BASIN-SCALE GEOMORPHOLOGY AND SEDIMENT TRANSPORT ANALYSIS FOR THE MOUSE/SOURIS RIVER ENHANCED FLOOD PROTECTION PLAN

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INTRODUCTION

Understanding the basin-scale geomorphology and dominant sediment transport processes active in any river system is an important first step when evaluating the potential impacts of large civil works projects. This paper focuses on the study of the Mouse/Souris River watershed in north-central North Dakota, conducted as part of the Mouse River Enhanced Flood Protection Plan. The work was conducted following the Mouse/Souris River flood of record in 2011 when the peak flow was more than five times the estimated 100-year peak flow for which existing channels and levees (constructed by USACE in the 1970's and 1990's) had been designed. In response to this catastrophic event, a plan to reduce the risk of flooding and flood-related damages was developed, including 21.6 miles of levees, 2.8 miles of floodwalls, two high-flow diversions, several transportation closure structures, and stormwater pump stations, among other measures.

This paper presents a framework for understanding how sediment is mobilized through the watershed and riverine system that is based on relating the geologic history of the basin to key present-day watershed (e.g., topography, soils, land use) and river (e.g., channel cross section, stream slope, planform) characteristics. The present day characteristics of the Mouse/Souris River are highly constrained by the area's glacial history, resulting in distinct river segments delineated by major geomorphologic features. Stream classification using basin-scale data affords a foundational understanding of the natural tendencies of the river that is essential in order to adequately evaluate the potential impacts on the morphodynamics (erosion and/or sedimentation) of the Mouse/Souris River associated with the proposed project.

GEOLOGIC SETTING

The configuration of today's Mouse/Souris River Basin is the result of the area's glacial history. The basin's origins can be traced to a catastrophic outburst of glacial melt water in Canada about 11,000 years ago (Lord (1991), Kehew and Teller (1994)). Floodwaters from this outburst carved what are now known as the Des Lacs and Mouse/Souris River valleys (Figure 1, Kehew and Clayton (1983)). The meltwater eventually flowed into glacial Lake Souris, which extended from Verendrye to the Canadian border, creating two distinct Mouse/Souris River reaches in North Dakota (upstream and downstream of Verendrye), each with its own behavior and structure.

Geologic events shaped not only the landscape but the paths the Mouse/Souris River now takes, affecting in particular its ability to convey water and sediment during extreme flood events. Signatures of the ancient glacial flood, such as shape and size of the Des Lacs and Mouse/Souris

River valleys and the lack of a confining valley downstream of Verendrye, still influence certain aspects of water and sediment movement (Figure 2). Of note for this study is that the highest potential for erosion will continue to exist in the river reaches upstream of Verendrye, while the downstream reaches will be more likely to experience sediment deposition in future floods.

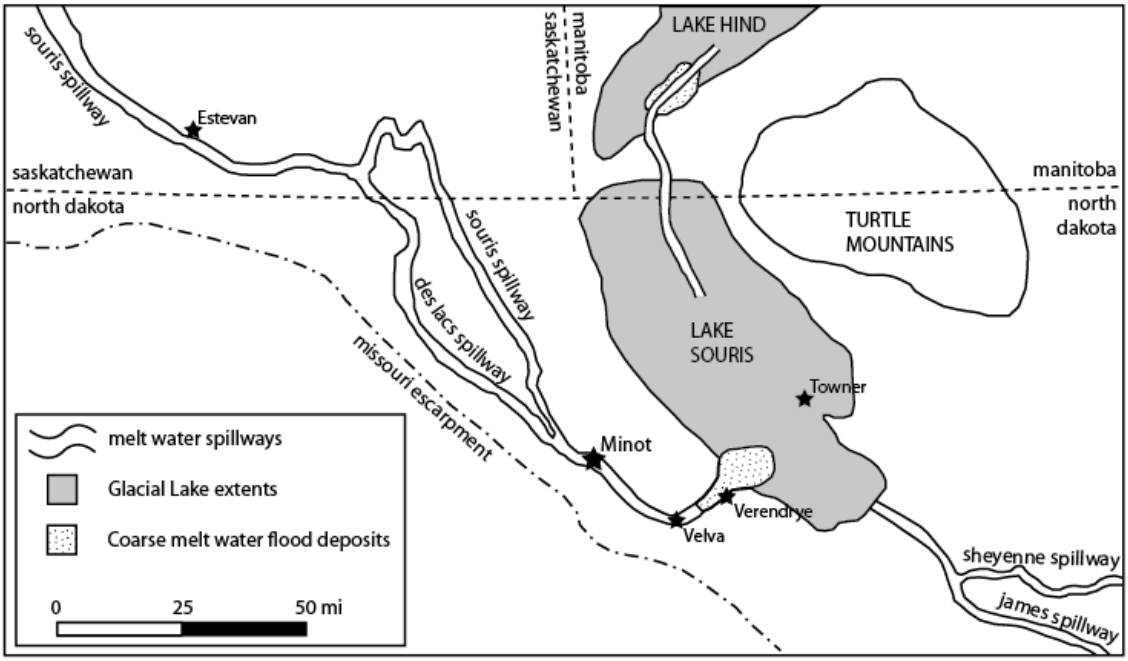

Figure 1 Schematic map of significant glacial landforms in the Mouse/Souris River watershed, after Kehew and Clayton (1983).

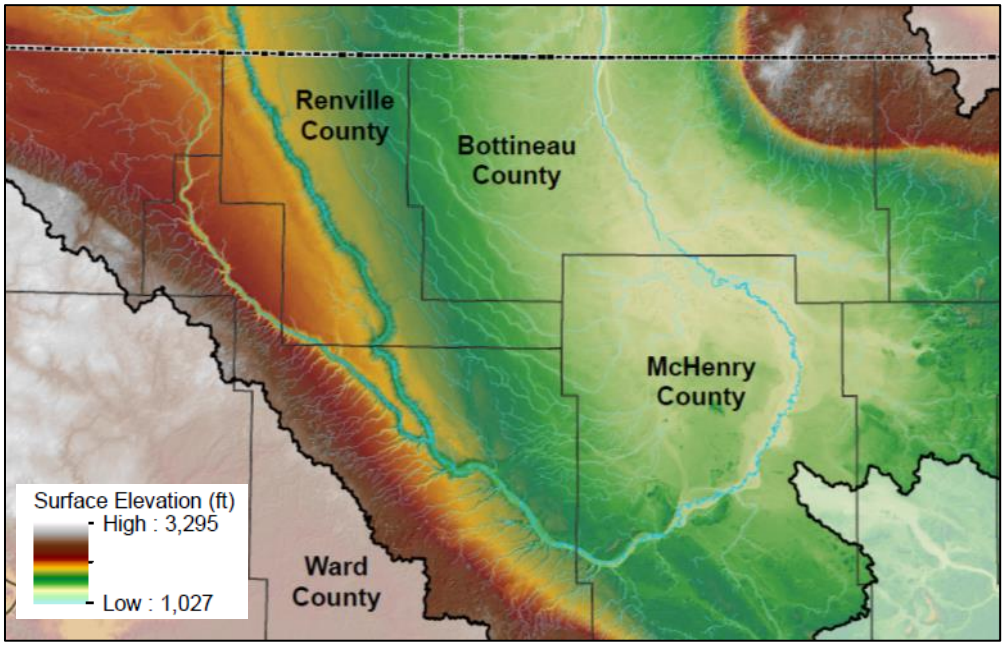

Figure 2 Mouse/Souris River watershed topography.

VALLEY AND STREAM CHARACTERISTICS AND CLASSIFICATION

The overall goal of stream classification is to organize and describe stream reaches based on shared attributes. The methods, metrics, and spatial and temporal scales used in stream classification systems vary widely, but such systems frequently use common characteristics such as river width, valley width, slope, sinuosity, and amplitude or radius of curvature (see for example Leopold et al. (1964), Montgomery and Buffington (1993), and Rosgen and Silvey (1996)). Grouping stream reaches based on quantitative characteristics presents the ability to look for patterns, identify commonalities and differences, and make inferences about the future behavior of the stream system. The emphasis of the analysis presented here is on developing an understanding of the processes at work in the Mouse River and its history rather than to take a point-in-time snapshot of the river under current conditions. For this study, streams were classified according to features of both the valley and the river channel.

Characteristics used in stream classification

- Valley width
- Valley slope (in direction of river flow)
- Valley sediment types (represented by % sand)
- Land use
- Channel width
- Channel cross-sectional area
- Channel slope (in direction of river flow)
- Channel length per unit valley length (sinuosity)
- Channel planform

The project team classified the Mouse/Souris River into nine reaches that vary in length and have been grouped according to similar valley, channel, and sediment characteristics (Figure 3). The nine reaches defined for the Mouse/Souris River can be broadly considered as three separate groups: upstream of Burlington (reaches G-H-I), between Burlington and Verendrye (reaches D-E-F), and downstream of Verendrye (reaches A-B-C). This grouping corresponds to the major geologic shifts along the Mouse/Souris River: the confluence with the Des Lacs River at Burlington and the entrance to the bed of glacial Lake Souris at Verendrye.

The reaches of the Mouse/Souris River between Burlington and Verendrye (reaches D-E-F) received the most attention in the study because 1) they are the areas with the steepest river gradient and contain soils most likely to be mobilized; 2) have been most affected by changes in the last several decades; and 3) will be the most directly affected by the proposed project. This section of the river is the most susceptible to erosion.

The reaches downstream of Verendrye (reaches A-B-C) may also be influenced by the proposed project because they lie downstream of the project features and receive sediment carried from upstream reaches. These reaches represent the portions of the river that have 1) the lowest river gradients; 2) soils typically finer than those in upstream reaches; 3) the most open water and wetlands; and 4) the lowest channel banks. This section of the river is the most likely to experience sediment deposition.

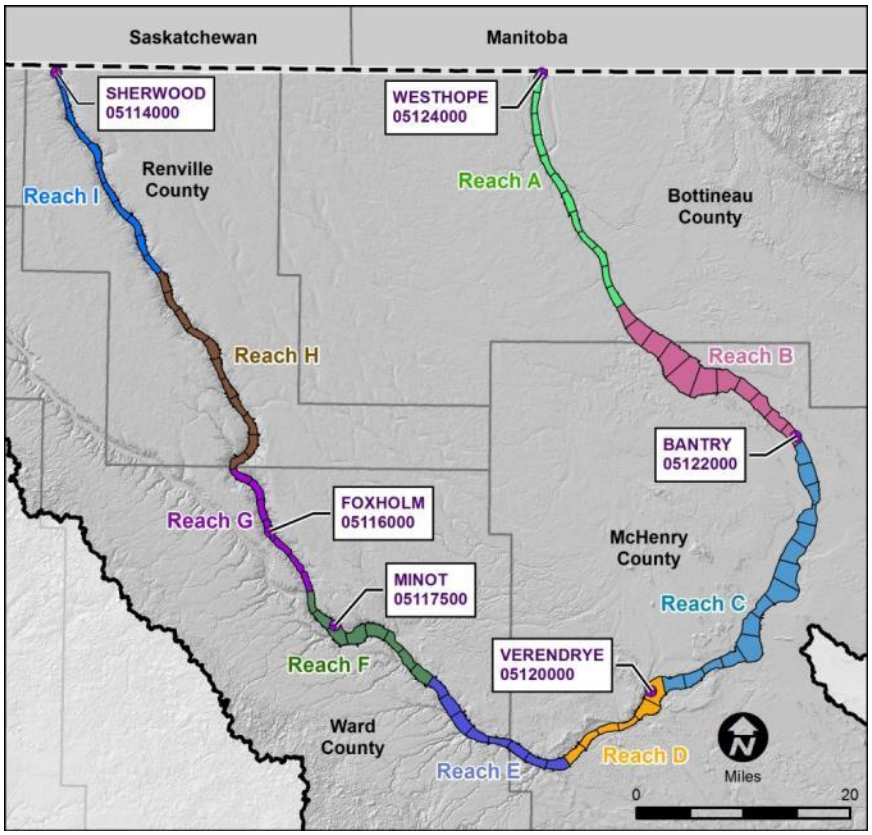

Figure 3 Mouse/Souris River valley geomorphic reaches.

The reaches upstream of Burlington (reaches G-H-I) will be less affected by the project partly because Lake Darling controls sediment movement in the system.

CHANGES IN RIVER SHAPE OVER TIME

The Mouse/Souris River valley has undergone significant anthropogenic changes in the past 150 years, including shifts in land use, increasing population, and construction of several federal flood-risk-reduction projects. The historical changes in the valley suggest how the river may adapt to future modifications of the channel and/or floodplain.

A key source of historic information about the Mouse/Souris River is aerial photography. The consulting team compared aerial photos taken in 1946 and 1969 with 2010 images and assessed the changes in the river's centerline. The 1969 photos show the river as it existed before the addition of flood-risk-reduction measures between Burlington and Velva. The 1946 images, although taken after the construction of Lake Darling, constitute the area's earliest full set of aerial photographs.

Comparing the images revealed that in areas not located near flood-risk-reduction works, changes in river alignment and in the river length (or sinuosity) over the past several decades have been minimal. While the Mouse/Souris River actively meanders, the observed rate of

channel migration—the slow but constant reshaping of a sinuous river—is not high for a river with its characteristics.

In contrast, pronounced changes in river length have occurred in reaches subject to the channel straightening and cutoff of bends that were part of federal projects (Figure 4). For the 10-mile-long section of river valley near Minot, these projects caused a reduction in stream length of more than 40% (9 river miles) between 1969 and 2010. The sinuosity (ratio of river length to valley length) for this section of the valley is now markedly different from that in the rest of the Mouse/Souris River valley, a condition that can cause excessive erosion and "unraveling" as the river attempts to compensate for the imposed reduction in length. Although no observable major changes in other river characteristics have occurred since the federal projects were completed, there is a limit to how much straightening can be performed without increasing erosion.

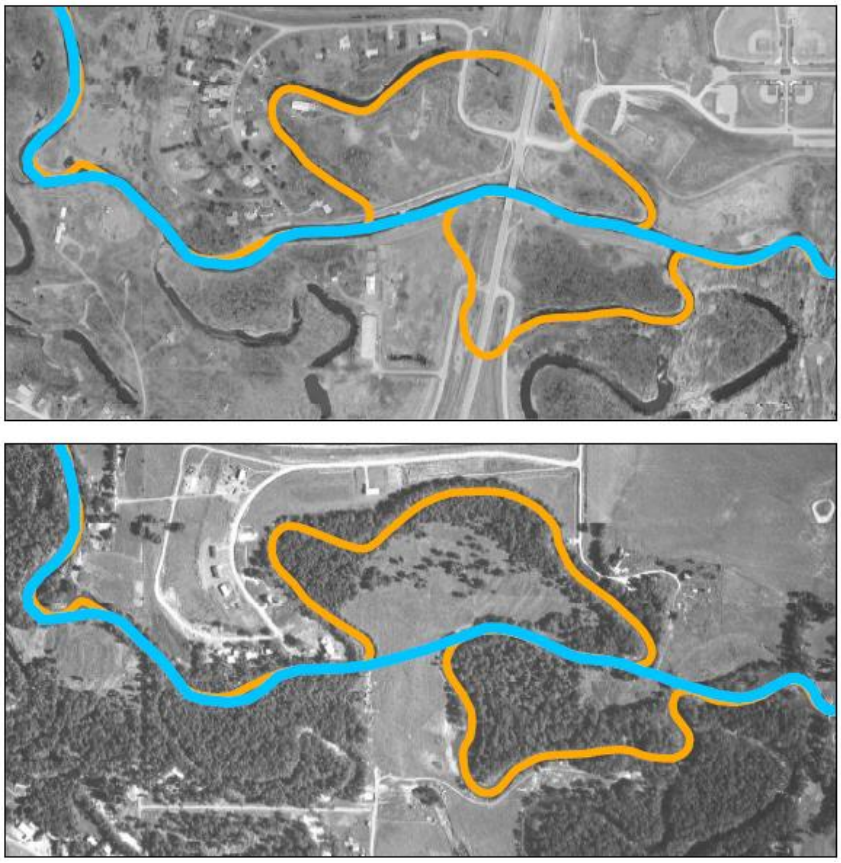

Figure 4 Aerial photographs from 1969 (bottom) and 2010 (top) showing a meander cut off by a federal flood risk reduction project.

SEDIMENT CHARACTERISTICS

Another important source of historic information is sediment transport data, including measurements of the type and quantity of sediment that is transported in the river system. Measurements of the channel-bed material size are especially important, because different types of soil particles interact differently with flowing water.

The available sediment-transport data for the Mouse/Souris River was collected mostly by the U.S. Geological Survey in the 1970s. Because the data is very limited in the most sensitive Burlington-to-Verendrye reach (especially with respect to channel-bed material and to sediment transport rates for a wide range of flows), the team could not quantify erosion or sedimentation potential. Based on the available data, the Mouse/Souris River in the vicinity of Minot appears to have bed material of primarily fine sand and relatively low suspended sediment concentrations (Figure 5).

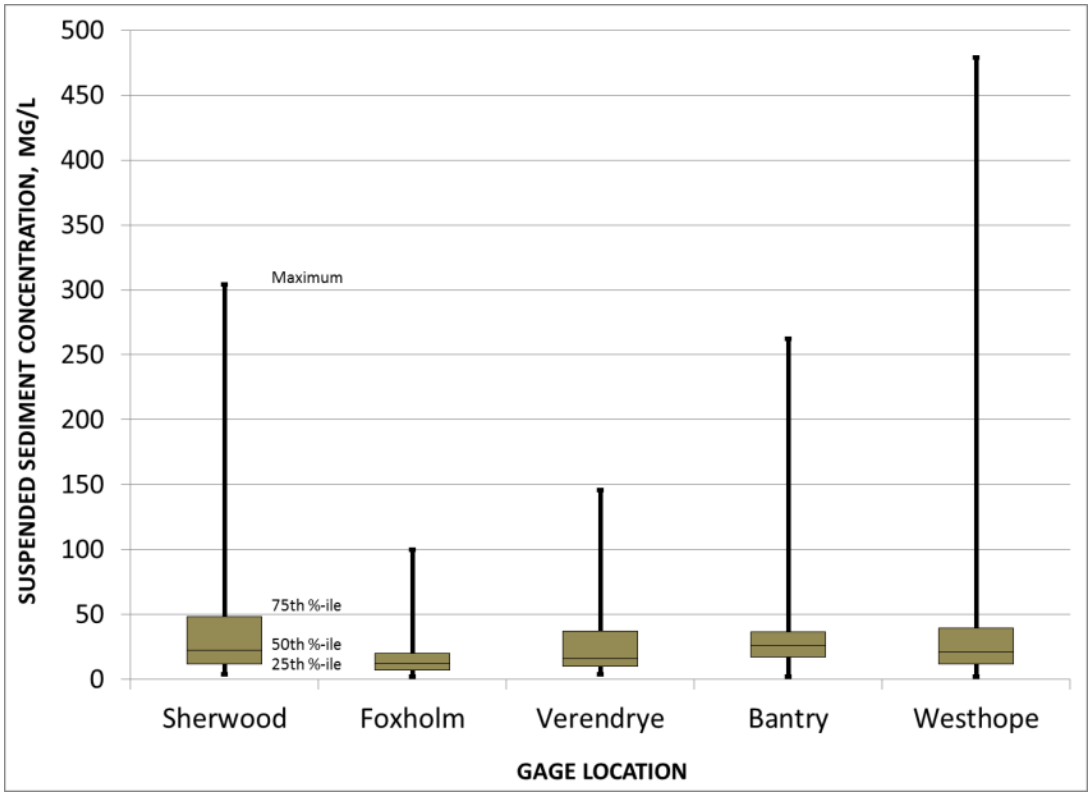

Figure 5 Mouse/Souris River suspended sediment concentration ranges.

PRELIMINARY EVALUATION OF POTENTIAL PROJECT IMPACTS

Based on the initial characterization of the processes of erosion, transport, and deposition of river sediment in the study area, it is possible to offer a preliminary qualitative assessment of erosion and sedimentation impacts that may occur in the Mouse/Souris River if the proposed flood-risk-reduction project is implemented.

As discussed above, the reaches of the Mouse/Souris River between Burlington and Verendrye are naturally more susceptible to erosion. Because the project will increase flow velocities in some locations during very high flow conditions, the project's most likely local impact is an increased risk of erosion. The design considerations of the preliminary project alignment are intended to reduce the potential for erosion by including areas of overbank excavation and widening many of the bridge openings and by providing scour protection near diversion

structures. However, current plans call for some bridge crossings to significantly constrict flood flows—a situation that may lead to erosion in extreme flood events.

In addition, there is a risk of increased erosion (both bank erosion and channel scour) where the river channel is constricted by levees occupying a significant portion of the floodplain. This is particularly true in areas where the river is restricted to a very narrow region between a levee on one side and a valley wall on the other. At these locations, flow convergence may result in increased erosion (Figure 6).

Figure 6 Significant erosion and channel migration after the 2011 flood opposite the existing levee at Velva.

The Souris Valley Golf Course in Minot (Figure 7) will continue to be an area within the proposed project limits that is subject to sediment deposition. In the preliminary alignment created for this project, the golf course is the only area within Minot where the river has an appreciable floodplain, which reduces flow velocity even during very large floods and allows sediment deposition to occur. Similar deposition is also likely just downstream of Minot where the river will leave the protected area and return to its natural floodplain.

Judging by the characteristics of the Mouse/Souris River's valley and channel and by observations from the 2011 flood, it is unlikely that erosion and sedimentation impacts from the project will extend beyond the most sensitive reaches between Burlington and Verendrye. However, additional field investigations and numerical modeling are warranted to validate this

initial conclusion, particularly as it relates to the development of river management alternatives in the rural areas.

Figure 7 Sand deposition after the 2011 flood at the Souris Valley Golf Course.

There is not sufficient information available (especially for sediment characteristics) to numerically quantify the magnitude of the erosion and sedimentation impacts discussed above. These impacts can be quantified by modeling the most sensitive reaches of the river—modeling that accounts for driving forces (e.g., shear stress) and sediment characteristics (especially of the bed material) and sediment loading.

CONCLUSIONS

Present day characteristics of the Mouse/Souris River are highly constrained by the area's glacial history, resulting in distinct river segments delineated by major geomorphologic features. Stream classification using basin-scale data affords a foundational understanding of the natural tendencies of the river that is essential in order to adequately evaluate the potential impacts on the morphodynamics (erosion and/or sedimentation) of the Mouse/Souris River associated with the proposed project.

The primary objective of this study was to characterize the river morphology and sediment transport processes in the study area and to use this characterization to conduct a preliminary evaluation of the proposed project's potential to result in undesirable erosion and sedimentation

impacts. The evaluation was qualitative due to the limited available historic information on sediment-related variables. The qualitative evaluation has served the purpose of identifying data gaps and additional analyses that will be required to determine the magnitude of the impacts and propose measures to lessen these impacts.

One of the preliminary conclusions of this study is that despite the significant existing alteration of some Mouse/Souris River reaches (such as channel straightening and levee construction), only isolated erosion and sedimentation impacts were observed in a very extreme event (the 2011 flood of record). Additional river alignment alterations associated with the proposed project or alterations in the rural areas could translate into a different outcome.

The main outstanding questions in this report that may be addressed in a future phase of study are 1) how will the project change sediment transport upstream and downstream of project features, and 2) what will be the magnitude of the associated erosion or sedimentation responses to such changes?

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