.9
5/19/2014 (Condition)	11/25/2014 (Condition)	0.52	0.9	1.8
11/25/2014 (Condition)	2/6/2015 (Pre-Dredge)	0.2	1.4	7.0
Comparison 5				
3/3/2015 (Post-Dredge)	5/19/2015 (Condition)	0.21	1.5	7.2
5/19/2015 (Condition)	10/23/2015 (Condition)	0.43	2.4	5.5

The results from Table 2 show a high variability in the sedimentation rates within the basin. This is primarily due to the influence of the Brazos River on the sedimentation in the basin. The annual rate was validated by comparing volumes between dredge events. The variable scale plot in Figure 3 below shows the Brazos River Discharge data collected from the USGS observation station located in Rosharon, TX (blue) vs. the average measured sedimentation within the FLNG basin (red) relative to the comparisons found in Table 2.

The plot appears to suggest a strong correlation between high discharge in the Brazos River and high sedimentation within the basin.

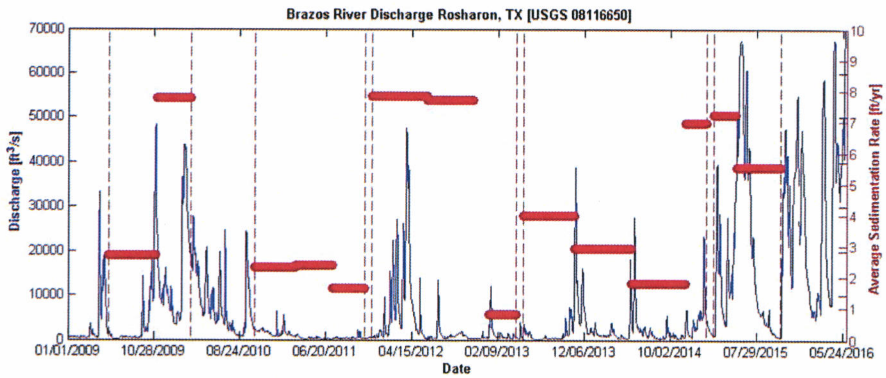


Figure 3. Brazos River Discharge and Sedimentation Rates

In addition to sedimentation rates, the spatial distribution of material throughout the basin was analyzed to determine any distinct sedimentation patterns within the basin. Figure 4 shows the typical distribution of material within the basin over time. The surveys showed that more material tends to deposit on the eastern end of the basin near the Freeport Navigation Channel. This corresponds to observations made that the basin tends to silt in faster adjacent to the Freeport Navigation Channel.

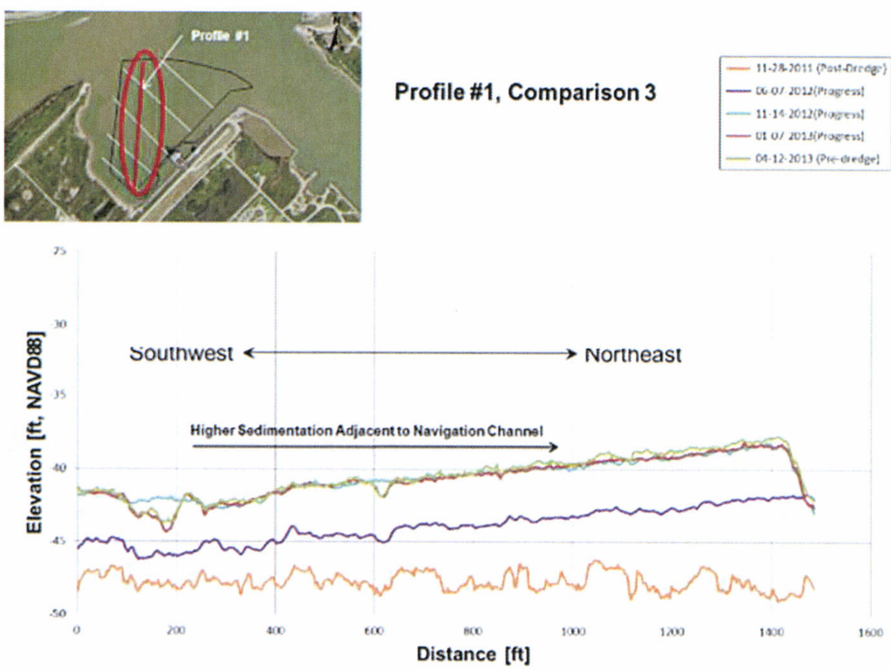


Figure 4. Survey Comparison 3 Profile

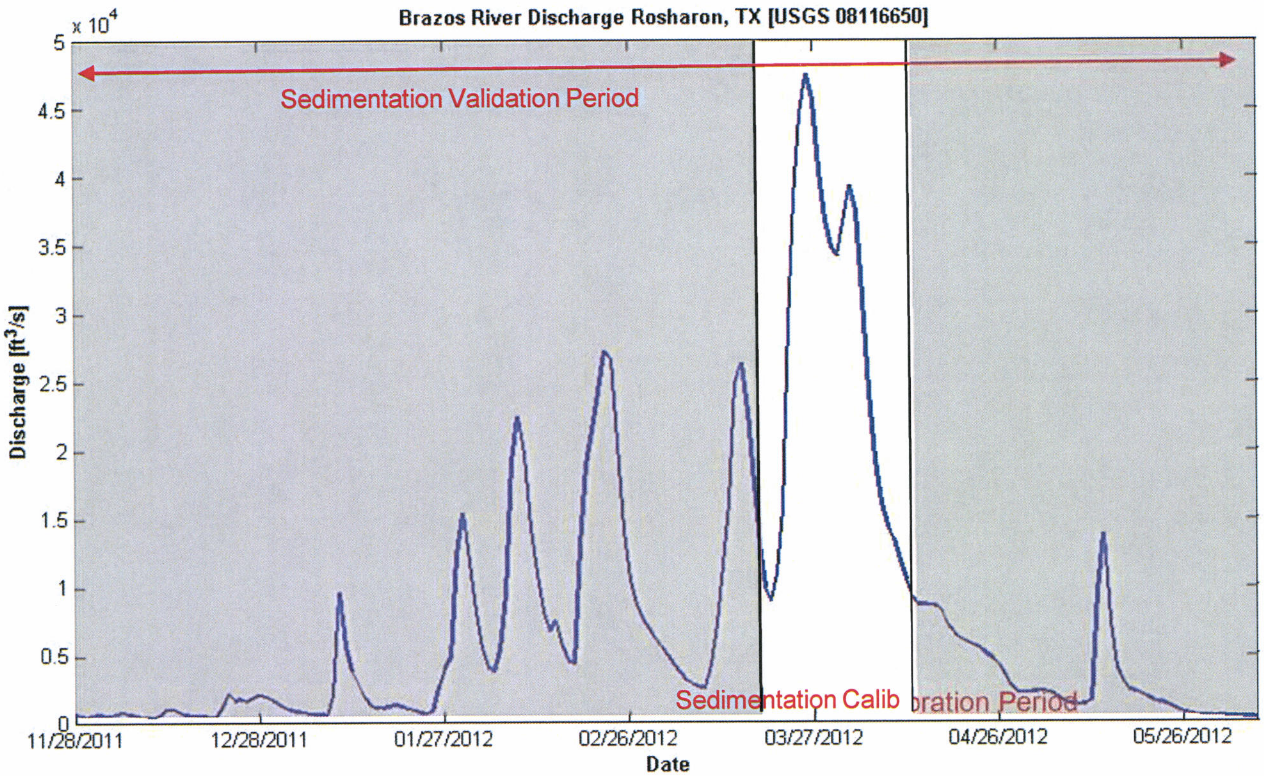
Hydrodynamic and Sedimentation Modeling

Hydrodynamic and Sedimentation modeling of the project site was performed using MORPHO (Kivva *et al*., 2006). MORPHO is a 2-D model that simulates depth-averaged surface water flow, sediment transport, and bottom-change morphology in the near-shore zone. The model was used to evaluate tidal and riverine generated currents as well as sediment transport patterns and sedimentation in the project vicinity and proposed basin.

Calibration and Validation

In order to ensure the accuracy of the model, an extensive calibration and validation was performed. Three distinct periods were chosen:

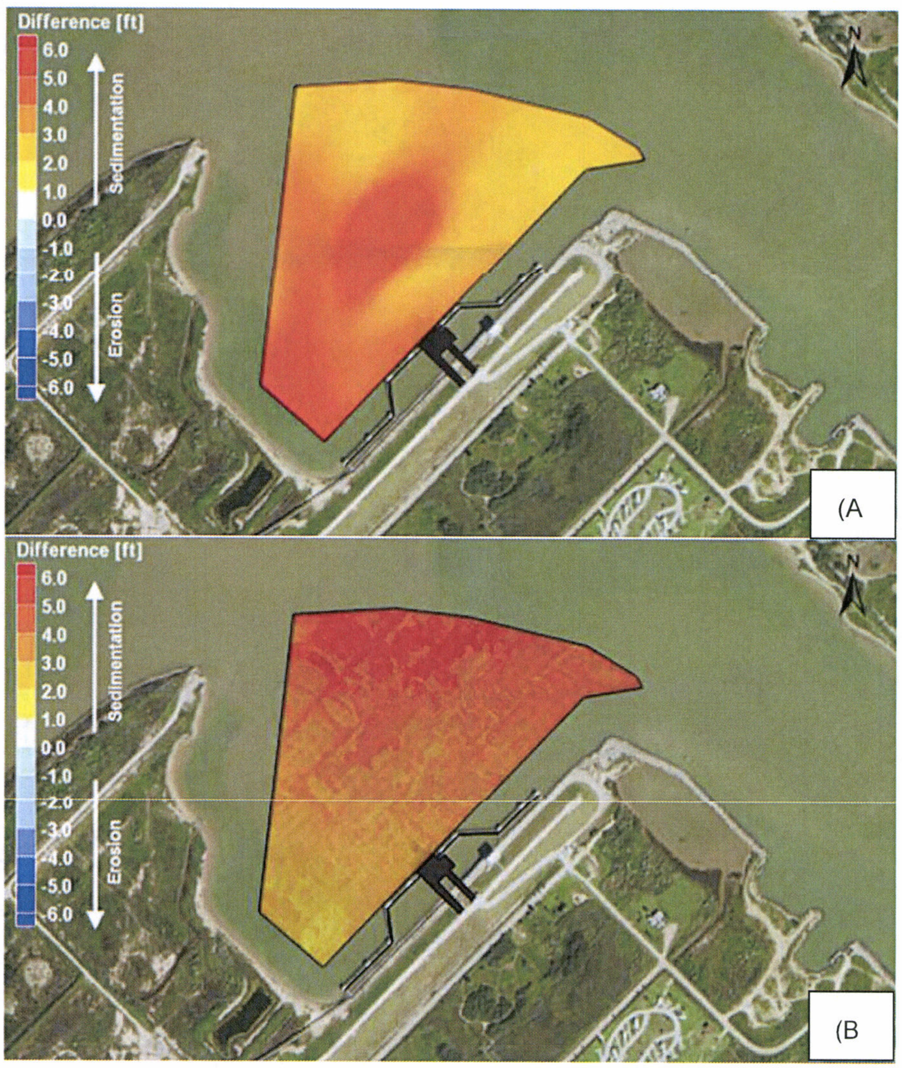
- Hydrodynamic Calibration: March 12, 2015 to March 21, 2015 due to the availability of both water level and velocity data in the vicinity of the project site.
- Sedimentation Calibration: March 20, 2012 to April 15, 2012 to overlap a high discharge event in the Brazos River.
- Sedimentation Validation: November 28, 2011 to June 7, 2012 to match the actual dredging survey comparison event and also to a time when high sedimentation in the FLNG basin and high discharges from Brazos River were observed. See below.



In order to calibrate the sedimentation model, a target sedimentation volume within the basin was determined. This target quantity was determined by scaling the observed sedimentation in the basin from November 28, 2011 to June 7, 2012 (6 month period). Prior to scaling, based on several discharge tests performed using the model it was determined that when the discharge from the Brazos River is less than 8,000 CFS the sediment does not reach the basin.

Using this threshold, the ratio of sedimentation during the modeling period to the total observed period (around 6 months) and for an entire year (September 25, 2011 to September 24, 2012) was calculated. It was estimated that 53% of the observed sedimentation (6 month period) occurred during the model calibration period (March 20, 2012 to April 15, 2012) and 48% of the total annual sedimentation would have occurred the model calibration period. Applying this to the observed sedimentation volume target sedimentation of 100,700 CY was chosen to calibrate the model. After the sedimentation model was calibrated the resulting sedimentation within the basin was approximately 100,874 CY. The results from the model were then extrapolated to the period from November 28, 2011 to June 7, 2012 in order to compare the modeled sedimentation patterns with those measured.

The comparison between the measured and modeled sedimentation in the basin can be seen in the figures below:



The calibration and validation results indicate that the model is accurately reproducing the hydrodynamics processes responsible for depositing the observed amount of sediment within the basin. This calibrated and validated model of the project site can now be used to test the expansion of the basin or installation of conceptual sediment diversion structures.

The calibrated model shows the highest sediment concentrations reaching the FLNG basin during peak ebb tides. The ebb tide allows flows originating from the Brazos River to enter the GIWW and reach the project site. During ebb tides, high water velocities also occur in the GIWW east of the project site. The water flows west and transports sediment from this area directly into the Freeport Channel. Although the concentrations from this area are not as high as those from the Brazos River, this area represents a constant influx of sediment to the Freeport Channel. A part of this sediment rich flow entering the Freeport Channel enters the FLNG basin in the form of a gyre and drops the sediment load in the basin due to sudden decrease in velocities, shown below:

During slack tides (period during which the water is completely unstressed i.e. not moving in either direction) the flows from the Brazos River and GIWW in the project area are reduced. At this time the gyre forming within the basin begins to shift out towards the Freeport Navigation channel with the center of the gyre shifting to the eastern end of the basin. During these times, water velocities reduce significantly in the area, allowing suspended sediments in the water column to drop out.

During flood tides the flows from the GIWW are forced back towards the east and west away from the project site, reducing the amount of sediment reaching the project site from the Brazos River and from the GIWW east of Freeport. The Flood tide does push flows from the Gulf back into the basin which would deposit remaining suspended sediment back into the basin.

Apart from the short term sediment deposition, the daily fluctuation of flows at the project site due to tides would serve to redistribute deposited sediment over time. The ebb tide flow patterns indicated that sediment would likely migrate towards the center of the basin, while during slack tides sediment would be forced towards the eastern end of the basin by the flows. Finally, during flood tides the flow patterns indicated that sediment would flow towards the north eastern end of the basin. The effect of the tides would also vary depending on the discharges from the Brazos River. During high discharge events the ebb tide would combine with the flows from the Brazos to increase velocities through the GIWW west of Brazos Floodgates while flood tide velocities would be reduced as the water would flow against the currents generated by the river discharges.

Extended Basin Modeling

The calibrated model was updated to include the expanded FLNG basin (designed at -46.5 ft NAVD88) and run for the same 1-month duration used earlier as the model calibration period (March 20, 2012 to April 15, 2012) to determine how the expanded FLNG basin would affect the hydrodynamics and sedimentation within the project site.

The extended basin modeling resulted in the larger basin filling in with approximately 122,200 CY of material throughout the modeling period; this is approximately 21% more sediment than what was observed in the smaller basin (as shown in Table 4). It should be noted that even though the sedimentation volume has increased for the large basin, the overall sedimentation height actually reduces by approximately 17% due to the sedimentation occurring over a much larger basin area. This may potentially reduce the dredging frequency. It was observed that most of the material is depositing in the center of the basin due to eddy formation resulting in low velocities in the center of the basin. Per the sedimentation analysis of the smaller basin, long term tidal, wind wave and vessel propwash effects would likely cause more sediment to deposit on the eastern end of the basin closer to the Freeport Channel.

Table 4. Large Basin Sedimentation Modeling Results

Alternative	Modeled Sedimentation [ft]	Modeled Sedimentation [CY]	Computed Annual Sedimentation [ft/yr]	Computed Annual Sedimentation [CY/yr]	Sedimentation Change
Existing	2.1	100,900	4.1	194,000	N/A
Expanded Basin	1.7	122,200	3.4	235,000	+21%

Sediment Diversion/Dredging Alternatives Analysis

We used the results from the modeling to determine the feasibility of additional measures to reduce the sedimentation in the FLNG Basin. We examined diversion structures in the GIWW, Freeport Harbor Channel, and the Lower Turning Basin; as well as alternative dredging design and maintenance procedures for the basin to incorporate a sedimentation reduction feature.

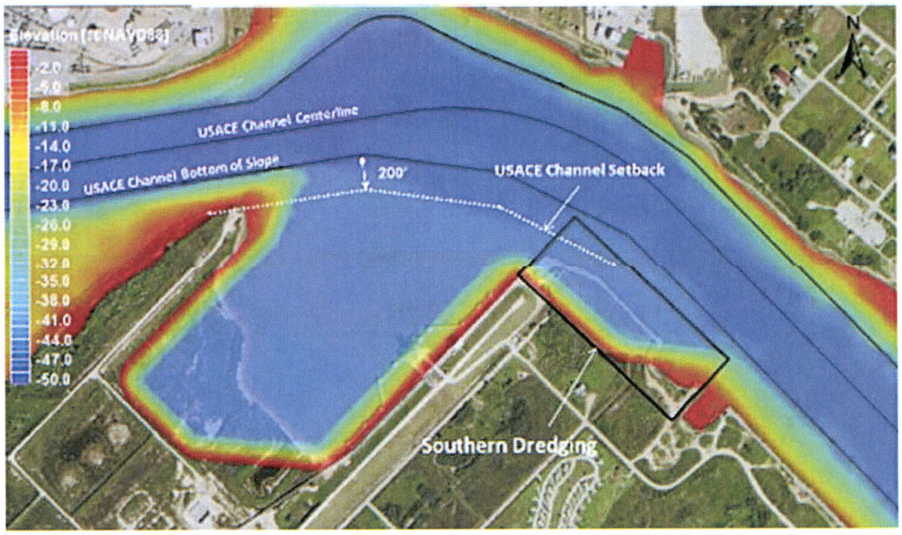
The modeling showed that, for the basin, high velocity currents along with high sediment concentration flows east along the GIWW from Brazos to Freeport. These flows then turn towards the Freeport Channel during an ebb tide on interaction with flows moving west from the Galveston Bay towards Freeport. As the flows reaches the southern end of the basin part of the flow is diverted into the basin where a large eddy forms. This eddy diverts the sediment rich high velocity water from the Freeport Channel into the basin where the velocities decrease significantly and the sediment is allowed to settle into the basin. The sediment diversion/dredging alternatives were developed to divert the ebb flow away from the basin and out towards the Freeport channel.

Below shows the Ebb flows in the basin:

Several alternatives were developed and tested which included the dredging and structural alternatives, but are not included in this report. The alternatives shown are representative of the most feasible alternatives tested.

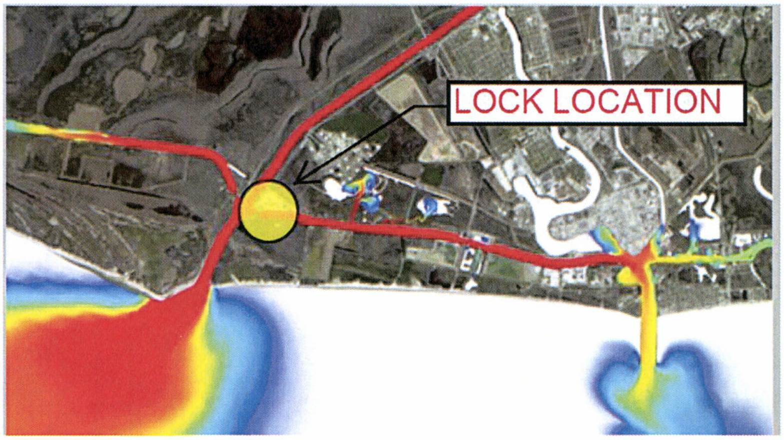
Southern Dredging

The area adjacent to the shoreline along the Freeport channel just south of the project site was dredged in order to channel the flow being diverted into the basin south towards the Freeport inlet. The goal of dredging this area is to reduce the diversion of ebb flows from the Freeport Channel into the FLNG basin. These flows can carry large quantities of sediment and cause deposition into the basin due to the gyred flows that form. The southern dredging alternative and the modeled flow pattern for this alternative are shown below: The modeling shows a 10% reduction in siltation for this option.



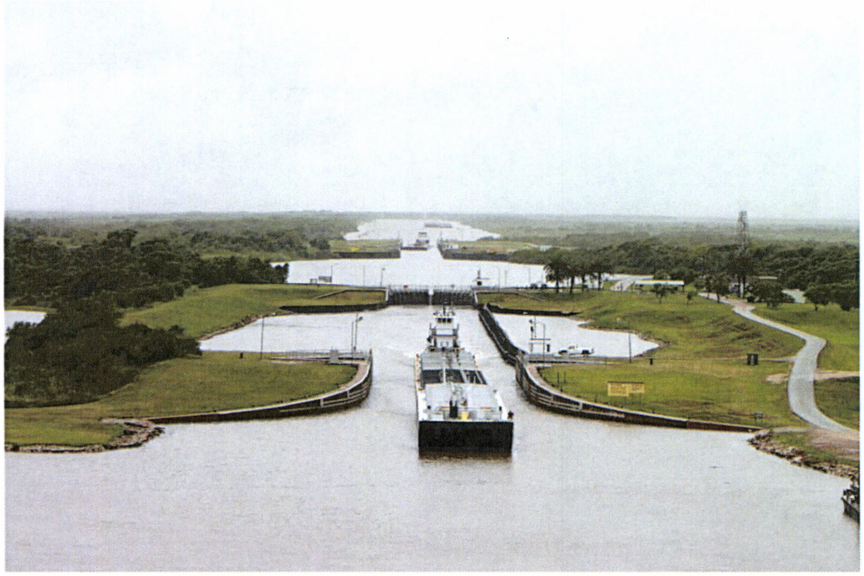
This option would require additional United States Army Corps of Engineers permitting. The additional dredging and modification of the rock groins to the south of the basin would trigger the need to modify our existing Corps permit. It most likely would need to include a section 408 permit review and a real estate instrument by the Corps. The timeline to complete the modification requests and documents needed, review and approval time, is approximately 18 months. This does not include any engineering or construction time. Engineering could be completed in conjunction with the review time by the USACE.

Another alternative that we initially looked at was to place locks at the GIWW and Brazos River. The main source of material is coming from the discharge of the Brazos. Having the locks in place and operating properly would significantly reduce the amount of material making its way down the GIWW.



We propose that these locks be similar to the locks at the Colorado River. With the locks closed, especially at high tide, there would be a major decrease in the amount of sediment traveling east along the GIWW.

Locks at the Colorado River



This option would require Corps permitting as well. However, FLNG would also have to come to agreement with USACE and the Texas Department of Transportation on a public private partnership to construct the locks. It would most likely be in the form of a section 204 agreement, Construction of Water Resources Development Projects by Non-Federal Interest. The agreement negotiations and finalization, permitting, review and approvals are estimated to take 36 months. This does not include any engineering or construction time. Engineering could be completed in conjunction with the review time by the USACE.

Conclusions and Recommendations

Sedimentation analysis and modeling was conducted to develop solutions and alternatives for the reduction of dredging within the Freeport LNG basin. Prior to the development of the numerical model, a sedimentation analysis was performed which showed the average elevation change in the basin due to sedimentation was approximately 4.1 ft/yr. The results also showed a strong correlation between Brazos River discharge and sedimentation within the basin where periods of higher discharges tend to increase the sedimentation rates in the basin. A functional sedimentation model was developed that simulates with good certainty the sedimentation volumes within the basin. The sedimentation model was then used to develop and test conceptual structural and dredging alternatives for the basin. The model incorporates tidal and riverine inputs as the driving factors behind the sedimentation of the FLNG basin. Insight gained from the analysis of existing surveys was also used to develop the model and to develop an advanced maintenance alternative that addresses the spatial distribution of sediment throughout the basin.

A number of options were considered to reduce the amount of sedimentation that is deposited into the FLNG basin. We looked at dredging deeper, adding diversion structures, additional dredging and combinations of the like. Due to navigation concerns, hard diversion structures were ruled out, as they constricted vessel movements in the basin. Dredging deeper caused the velocity of the ebb current to drop to a critical point, where additional sedimentation was deposited. A feasible option was to remove the southern point of the basin. This removed a hard point, where the current hit the point and then diverted material into the basin.

The modeling and sedimentation results were also used to determine the approximate volume of dredging for the basin prior to 2018. The analysis produced an estimate of approximately 863,000 CY for dredging on December 31, 2017. This estimate is subject to variability due to the unpredictability of the natural processes driving the sedimentation in the basin.

We believe that further modeling and analysis should be completed to investigate the possibility and advantages of adding locks at the GIWW and Brazos intersection. It is our opinion that preventing the sediment to travel east along the GIWW will greatly reduce siltation in the basin. LEI, along with HM, believe that the best depiction of the sediment movement is shown in a movie of the modeling runs. The link below is to the movie.
https://www.dropbox.com/s/cn8ynjeu4fgbyql/zoomed%20out%20sediment%20concentration_MMLogo.avi?dl=0

Should you have any questions, please feel free to contact me directly. We look forward to continuing our excellent working relationship with FLNG.

Sincerely,
Lloyd Engineering, Inc.
TXBPE # 2846

P.O. Parker, P.E.
Executive Vice President

Copy: Stan Lloyd, P.E.