TECHNICAL MEMORANDUM

To: Matt Moore – South Washington Watershed District

From: Jonathon Kusa, Dan Miller, Ben Lee, Dan Mielke – Inter-Fluve, Inc.

Date: May 3, 2016

Re: Grey Cloud Slough Restoration Third Party Review.

Executive Summary

Inter-Fluve, Inc. (Inter-Fluve) has completed a third party review of sediment transport analyses along Grey Cloud Slough (GCS) completed by Houston Engineering Inc. (HEI). We agree with the general approach and methods used for the analysis. There are some revisions and additional analyses that could be made to strengthen and confirm the associated design recommendations including:

- Incorporate the wide flow areas along the downstream half of GCS into the model or provide discussion to justify their omission.
- 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.
- Sample bed sediment for use in the model or conduct a sensitivity analysis with larger and smaller sediment to evaluate influence on results.
- 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.
- Consider layering a rapid assessment of existing bank stability onto the scour and deposition results to estimate level of risk of bank erosion and channel migration if lateral migration is a concern.

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 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) .

Background

GCS is located along the east side of Grey Cloud Island within the pool formed in 1931 by construction of Lock and Dam number 2 on the Mississippi River. The inlet to the 15,000-foot long GCS is at approximately Mississippi River Mile 827.5. The Grey Cloud Island Drive South road embankment crosses the slough approximately one quarter mile downstream from the inlet. Culverts installed in 1923 through the road crossing were reported to be blocked during an emergency road raising in 1965 – resulting in current conditions and lack of flow through the slough.

Offices Nationwide
2121 Randolph Ave, 2nd Floor, St. Paul, MN 55105
617.714.5537 www.interfluve.com

The South Washington Watershed District (SWWD) is investigating the feasibility of restoring flow to GCS to improve water quality, fish passage and navigability. A feasibility report of a number of conceptual alternatives to provide conveyance through the road embankment was prepared by Houston Engineering Inc. (HEI, 2012). Partly in response to citizen concerns about potential deposition and channel migration of the Restoration Project, Inter-Fluve was retained to provide a third party review of the sediment transport analysis completed by HEI. Water quality, fish passage and navigability considerations in the HEI report are not included in this review.

Existing Information

Existing information made available to Inter-Fluve for review included:

- *"Grey Cloud Slough Restoration Feasibility Study and Addendum"* (HEI, 2012);
- HEI's HEC-RAS model for Mississippi River Pool 2 and Grey Cloud Island channels;
- HEI's sediment transport HEC-RAS model for Grey Cloud Slough;
- PowerPoint presentation "*Historic Aerial Photography Geomorphologic Analysis of Sedimentation near Grey Cloud Slough*" which included descriptions of project and historic aerial photos of the project and similar side channels";
- *"Mississippi River (Pool 2) 2-D ADH Model Development*" report by WEST consultants (2011); and,
- Comments and observations by a concerned citizen.

Review

Inter-Fluve reviewed the available information, focusing on river processes of sediment transport and geomorphic response evident in the historic aerial photographs. Key sections of the HEI report are summarized, followed by Inter-Fluve's comments and/or recommendations.

Project History. Recounting the historical events noted by HEI, a bridge was constructed across the slough in the early 1900s along the same alignment as the current Grey Cloud Island Drive South roadway. This bridge was replaced with culverts in 1923. Lock and Dam number 2 was completed, forming Pool 2 of the Mississippi River in 1931. The culverts were subsequently blocked during an emergency road raising in response to the 1965 flood. The road embankment blocks flows to the slough to this day. High flow events, summarized by HEI (2012), indicate that approximately four large flood events in excess of 80,000 cfs occurred prior to blockage of the culverts. Approximately seven large flood events in excess of 80,000 cfs have occurred since blockage of the culverts. The inlet to GCS appears to have maintained a similar plan form in the historic aerial photo series from 1937 to the present.

> Inter-Fluve Comments:
>
> As HEI noted in their report and evident in the HEC-RAS model thalweg profile, an area of deposition approximately 3 feet deep has occurred near the inlet to GCS. No large deposition bars, change in bank locations, evidence of erosion or significant reduction in capacity were noted. Ideally, gradation and volume of sediment deposited would be used to ascertain the geomorphic driver generating the deposition, but it is not included in the existing information. Consequently, based only on the current evidence provided, Inter-

Fluve would agree that the volume of sediment entering the GCS slough has not caused excessive deposition over the period of record.

Hydraulic modeling. The HEC-RAS modeling by HEI was completed in two steps. The first step was to construct a HEC-RAS model of hydraulic conditions without sediment transport to determine the flow split into GCS from the Mississippi River (split flow model). The second step was to create a separate HEC-RAS model that included only GCS to run the sediment transport model. A split flow model cannot run a sediment transport analysis in HEC-RAS. The upstream boundary conditions were specified as the resultant discharge from the split flow model. The downstream boundary condition was specified as a water level rating curve at Mooers Lake that resulted from the split flow model.

Inter-Fluve Comments:

HEI state that they validated the model to a previously calibrated model from 1972. More islands have formed along the main channel since 1972 which may influence hydraulic conditions at the inlet to GCS. Although updating the HEI HEC-RAS models with more recent data referenced in WEST's ADH model report should be considered, in our opinion it is unlikely to alter the GCS analysis and results.

Full split flow model:

- Consideration should be given to modeling Baldwin Lake as an ineffective flow area (Sections 69417 through 82514) for flows that do not overtop the berm between the main stem and the flood plain lake. Similarly, this approach should be considered for the river right flood plain between cross sections 60970 and 71777. These refinements would remove conveyance through an area that is not physically accessed by these lower flows. Or, limit conveyance to the capacity of the inlet channels - which are significantly smaller than the flood plain conveyance area - into the low flood plain areas.

Sediment transport model through Grey Cloud Slough:

- Cross sections along the downstream half of the slough are located at islands and hydraulic controls (Sections 1410 through 5532). From the Figure 4 plan view, the islands are isolated occurrences with persistent wide flow areas between the sections. The model will be accurate for characterizing water surface and energy at these locations. Analysis or discussion of sediment transport conditions through these wide flow areas should be included.
- Model cross section 7389 channel width includes an apparent backwatered flood plain along river-left. Model results for the channel top width increase from an average 140ft to over 438ft at this section. The channel width should be edited to be more consistent with adjacent cross sections.

Sediment Transport. The sediment transport analysis was based on average monthly flows for April through September. These months were chosen based on navigation and boating and water quality seasonality. Large flood conditions were modeled with a 100-year 30-day event.

Inter-Fluve Comments:

Larger flood events are the primary drivers of sedimentation in Upper Mississippi River sloughs and side channels (Belby, 2005; Knox, 2006). Estimating sedimentation rates with monthly mean flows does not accurately portray geomorphic processes in this environment. We recommend adding a typical 2-year flow hydrograph - similar to the 100-year event simulation. The 2-year event generally can be representative of geomorphic channel forming flow conditions. The 100-year event included in the HEI analysis is a good representation of large floods and sediment conveyance. Alternatively, a long-term simulation of the actual flow record (multiple years) could be modeled. This would provide a better characterization of sedimentation patterns through time.

Sediment. Suspended sediment data was based on the Saint Paul USGS gage data. Bed sediment data was obtained from the WEST Consultants' ADH model results.

Inter-Fluve Comments:

Suspended sediment: Grain size distribution was based on "two measurements" at the USGS Saint Paul gage. Two data points are insufficient for estimating this distribution as concentrations typically fluctuate greatly with increasing discharge, time of the year, antecedent watershed conditions, hysteresis effects, etc.

TSS vs SSC: Total suspended solids (TSS) is not the same as suspended sediment concentration (SSC) (Gray et al., 2000). SSC should be used for the sediment transport model. HEI should clarify if TSS or SSC were used.

Bed sediment: Bed material gradation should be refined by sampling slough substrates. If this isn't feasible, variation in model predictions should be explored with a sensitivity analysis using larger and smaller bed sediment gradations.

Sediment source: From cross sections in the two models, the main stem Mississippi River channel bed is about 10ft deeper than the Grey Cloud Slough inlet. It is unlikely that bed load sands would be delivered into the inlet. This could be verified by sampling bed materials or conducting a sensitivity analysis on model results using either sediment supply as equilibrium load based on the bed sand gradation versus the suspended sediment load.

Predicted scour and deposition. The HEC-RAS sediment transport model compares sediment inflow to outflow from a control volume at each cross section and distributes the difference as vertical depth of scour or deposition across the active channel. Lateral migration was not explicitly included in the model. The HEC-RAS sediment transport model output includes changes in channel invert elevation from deposition and erosion. Sedimentation rates based on the average monthly flows were between 0.01 and 0.05 ft/year (with only April through September months modeled). As noted in the HEI report and seen in the model results, sediment responses make sense:

- Stream bed scour occurs near the inlet through a localized hump of sediment deposition evident in the thalweg profile. Immediately downstream is a zone of deposition through a locally deep section of Grey Cloud Slough.
- As expected, scour occurs at the proposed bridge with subsequent deposition immediately downstream.

- Slight tendencies of scour and deposition occur along the slough to the outlet. This most likely is in response to variations in depth, width and local energy.

Inter-Fluve Comments:

The sedimentation rates based on average monthly flows are likely not the best possible estimate since they (1) do not represent large floods that drive sedimentation rates, (2) do not represent channel forming conditions (approximately a 2-year event) that are most representative of geomorphic channel patterns, and (3) do not capture the entire year. Further, wider channel sections along the GCS are not included in the model (larger flow area leads to lower velocities and greater potential for deposition). In an environment like GCS, organic matter and unconsolidated fine sediment may be relatively thick. After activating flow in the slough, these materials may quickly flush downstream, changing the geometry of the slough, and, thus, the hydraulic conditions. HEI did not note what type or extent of material was present in GCS.

Although the sedimentation rates appear minimal, they are consistent with rates observed in other Mississippi River floodplains and backwaters that have accreted sediment relatively quickly (Belby, 2005). After a few years of sedimentation, there may be hydraulic feedback from GCS that reduces the flow conveyance through the channel. This could exacerbate sedimentation. The HEC-RAS model does not explicitly address this potential progressive growth of deposition. Inter-Fluve recommends several iterative model runs to predict the potential for progressive deposition in this through flow environment. The predicted channel invert change can be saved out as a new geometry and rerun to provide a quasi-dynamic evaluation of channel response.

To evaluate potential for lateral migration of the GCS channel, risk of bank erosion could be further examined by overlaying a rapid assessment of observed bank stability with HEC-RAS predicted trends of deposition or erosion. Bank stability assessment would identify areas of stable, metastable and unstable banks and their respective bank height, slope and vegetation condition. Alternatively, a comparison of bank and bed resistance to erosion would aid in predicting if deposition would ultimately pass through the system or cause erosion of less erosionally resistant banks.

Other Pool 2 Side channels. Systemic increase in bar development was noted at a number of side channels and other areas along the main stem throughout Pool 2. The aerial photo summary provided shows these areas and conditions captured in aerial photos from 1937 to the present. HEI's PowerPoint presentation notes indicate that GCS is different from the side channels that filled in elsewhere in Pool 2 as GCS: (1) is a "break-out" channel, (2) "has a larger difference in water surface between the upstream and downstream junctions with the Mississippi River", and (3) is natural and was not constructed.

Inter-Fluve Comments:

HEI needs to define what a 'break-out' channel is and why hydraulic and geomorphic processes differ from other side channels. It is not clear based on the PowerPoint presentation. We presume this refers to GCS being a defined channel – as opposed to a broad inundated floodplain in which channels are forming through deltaic deposition patterns.

Energy gradient is a better metric than elevation difference for potential sedimentation. A larger difference in water surface elevation does not always mean there is less potential for sedimentation. The comparison side channels are all much shorter than GCS. It is possible that the energy grade through GCS is similar to the other channels in Pool 2 that have filled with sediment.

Many of these depositional areas are typical of sediment load entering a low gradient and broad area depositing in a deltaic pattern. A simple examination in Google Earth shows that most of these newly formed channels have a width ranging from of about 130ft to 225ft with an average around 150ft. Although the location and pattern changes through time, the general width of active channels appears to remain similar. GCS width is less than these new channels that are forming in broad inundated flood plain areas. This suggests that GCS will pass sediment without excessive deposition.

Additional Inter-Fluve Comments:

Consider adding more discussion on acceptable risk and service life of the project. Rivers are dynamic environments that are difficult to accurately predict. What change of conditions is acceptable and is a monitoring and adaptive management plan needed?

Consider conducting a 2D model of proposed conditions. This could be completed for the main channel near the inlet to GCS and within GCS and Mooers Lake to: (1) determine how lateral accelerations influence velocities and potential for sediment mobilization/deposition at the inlet to GCS, (2) provide a more accurate estimate of discharge in GCS, and (3) predict areas of deposition and erosion in GCS.

References

Belby, C.S. 2005. Historical Floodplain Sedimentation Along the Upper Mississippi River, Pool 11. Master of Science Thesis, University of Wisconsin-Madison.

Gray, J.R., G.D. Glysson, L.M. Turcios, and G.E. Schwarz. 2000. Comparability of Suspended-Sediment Concentration and Total Suspended Solids Data. US Geological Survey Water-Resources Investigations Report 00-4191, Reston, VA.

Knox, J.C. 2006. Floodplain sedimentation in the Upper Mississippi Valley: Natural versus human accelerated. Geomorphology, 79: 286-310.