HoustonEngineering Inc.

Technical Memorandum

To: Matt Moore
SWWD Administrator

From: Greg Bowles PE
Lisa Odens PE, CFM
Houston Engineering, Inc.

Subject: Grey Cloud Slough Restoration Third Party Review Response

Date: May 10, 2016

Project: 4876-032

BACKGROUND

Inver-Fluve, Inc (Inter-Fluve) has completed a third party review of sediment transport analyses along Grey Cloud Slough (GCS) completed by Houston Engineering (HEI). Comments from Inter-Fluve were received in a memorandum dated May 2, 2016 titled, "Grey Cloud Slough Restoration Third Party Review." Their review included 5 comments (below) within the executive summary and stated:

> *We agree with the general approach and methods used for the analysis. […] Although rivers are dynamic environments and change is inevitable, lack of evidence of excessive deposition at the GCS inlet, results of HEI's sediment transport analysis, and the location of other side channels noted to be rapidly forming within inundated broad floodplain areas with typical channel widths greater than GCS suggests that the proposed GCS construction project will likely meet the hydraulic conductivity objectives outlined in the Grey Cloud Slough Feasibility Study (June 2012).*

RESPONSE TO COMMENTS

COMMENTS

Inter-Fluve had 5 comments in their executive summary, which have been addressed with further modeling and the narrative below within this memorandum.

1. *Incorporate the wide flow areas along the downstream half of GCS into the model or provide discussion to justify their omission.*
2. *At a minimum, add a 2-year flood event analysis to represent geomorphic channel forming conditions. Ideally, complete a long-term sediment transport simulation of GCS.*
3. *Sample bed sediment for use in the model or conduct a sensitivity analysis with larger and smaller sediment to evaluate influence on results.*

4. *Conduct a sensitivity analysis in the model using a range of suspended sediment sources and an equilibrium sediment load based on bed material to evaluate influence on results.*
5. *Consider layering a rapid assessment of existing bank stability onto the scour and deposition results to estimate level or risk of bank erosion and channel migration if lateral migration is a concern.*

PROPOSED STRUCTURE

Three alternatives were analyzed in the June 2012 feasibility study (8'x6' box, 16'x16' box and a bridge option). In the analysis below all modeling was done using the latest proposed alternative, a 42-span concrete arch bridge.

MOORE'S LAKE

The full HEC-RAS model used for hydraulic analysis included the flow splits and cross sections of Moore's Lake. Due to capability limitations in the sediment transport component of HEC-RAS, sediment transport through junctions cannot be modeled. As a response to this review, cross sections downstream of the GCS inlet were modeled with discharge data taken from the full hydraulic HEC-RAS model. Sediment transport loadings were assumed and calculated to be similar concentration and composition to those in GCS. Without modeling upper Moore's Lake and the junction, there are many assumptions required to model Lower Moore's Lake, therefore we consider these results to be for the purpose of sensitivity analysis only.

MODELED EVENTS

In the original sediment transport modeling discussed in the feasibility report, two events were modeled: the median summer discharges (April through September) and the 100-yr discharge for a 30-day duration. These events encompass the range of events that are likely to be channel forming or cause significant sediment transport. GCS is a breakout stream from the main channel; during low flow conditions such as the 2-year, it is anticipated that most of the sediment will remain in the main channel. Our analysis was intended to include both typical expected discharges and the larger discharge events where flows would contribute larger sediment amounts.

In response to comments, HEI ran a 2-year event, assuming a 30-day duration, similar to previous 100-year modeling. As expected, the results are contained within the impacts due to the median summer discharges and 100-year discharges. The 2-year event was not explored further with sensitivity analysis.

The assumed loading inputs (based on original sediment transport assumptions, proposed 42-foot concrete arch bridge, and full hydraulic HEC-RAS modeled flow splits) are summarized in **Table 1** for the 2-year, 100-year, and median summer discharge events.

Table 1: Sediment Transport Discharge and Loading Inputs

Location	2-year	100-year	Median Summer Discharge					
			April	May	June	Jul	Aug	Sep
Mississippi River								
Flow (cfs)	38,500	150,000	26,900	21,700	18,900	14,600	8,870	8,140
TSS (mg/L)	61.00	65.14	58.61	56.70	55.24	51.90	42.42	40.26
Grey Cloud Slough								
Flow (cfs)	1,472	6,753	901	684	572	414	250	235
Sediment Load (tons)	7,266	35,590	4,272	3,242	2,556	1,796	887	765
Lower Moore's Lake								
Added Flow (cfs)	329	10,928	232	187	161	125	80	70
Added Sediment Load (tons)	1,624	57,595	1,100	886	720	542	284	228

SENSITIVITY ANALYSIS

HEI ran a sensitivity analysis to test the model response to 3 variables: variation in bed gradation, variation in sediment gradation, and increased sediment load. For bed and sediment gradation sensitivity, the gradations were shifted towards a larger size gradation and a smaller size gradation. These gradations are shown in **Table 2** and **3**. To test the model's response to sediment load, the model was run assuming quantities twice and ten times the calculated load. The banks along GCS are mostly limestone outcrops, thus bank stability is not anticipated to be an issue.

Table 2: Sediment Gradation Rating Curve Sensitivity Analysis

Classification	Diameter in mm	Percent Within Range		
		USGS Gage at St. Paul	Skewed Larger	Skewed Smaller
Clay	0.002-0.004	0.51	0.01	0.69
Very Fine Silt	0.004-0.008	0.085	0.2	0.1
Fine Silt	0.008-0.016	0.095	0.3	0.105
Medium Silt	0.016-0.032	0.1	0.085	0.105
Coarse Silt	0.032-0.0625	0.105	0.095	0
Very Fine Sands	0.0625-0.125	0.105	0.1	0
Fine Sands	0.125-0.25	0	0.105	0
Medium Sands	0.25-0.5	0	0.105	0

Table 3: Bed Gradation Rating Curve Sensitivity Analysis

Classification	Diameter in mm	Percent Finer		
		RM 827.7	Skewed Larger	Skewed Smaller
Clay	0.004	0	0	0
Very Fine Silt	0.008	0	0	0
Fine Silt	0.016	0	0	0
Medium Silt	0.032	0	0	1
Coarse Silt	0.0625	0	0	6
Very Fine Sands	0.125	1	0	24
Fine Sands	0.25	6	0	92
Medium Sands	0.5	24	1	98
Coarse Sand	1.0	92	6	100
Very Coarse Sand	2.0	98	24	100
Very Fine Gravel	4.0	100	92	100
Fine Gravel	8.0	100	98	100
Medium Gravel	16	100	100	100

RESULTS

The results of the sensitivity analysis for the median summer discharge and 100-year discharge for 30-day duration are shown in **Table 4** and **5** respectively. **Figure 1 and 2** show the change in bottom channel elevation for all sensitivity analysis for the median summer flow and 100-year discharge respectively. The results shown using the base assumptions are similar to those shown in the feasibility report. There is some local scour around the structures which will be stabilized, and the remaining portions of the channel show no concerning scour or deposition.

The sensitivity analysis showed very little impact to the results due to changes in bed or sediment gradation. Under the assumption that GCS received 10 times the calculated sediment loading, the model showed a large impact to downstream sediment accumulation. Under this assumption 355,590 tons of sediment are delivered to GCS, which is 45% of the calculated load in the Mississippi River. Given all the known data, this is an extremely unlikely scenario that was modeled to gain perspective. Even within this nearly impossible event, at most 1.33 feet of sediment accumulated in Moore's Lake and GCS. Under base assumptions, this same location resulted in only 0.05 feet of accumulation. A more realistic skew in sediment load is the twice calculated load analysis. Even this showed at most 0.33 feet of accumulation in GCS during the 100-year, compared to 0.28 under base assumptions.

CONCLUSION

HEI has performed multiple modeling sensitivity analysis to confirm and strengthen the previous conclusion. It is recognized that streams are dynamic systems; GCS and Moore's lake will naturally adjust channel dimensions as sedimentation occurs to form a stable channel and balanced sediment transport regime. The sensitivity analysis and modeling results do not warrant a change to the proposed structure sizing and dimensions. The proposed 42-foot span concrete arch bridge meets the design criteria.

Table 4: Median Summer Discharge Sensitivity Analysis Results

	MEDIAN SUMMER DISCHARGE	Base Condition (Original Assumptions with Moore's Lake and Proposed Crossing)	Base Condition with Skewed Smaller Bed Gradation	Base Condition with Skewed Larger Bed Gradation	Base Condition with Skewed Smaller Sediment Gradation	Base Condition with Skewed Larger Sediment Gradation	Base Condition with 2X calculate Load	Base Condition with 10X calculate Load
Loading Results	Duration (days)	183	183	183	183	183	183	183
	Total Incoming Sediment Load Through GCS (Tons)	13,519	13,519	13,519	13,519	13,519	27,039	135,194
	Accumulated Mass Through GCS (Tons)	1,170	566	1,275	121	2,531	2,830	21,318
	Percent of Sediment Deposited in Reach Through GCS	9%	4%	9%	1%	19%	10%	16%
	Total Incoming Sediment Load Through Moore's Lake (Tons)	17,280	17,281	17,282	17,283	17,284	34,567	172,796
	Accumulated Mass Through Moore's Lake (Tons)	4,698	4,623	4,777	3,212	8,045	11,116	76,995
	Percent of Sediment Deposited in Reach Through Moore's Lake	27%	27%	28%	19%	47%	32%	45%
Change in Stream Bottom	Maximum Accumulation Upstream of Crossing (Excluding Stabilized Crossing) (ft)	0.55	0.78	0.04	0.48	0.70	0.71	1.50
	Maximum Erosion Upstream of Crossing (Excluding Stabilized Crossing) (ft)	-1.67	-2.60	-0.19	-1.70	-1.43	-1.58	-0.84
	Maximum Accumulation Downstream of Crossing (Excluding Stabilized Crossing) (ft)	0.01	0.06	0.01	0.01	0.01	0.02	0.11
	Maximum Erosion Downstream of Crossing (Excluding Stabilized Crossing) (ft)	NA	-0.02	NA	NA	NA	NA	NA
	Maximum Accumulation in Moore's Lake (Excluding Stabilized Crossing) (ft)	0.03	0.05	0.03	0.01	0.05	0.08	0.70
	Maximum Erosion in Moore's Lake (Excluding Stabilized Crossing) (ft)	NA	NA	NA	NA	NA	NA	NA

Table 5: 100-year Discharge Sensitivity Analysis Results

	100-Year Discharge	Base Condition (Original Assumptions with Moore's Lake and Proposed Crossing)	Base Condition with Skewed Smaller Bed Gradation	Base Condition with Skewed Larger Bed Gradation	Base Condition with Skewed Smaller Sediment Gradation	Base Condition with Skewed Larger Sediment Gradation	Base Condition with 2X calculate Load	Base Condition with 10X calculate Load
Loading Results	Duration (days)	30	30	30	30	30	30	30
	Total Incoming Sediment Load Through GCS (Tons)	35,590	35,590	35,590	35,590	35,590	71,180	355,900
	Accumulated Mass Through GCS (Tons)	2,147	640	2,537	(203)	7,773	6,446	59,111
	Percent of Sediment Deposited in Reach Through GCS	6%	2%	7%	-1%	22%	9%	17%
	Total Incoming Sediment Load Through Moore's Lake (Tons)	93,185	93,185	93,185	93,185	93,185	186,370	931,850
	Accumulated Mass Through Moore's Lake (Tons)	20,544	18,900	22,757	445	44,770	49,005	376,449
	Percent of Sediment Deposited in Reach Through Moore's Lake	22%	20%	24%	0%	48%	26%	40%
Change in Stream Bottom	Maximum Accumulation Upstream of Crossing (Excluding Stabilized Crossing) (ft)	0.53	0.42	0.53	0.80	0.78	0.14	0.49
	Maximum Erosion Upstream of Crossing (Excluding Stabilized Crossing) (ft)	-2.21	-4.99	-1.43	-3.03	-1.48	-1.12	-0.70
	Maximum Accumulation Downstream of Crossing (Excluding Stabilized Crossing) (ft)	0.28	0.80	0.17	0.28	0.27	**0.33**	**1.33**
	Maximum Erosion Downstream of Crossing (Excluding Stabilized Crossing) (ft)	NA	-0.11	NA	NA	NA	NA	NA
	Maximum Accumulation in Moore's Lake (Excluding Stabilized Crossing) (ft)	0.05	0.06	0.05	0.01	0.38	0.11	**1.33**
	Maximum Erosion in Moore's Lake (Excluding Stabilized Crossing) (ft)	NA	-0.14	NA	NA	NA	NA	NA

Figure 1: Median Summer Flow Sensitivity Analysis

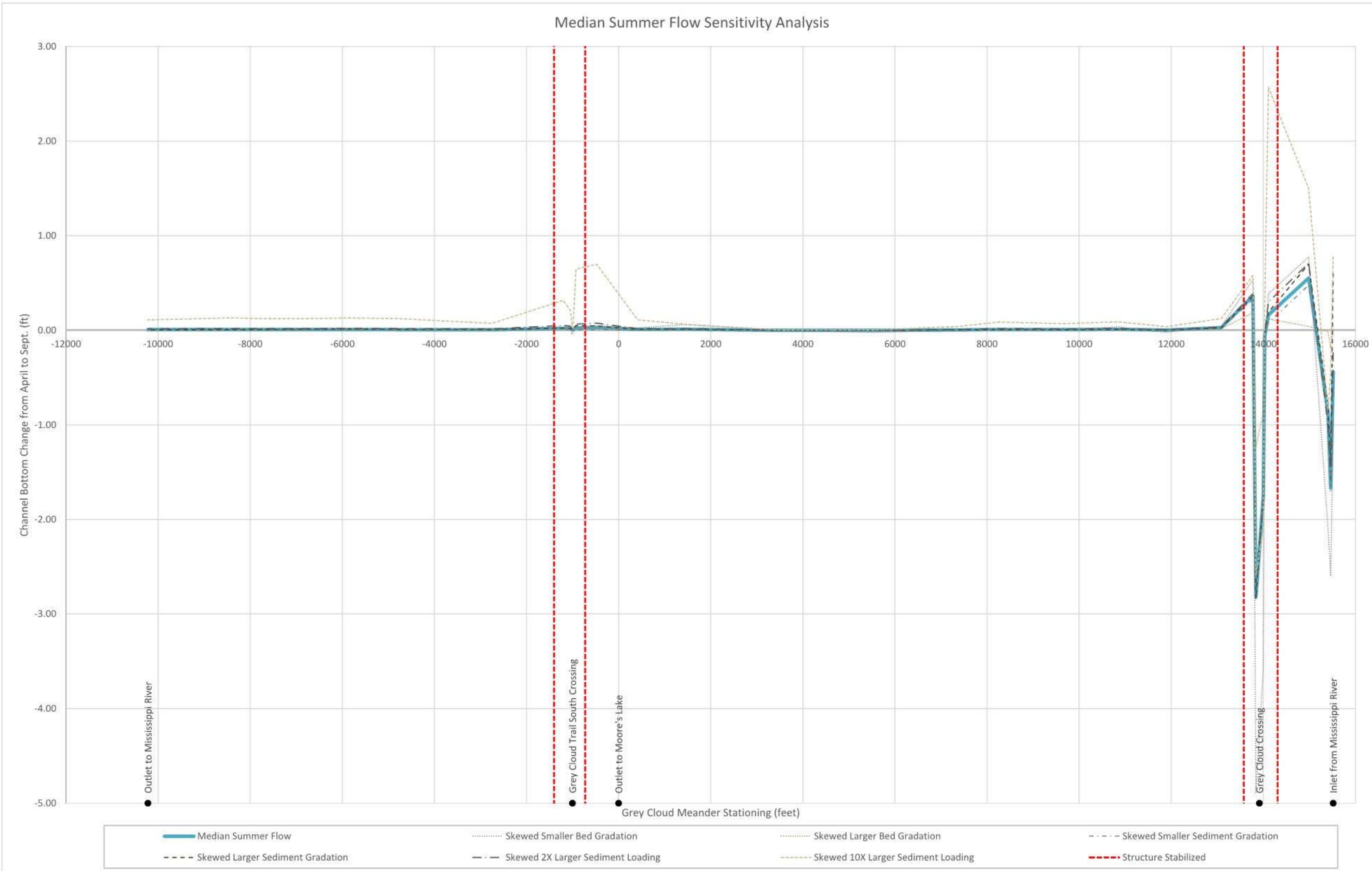

Figure 2: 100-yr Sensitivity Analysis