Executive summary

Background: the 2011 Mouse River flood

The erosion and sedimentation resulting from the 2011 flood of record were attributable to some of the most extreme conditions witnessed along the Mouse River in the last 150 years. The record runoff volume and high flow velocities resulted in what was likely the largest amount of sediment mobilized from the watershed and the river channel itself, leading to significant amounts of fine sediment being deposited in some areas of the floodplain.

Given the magnitude of the 2011 flood, there was remarkably little erosion in the most developed portions of the Mouse River between Burlington and Velva. The most significant erosion took place where river flow was most restricted, such as at bridge crossings (see Figure 1). Localized erosion was also observed in several sections of the river where levees had been constructed on one side of the river, which may have increased the erosive forces on the opposite bank.

Erosion in rural areas was highly localized. It occurred at bridge crossings and in locations where the flooding river is naturally constricted on one or both sides by valley walls. In addition, erosion was observed in locations where the river encountered loose sandy or silty soils with little cohesive material. In many cases, the material moved by localized erosion was deposited in backwater areas a short distance (1 to 2 miles) downstream.

Flood-related sedimentation impacts on the Souris Valley Golf Course in Minot were also notable because the golf course is one of the few areas in the city where the Mouse River is not confined by levees or steep valley walls directly on either bank. Several inches of fine sand were deposited on the golf course (Figure 2). Similar deposits of sand were observed near the Highway 2 bypass on the downstream side of Minot, where the absence of levees and steep valley walls allowed the Mouse River to flow out of its banks and onto the floodplain.

Although 32,000 acres of McHenry County farmland was affected by flooding, widespread sediment deposits were small (fractions of an inch in depth) because the river flooded at relatively shallow depths over a very large area. There was significant deposition of organic matter (algae) and flood debris on these lands. The largest sediment deposits—up to several feet in places—occurred mainly in old river channels (oxbows) and other lowlands, especially in northern McHenry County near the J. Clark Salyer National Wildlife Refuge.

The Mouse River, like any other river or stream, will have areas of observable erosion and sedimentation under natural conditions. Furthermore, changes over time in a river's course (called channel migration) are common, with erosion occurring on the outer banks of river bends and sedimentation on the inner banks as the river channel continuously reworks itself across its valley. Rivers move sediment in addition to water; this is their natural behavior. A river in a state of equilibrium does not translate into a channel of fixed dimensions or a completely static alignment. On the contrary, a river in equilibrium moves a bit in one place while not moving much in another place. Maintaining such equilibrium is the challenge for any project.

Figure 1: Significant erosion downstream of the Highway 41 bridge at Velva is illustrated by the proximity of the pine trees to the riverbank—before the 2011 flood, about 300 feet of land stood between these trees and the river

Figure 2: Sand deposition occurred on the Souris Valley Golf Course in Minot because it lies in an area where the river is relatively unconfined by levees or steep valley walls

Study purpose

In the aftermath of record flooding along North Dakota reaches of the Mouse River in June 2011, the North Dakota State Water Commission retained a consulting team led by Barr Engineering Co. to develop a plan to reduce the risk of flooding from future events of similar magnitude. The Preliminary Engineering Report (PER) for this plan, completed in February 2012, included a preliminary alignment for flood risk reduction. It also included engineering, environmental, and cost considerations for the project along the Mouse River reach between Burlington and Velva, as well as for Mouse River Park.

At the request of the Souris River Joint Board , the consulting team has turned its focus to rural areas along the entire Mouse River length within North Dakota. As part of this effort, and in order to complement the PER recommendations, the consulting team has completed the first phase of a study of erosion and sedimentation issues associated with the project. An assessment of the project's potential impacts on erosion and sedimentation may be necessary to support environmental review and permitting of the project, and is needed to determine whether the design of flood-risk-reduction features should be modified in future phases of plan development to help minimize impacts. This assessment considers not only the plan as presented in the PER, but also offers factors to consider during the development of river management alternatives in the rural areas.

Before the potential project impacts can be quantified, however, it is important to understand the processes that shape the landscape in the Mouse River watershed—including human influences and the basin's geologic history. Furthermore, this understanding provides a basis for estimating the likelihood and magnitude of any erosion and sedimentation impacts associated with the project.

The study's main findings are presented in this executive summary. Detailed information is contained in the main report and appendices. The general objectives of the study's first phase were to:

- Provide an initial characterization of the processes of erosion, transport and deposition of river sediment in the study area based on available data

- Use the initial characterization as the basis for conducting a preliminary qualitative evaluation of the project's potential to result in undesirable erosion and sedimentation

- Identify the modeling and additional data needed in the next phase of the study, during which the team will perform detailed field investigations and sediment transport modeling to not only quantify the project's potential impacts, but to propose measures for minimizing adverse impacts from implementation of the PER project

Report components

Geologic setting: The geologic history of the watershed and the basin-wide topography and land use have formed the landcape through which the Mouse River flows, and influence the long-term processes that shape the river. The report includes a literature review of the basin's geologic history and summarizes the watershed-wide conditions.

Valley and stream characteristics: By comparing characteristics of the river and its valley along the river's length, engineers and scientists can identify the broad sections of a river that behave differently from one another. The report includes analysis of the current conditions along the Mouse River and divides the river into nine distinct reaches.

Changes in river shape over time: The best way to understand a river's tendency to erode and deposit sediment is to look for changes in the river's position or cross-sectional shape over time–including changes such as channel straightening. The study includes analyses of both historic aerial photography of the Mouse River and a limited set of available historic cross-sectional surveys performed by the USGS.

Sediment characteristics: In order to quantify erosion and sedimentation, the type and quantity of sediment in the river system must be well defined because the erosion, transport, and deposition patterns vary among different types of soils. The report includes a compilation of the limited data available on river-bed sediment sizes and suspended sediment concentrations.

Lessons from the 2011 flood: The erosion and sedimentation issues caused by this massive flood highlight the areas of most concern on the Mouse River. The report includes a summary of erosion and sedimentation from 2011 based on a site visit and interviews with the U.S. Army Corps of Engineers and rural resource managers.

Geologic setting

The configuration of today's Mouse 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. Floodwaters from this outburst carved what are now known as the Des Lacs and Souris/Mouse River valleys (Figure 3). The melt water eventually flowed into glacial Lake Souris, which extended from Verendrye to the Canadian border, creating two distinct Mouse 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 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 Souris/Mouse River valleys and the lack of a confining valley downstream of Verendrye, still influence certain aspects of water and sediment movement (Figure 4). The central issue for this study was 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.

Valley and stream characteristics and classification

Engineers and scientists use shared characteristics to group and describe river reaches as part of establishing baseline conditions for rivers and predicting their future erosion and sedimentation patterns. This practice is called stream classification. For this study, streams were classified according to features of both the valley and the river channel.

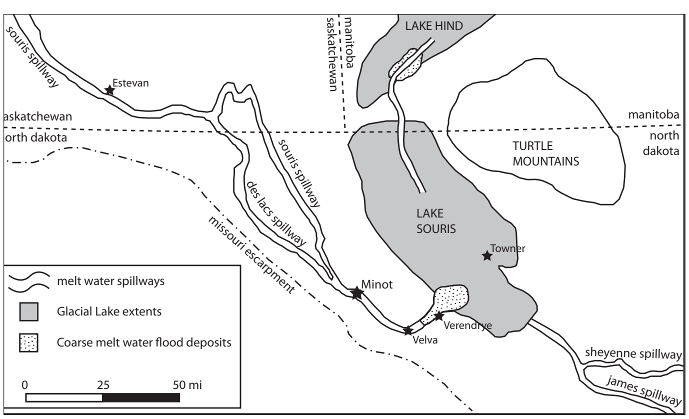


Figure 3: The Des Lacs and Souris/Mouse valleys were carved by an outburst of water from a glacial lake to the northwest, and entered Lake Souris near what is now Verendrye

The project team classified the Mouse River into nine reaches that vary in length and have been grouped according to similar valley, channel, and sediment characteristics (Figure 5). The nine reaches can be broadly considered as three 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 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 River between Burlington and Verendrye (reaches D, E, F) received the most attention in this study because 1) they are the areas with the steepest river gradient and contain the 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 PER project. This section of the river is the most susceptible to erosion.

The reaches downstream of Verendrye (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.

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

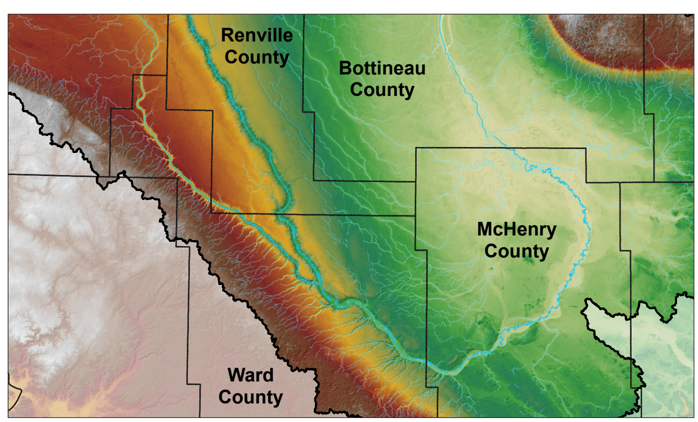


Figure 4: The glacial history of the Mouse River watershed can still be seen in the distinct valleys in Renville and Ward counties and the flat topography in McHenry and Bottineau counties (green depicts low elevations)

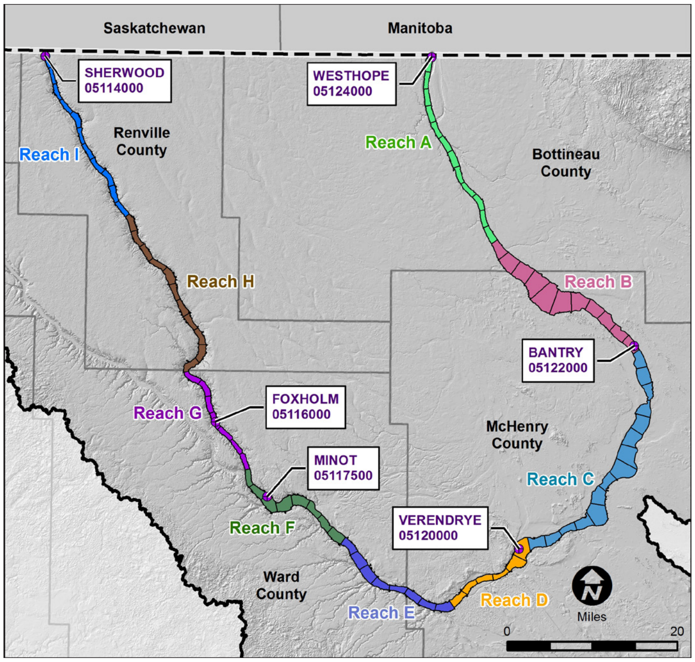


Figure 5: Stream classification yielded nine distinct reaches of the Mouse River (callouts show the locations of USGS flow-gaging stations)

Characteristics used in stream classification

- Valley width
- Valley slope (in direction of river flow)
- Valley sediment types (percent sand—see Figure 6)
- Land use
- Channel width
- Channel cross-sectional area
- Channel slope (in direction of river flow)
- Channel length per unit valley length (sinuosity)
- Channel course as viewed from above (Figure 7)

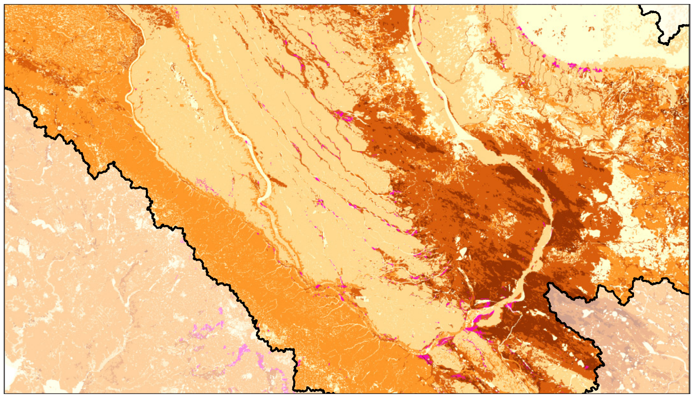


Figure 6: Watershed-wide information, including the different percentages of sand in surface soils, was used to characterize the Mouse River valley (the darkest shades indicate soils made up of at least 80% sand)

Changes in river shape over time

The Mouse River valley has undergone significant man-made 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 River is aerial photography. The consulting team compared aerial photos taken in 1946 and 1969 with 2010 images, and assessed 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 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.

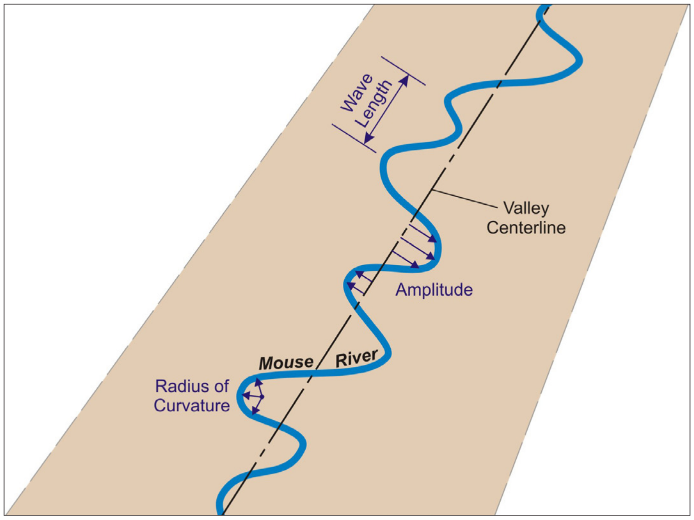
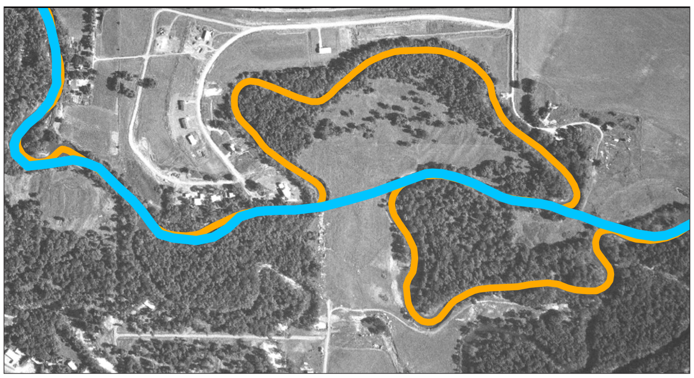


Figure 7: Stream classification included analyzing the river's pattern, which indicates how the river is responding to the forces that shape it

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 8). 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 of the rest of the Mouse River valley, a condition that can cause excessive erosion and "unraveling" as the river attempts to compensate for the imposed redution 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 done without increasing erosion.



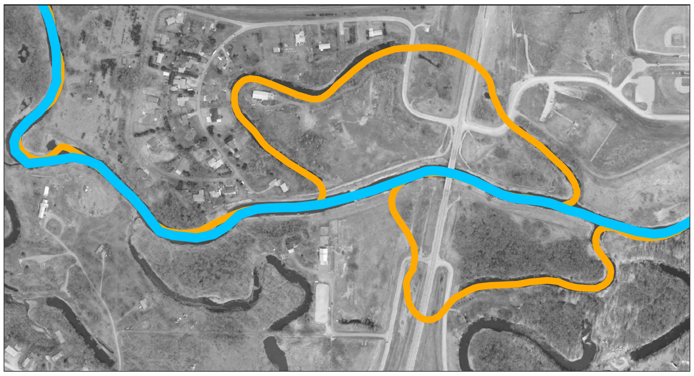


Figure 8: Aerial photos from 1969 (top) and 2010 show natural bends cut off by federal projects over the last several decades, which has reduced the river's length by 9 miles in the reach that includes Minot. The river's original course appears in orange; its current course in blue.

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 River was collected mostly by the U.S. Geological Survey in the 1970s. Because this 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 though, the Mouse River in the vicinity of Minot appears to have bed material of primarily fine sand and relatively low suspended sediment concentrations (Figure 9).

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 River if the proposed flood-risk-reduction project is implemented.

As discussed above, the reaches of the Mouse 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 alignment already are intended to reduce the potential for erosion by including areas of overbank excavation and widening many of the bridge openings

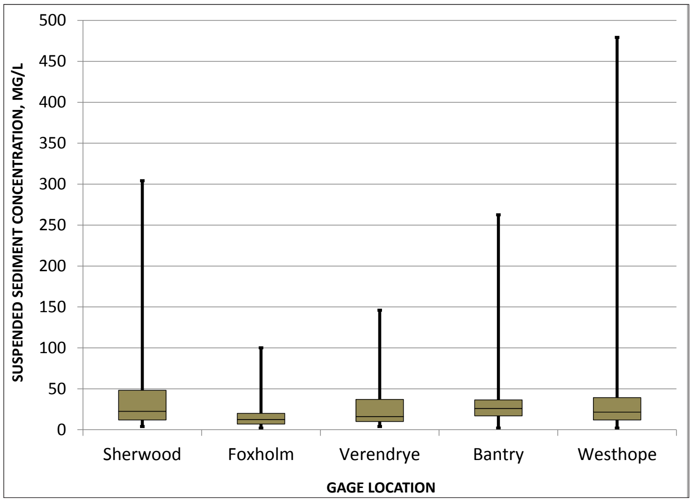


Figure 9: Suspended sediment concentrations vary along the Mouse River but are generally less than 50 milligrams per liter, indicating that typical flows in the river do not carry large amounts of sediment

(Figure 10), 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.

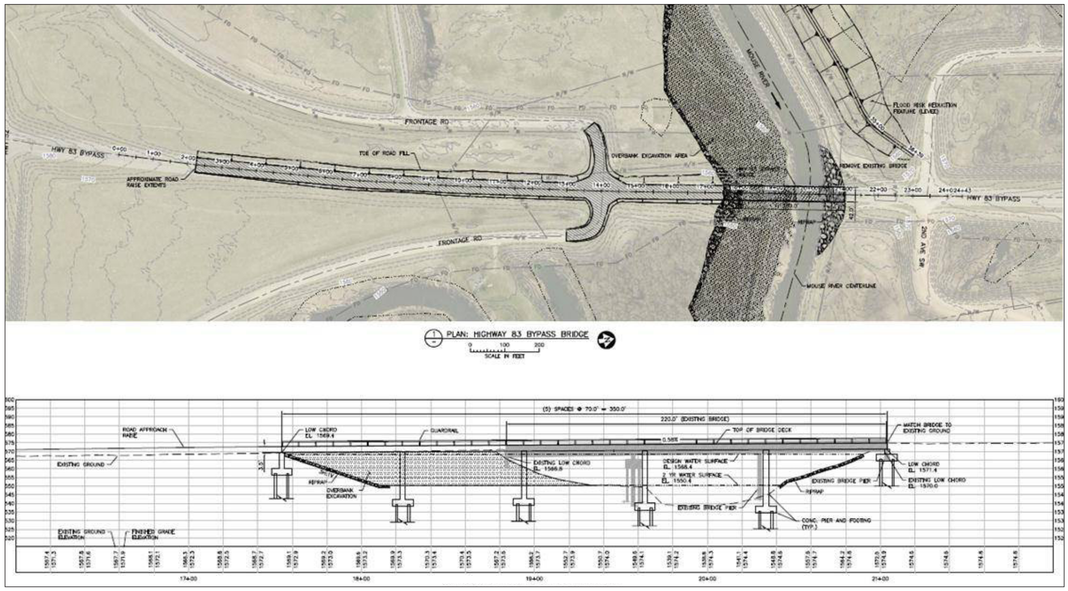


Figure 10: The PER includes designs to widen bridge crossings and reduce potential erosion—and therefore reduce downstream sedimentation

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 11).

The Souris Valley Golf Course in Minot will continue to be an area 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.

Figure 11: The most severe erosion in 2011 occurred where levees or steep valley slopes constricted the flow or water, such as this point on the Des Lacs River in Burlington

Judging by the characteristics of the Mouse 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.

There is not sufficient information available (especially on 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 load estimates).

One of the preliminary conclusions of this study is that despite the significant existing alteration of some Mouse 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 PER project or alterations in the rural areas could translate into a different outcome.

Future tasks to improve impact assessment

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 PER project's potential to result in undesirable erosion and sedimentation impacts. The evaluation has been 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.

The main outstanding questions in this report that should be addressed in a next phase of erosion and sedimentation 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?

A more quantitative analysis will likely be required to support the environmental review and design tasks; therefore, additional data collection, modeling, and analyses should be conducted in a future phase of study. These tasks should include:

- **Field sediment data collection.** It is recommended that data be collected on suspended sediment concentrations and gradations; bed and bank material gradations; and bed loading rates and gradations to use as input in the estimation of impacts (Figure 12).

Just as flood modeling requires an understanding of precipitation patterns and water flow behavior, answering the erosion and sedimentation questions above requires an understanding of the driving and resistant forces of sediment movement through the river system. It is important to quantify the balance between the magnitude and frequency of flows (the driving forces) versus the type of sediment in the watershed and in the channel (the resistant forces) in order to quantify sediment movement and associated erosion and sedimentation—under both existing conditions and with-project—so that impacts can be determined and engineering solutions can be proposed. **This may be necessary also to support environmental review and permitting of the project.**

- **Field channel cross-section surveys.** New data should be collected at a limited number of locations to increase understanding of the Mouse River's local geomorphology (landform-shaping processes) in areas most sensitive to project-related changes (see Figure 13).

- **Historic cross-section measurements.** Archived USGS data should be obtained to provide a better understanding of how the Mouse River has been affected by previous flood-risk-reduction efforts and how it might continue evolving after implementation of the proposed PER project or the river management alternatives in rural areas.

- **Sediment transport modeling.** Modeling is necessary to quantify the project's effects on sediment transport in the river. Depending on the degree of predicted impacts, changes to project features may be recommended.

Figure 12: Bed-material samplers are used to collect soil and sediment from river bottoms, a task recommended for a future phase of study

Figure 13: Field channel cross-section surveys include identifying indicators of predominant channel-shaping flows