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A Little Flood Geology

Part II: Examples from Central Montana

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Abstract

As argued in Part I of this series, floods are a key category of geologic processes. Common floods make important analogues to megafloods, including the Deluge of Noah's day. This paper provides some examples of geologic work by floods and related processes in Central Montana as experienced by the author, and also provides ideas about how these may apply to the study of earth history.

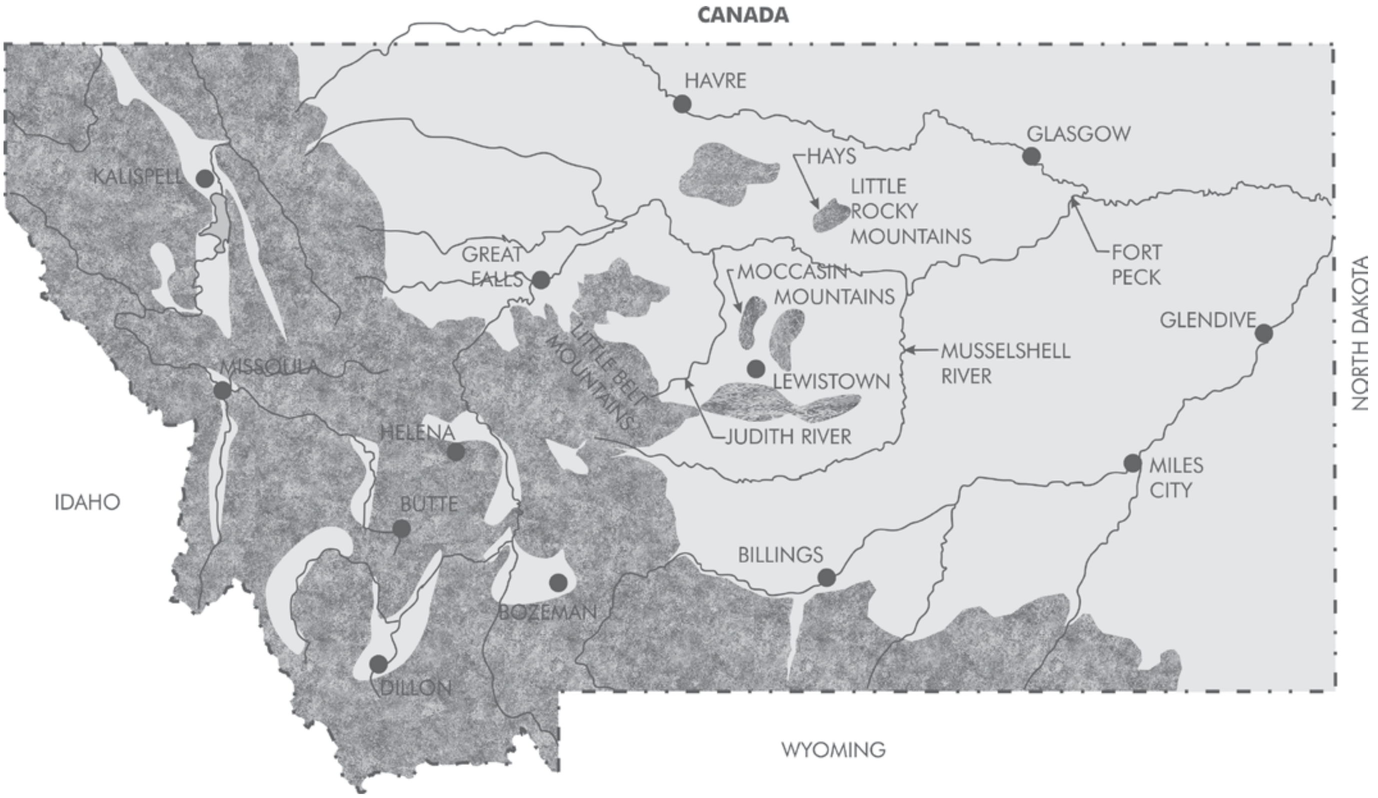

Figure 1. Map of Montana showing major rivers and mountainous areas (stippled).

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Introduction

Geologists have begun to increasingly recognize that uniformitarianism falls flat when attempts are made to apply present process rates to natural history speculations. As introduced in Part I of this series, a great canyon or valley cannot be eroded sand grain by sand grain if the current is too weak to move sand grains. Bedrock cannot be eroded if the physical weathering processes are incapable of breaking it down. Geologic processes often resemble the adage about war: "Long periods of boredom interspersed with short periods of terror." Nearly all geologic work by streams occurs during floods.

Central Montana in 2011

Montana has a semi-arid climate, but the relatively low temperatures and typical timing of precipitation allow much of the state to grow small grains and other crops. Snow pack normally melts in the early spring, and most of the year's precipitation falls as rain from late April through early June. The early years of this century were largely characterized by late winters and cold, late springs. An above-average snow pack in 2011 combined with a late, cold spring to produce unusual flooding. Much of the snow did not melt until the spring rains arrived, and the results were a great educational experience for geologists and geotechnical engineers. Mass wasting and flood processes resulted in a remarkable amount of localized change in the landscape, along with some puzzling effects.

Many of these effects were widespread and not limited to Montana, as reported in the Great Falls *Tribune*, Minot *Daily News*, and many other news outlets of various media, but the regional effects are outside the scope of this paper. Flooding occurred on a larger scale outside the study area, e.g. shutting down Interstate 90 in southern Montana and the Burlington Northern Santa Fe

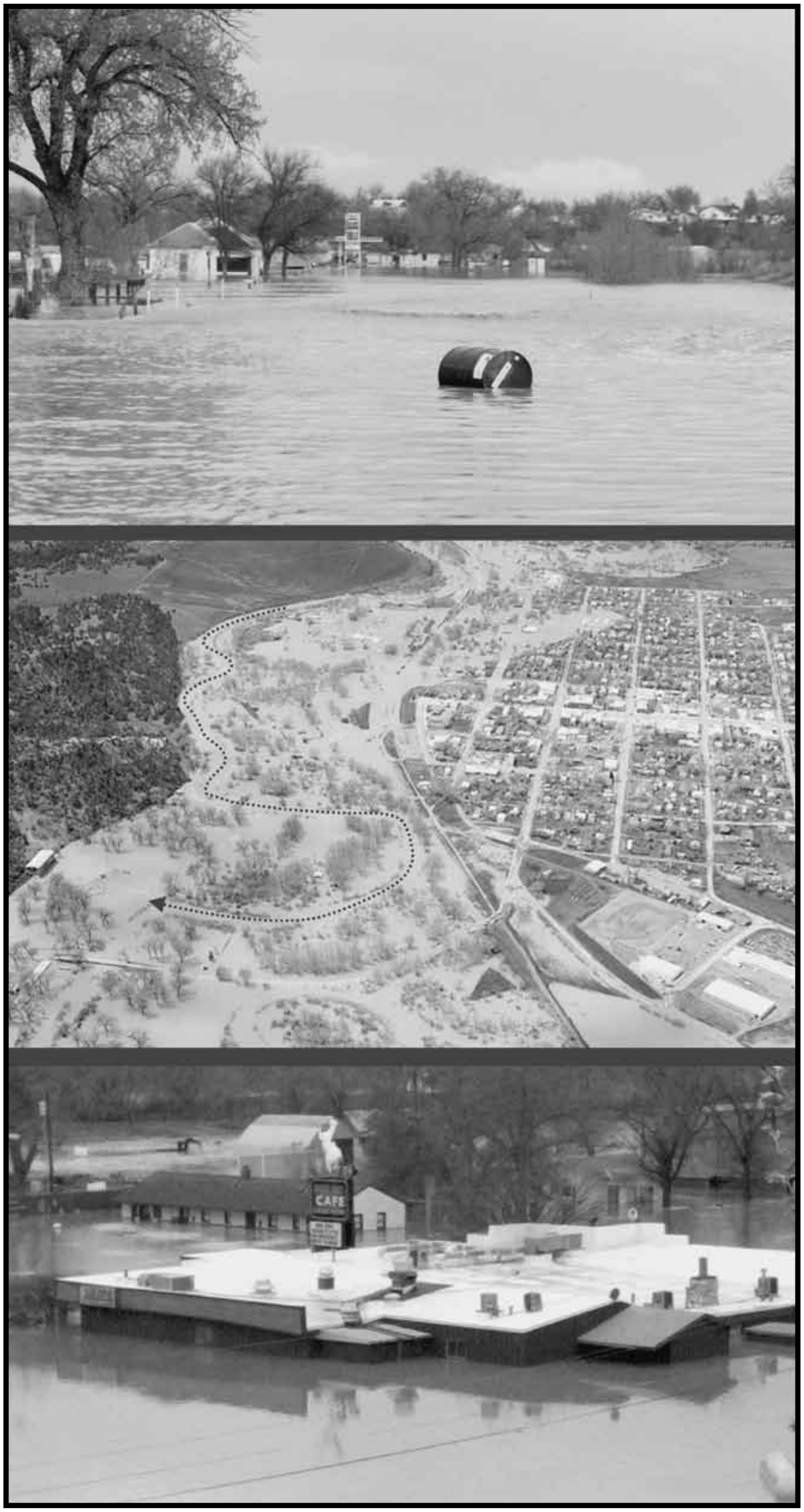


Figure 2. Images of 2011 flooding in Roundup, Montana. Top: looking east along highway on west side of Roundup. Center: aerial view from east with normal course of Musselshell River indicated by dashed line. Bottom: the Busy Bee Cafe. Photographs courtesy City of Roundup.

Table I. Musselshell River Peak Annual Discharge

Year	Peak Discharge in Cubic Feet Per Second			
	Martinsdale	Harlowton	Roundup	Mosby
1964	—	1,850	2,030	11,900
2011	4,800	5,400	15,000	26,000
2014	1,750	1,750	11,000	21,000
Average	1,028	1,316	2,253	5,346
Standard Deviation	1,148	1,154	2,699	5,138

mainline in Minot, North Dakota—even threatening a nuclear power plant in Nebraska—but my focus is on specific effects of geologic interest and personal knowledge in Central Montana.

Surficial Geology

The Musselshell and Judith Rivers (Figure 1) are diminutive, northward-flowing tributaries of the Missouri. The Musselshell River drains the areas south and east of the Big Snowy, Little Snowy, and Judith Mountains, while the Judith drains the areas north and west of these ranges. Lewistown, an important Montana city, is tucked into the area between three mountain ranges on the east side of the Judith Basin. The Musselshell River empties into the Fort Peck Reservoir, while the Judith River empties into the Missouri River upstream of the reservoir.

Musselshell River. At Roundup, the largest town on the Musselshell River, the degree of flooding was historic. The Billings *Gazette* (May 27, 2011) ran dozens of photographs of the flooding, as did many news outlets. The highway remained the main thoroughfare, though the vehicles using it were boats instead of automobiles. While the approaches were flooded, the highway bridge over the river was not damaged, and the deck remained above water level, facilitating efforts at stream gauging by the U.S. Geological Survey. Meals were served at St. Benedict's Church on high ground; they certainly could not be served any longer at the submerged Busy Bee Café (Figure 2). Roundup

Figure 3. Aerial view of Hanover Road west of Lewistown, Montana, showing large amount of earthwork necessary to relocate road away from edge of valley where 2011 flood seriously damaged the road. Photograph taken 2014, obtained from Google Earth.

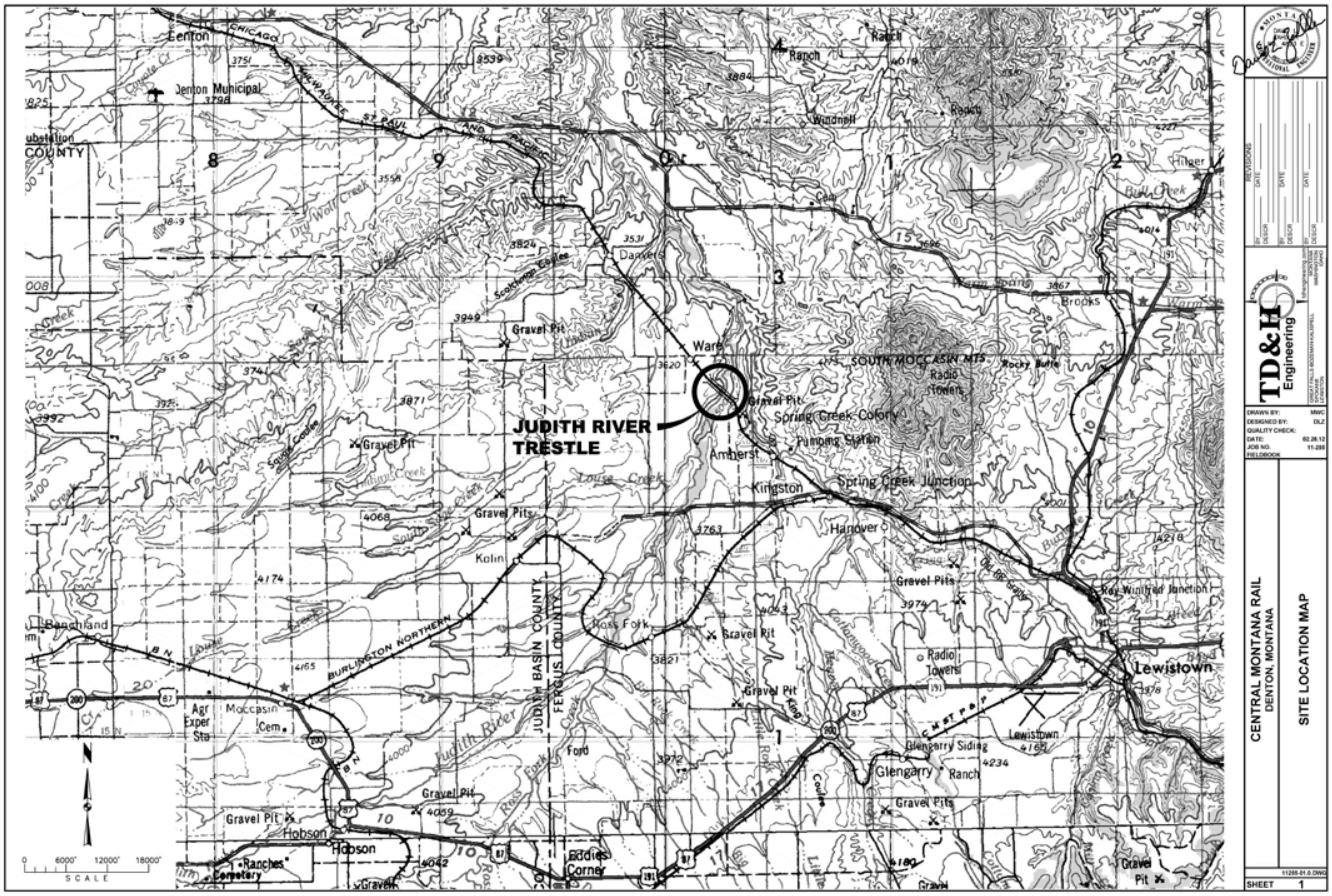


Figure 4. Map showing location of Hanover Road and Judith River Bridge northwest of Lewistown, Montana. Figure courtesy of TD&H Engineering.

had not experienced a flood of this scale. As shown in Table I, the 2011 flood at peak discharge represented most of five standard deviations above the mean annual peak discharge and was reportedly the equivalent of a "157-year flood" per U.S. Geological Survey data.

Judith River. The Judith Basin, the area between the Little Belt and Moccasin Mountains (Figure 1) drained by the Judith River, experienced localized mass wasting (slumps, landslides, etc.) and washouts. Many roads and bridges, including important bridges northwest of Lewistown, were damaged. The Hanover Road, connecting the areas east and west of the Ross Fork of the Judith River, was cut by a landslide, closing the road for an extended time (Figure 3). I observed some of the geotechnical field work for its rerouting. Downstream of the road bridge is the dramatic Central Montana Rail steel trestle (Figures 4, 5). While data for the Judith River are not as abundant as for the Musselshell, the same trends in peak flows for the important flood years of 1964, 2011, and 2014 are evident (Table II).

The Central Montana Rail Bridge (viaduct) over the Judith River was built

Table II. Judith River Peak Annual Discharge

Year	Peak Discharge in Cubic Feet Per Second		
	Utica	Estimate at Bridge	Mouth
1964	1,070	2,000	—
2011	4,960	10,000	15,300
2014	—	3,500	5,500
Average	627	—	4,226
Standard Deviation	666	—	4,071

Figure 5. West half of Judith River trestle in 2011 after Judith River flooding damaged it (note misalignment of bridge spans).

by the Chicago, Milwaukee & Saint Paul Railroad and was designed to be supported by piers founded on bedrock. With 64 piers supporting the steel bents (towers), this was a considerable expense, and to cut costs, the railroad opted to found them on spread footings. For most of 99 years, this was satisfactory, though piers adjacent to the little river where it passed under the trestle had to be protected by driving sheet piling around them and filling the space with concrete. Flooding events through the bridge's history had not resulted in major erosion or deposition. The Judith River is a small, gravel-bed river with a gradient in the neighborhood of 0.5 percent in the study area. Like most streams in this region, the Judith is an *underfit* stream; in fact, this stream is like many others in occupying a valley capable of handling a flow many times its size. Over the Memorial Day weekend of 2011, the swollen Judith River, while still occupying only part of the valley bottom, changed course and moved east approximately 115 meters (375 feet). Just under the bridge, it encountered a low colluvial ridge that diverted it west. The river then swung slightly south and ran under the bridge lengthwise west-northwest to the original channel (Figures 6, 7). This put ten additional piers at risk, and the little river undermined some, resulting in significant damage to the bridge (Figures 8, 9). The span was closed to traffic for 3½ years until repairs could be made (Figure 10).

The natural course of the river during normal flow was thus redirected northeast against the bank (Figures 6, 9). The channel formed between 1996 and 2011 was filled with gravel and a thick, flat-topped gravel bar was deposited over it the entire distance from the 1996 channel to the new channel (Figure 11). Any small flood would follow the east side of the new gravel bar and cut further into the unconsolidated material at the bend. I had suggested cutting a channel to speed this natural process so the river would immediately occupy its future course and leave most of the bridge unthreatened. However, the likely difficulty of obtaining the required environmental permits convinced the involved parties to simply armor all of the bridge piers and let the river continue to run lengthwise under the bridge. Ironically, the construction equipment during bridge repair managed to incidentally divert the river back toward its previous course. The indicated future course of the river is therefore less certain, but it may well be carved as shown by some future flood event. Relatively little change (at least, without large machinery!) occurs in the meantime.

Fort Peck. The Fort Peck Dam (Figure 1) was built 1933–1939, and the era of upper Missouri River navigation came to an end. The dam is an earth-fill structure with a reservoir capacity of 23.0 km^3 (18,688,000 acre-feet). The penstocks are tunnels excavated in Bearpaw Formation shale. The penstock-turbine and bypass tunnels have a combined capacity of 1,840 m^3/s (65,000 cfs). The emergency spillway is 2.3 miles (3.8 km) south of the dam, with the head in a saddle and the tail channel joining the Missouri River 8.3 miles (13.8 km) downstream of the dam. It was designed for a discharge capacity at maximum operating pool elevation of 6,513 m^3/s (230,000 cfs). The maximum discharge per U.S. Geological Survey records was in 1953 at 3,880 m^3/s (137,000 cfs). Only occasionally has water actually flowed over this spillway. I have worked on several projects at Fort Peck through the years, but I never saw water over the spillway before 2011. The dry years at the end of the twentieth century resulted in a much-reduced reservoir level, and I never expected to see the reservoir close to full. The remarkable runoff of 2011 filled the reservoir, and cottonwood trees at least thirty feet tall on the upstream side of the dam became a hangout for fish without a branch showing above the surface.

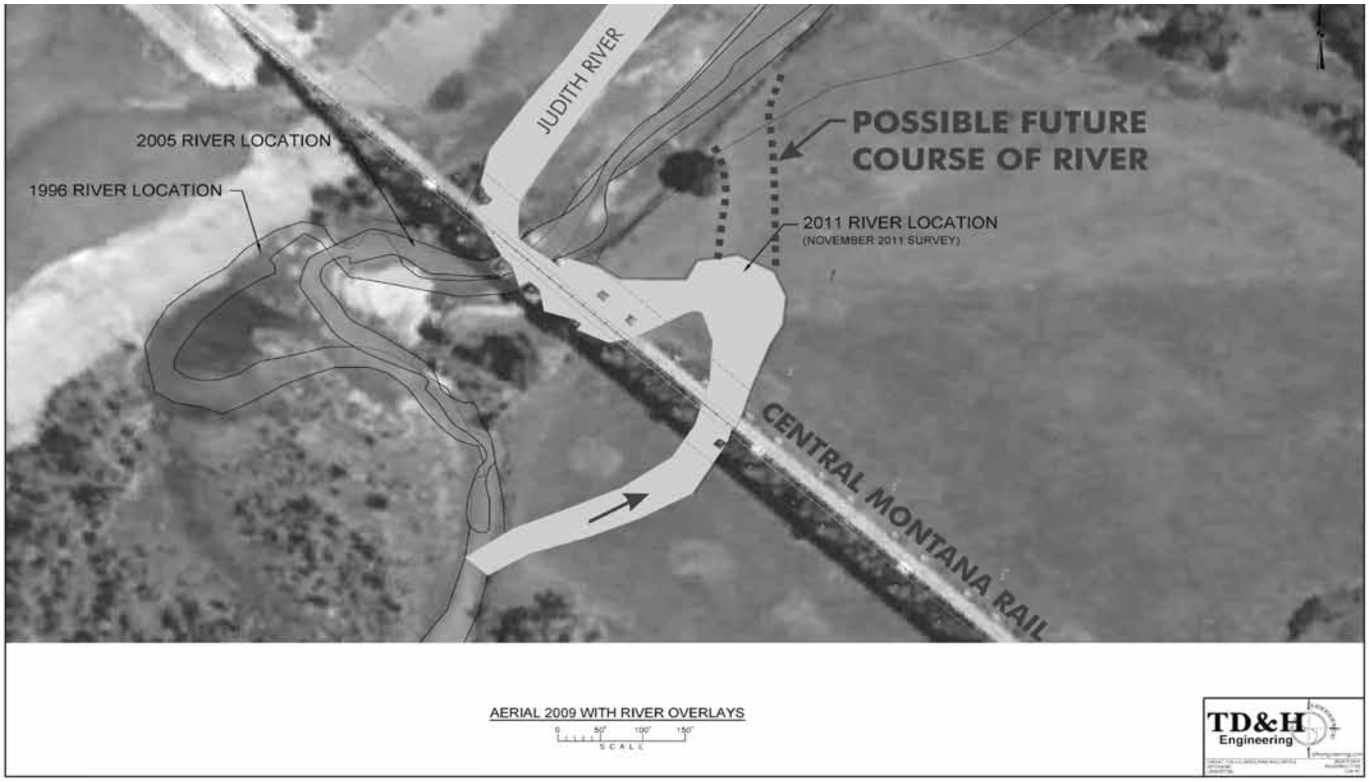


Figure 6. Aerial view of Judith River viaduct showing changes in course of Judith River over recent decades. Base figure courtesy of TD&H Engineering.

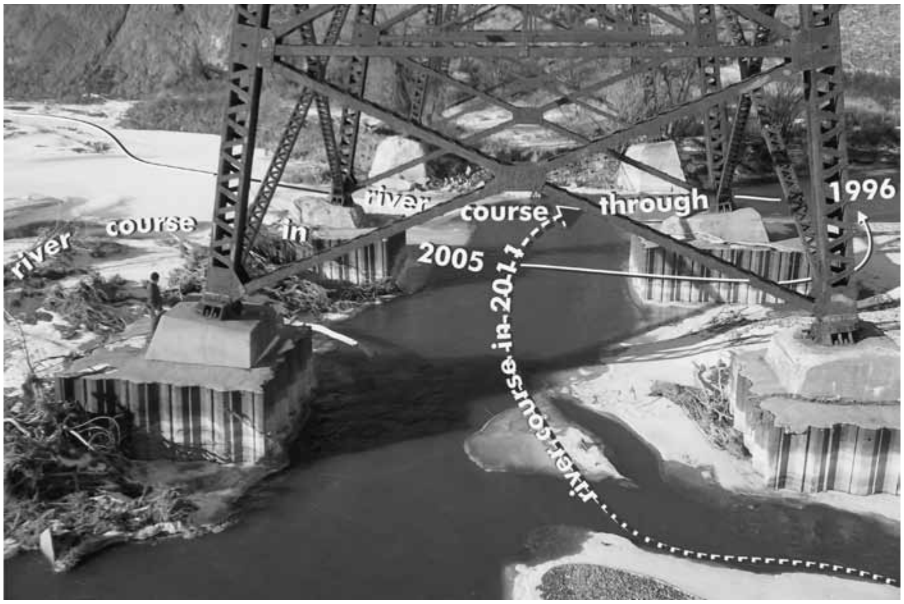
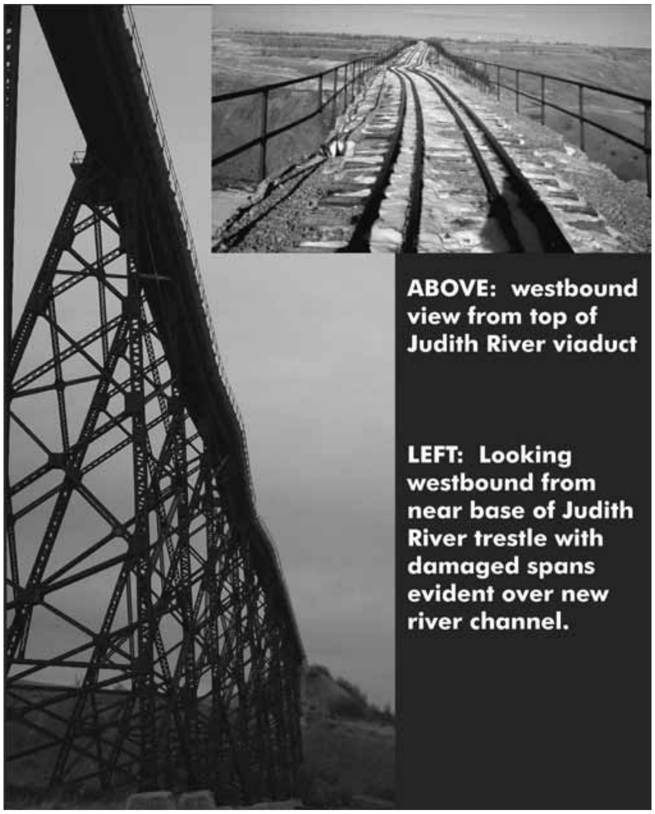


Figure 7. The four piers previously armored weathered the 2011 flood with only trivial damage. Channel movements are indicated from years their positions were recorded. Author (178 cm tall) stands on Pier 51. Note flood debris against upstream sides of armored piers. Sheet pile armoring protected these piers from being undermined by flood scour. Photograph from December, 2011.

When I saw the spillway in June of 2011, it was flowing approximately 1,866 m^3/s (65,900 cfs). The plunge pool was masked by a towering cloud of spray (Figure 12). Considerable damage occurred to the plunge pool where the flow eroded away the soft Bearpaw shale and undermined some of the concrete. An extensive reconstruction and reinforcement program was designed by the U.S. Army Corps of Engineers and included refilling the deepened plunge pool using roller compacted concrete. Such rapid flows (supercritical flow) elsewhere have been documented to remove hard rock and concrete, especially where cavitation has ensued (Holroyd, 1990).

Subsurface Geology

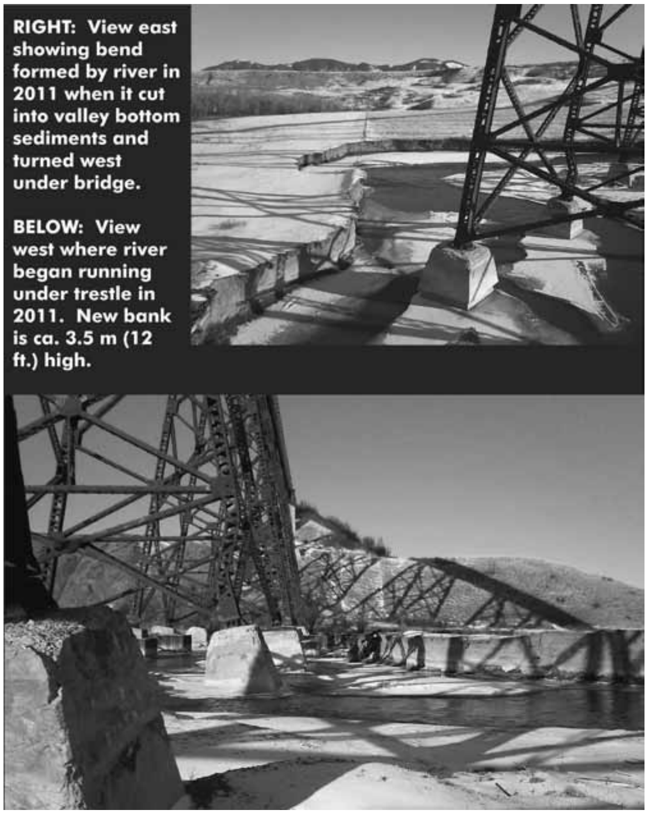
Hays is a small community nestled against the northwest side of the Little Rocky Mountains on the Fort



ABOVE: westbound view from top of Judith River viaduct

LEFT: Looking westbound from near base of Judith River trestle with damaged spans evident over new river channel.

Figure 8. Bridge damage resulting from 2011 Judith River flooding.



RIGHT: View east showing bend formed by river in 2011 when it cut into valley bottom sediments and turned west under bridge.

BELOW: View west where river began running under trestle in 2011. New bank is ca. 3.5 m (12 ft.) high.

Figure 9. Formation of new river channel in May of 2011 resulted in scour that undermined piers and damaged the Central Montana Rail Bridge over the Judith River.

Figure 10. The first revenue train following repair of the viaduct was the *Charlie Russell Chew Choo* dinner train on November 21, 2014. Grain trains still had to wait for repair of the Ross Fork Bridge. Note the new piers supporting bents directly under the train. Photograph courtesy Central Montana Rail.

Figure 11. Wide gravel bar deposited by 2011 flood buried the pre-2011 river channel. Author (at right) provides scale.

Belknap Indian Reservation (Figure 1). The Jesuits founded the Saint Paul Mission in 1886, well before the formation of the reservation, and I have been called upon to work on several projects for the school and other buildings at the mission. Little Peoples Creek runs through the mission property. It emanates from Mission Canyon, the type locality for the Mission Canyon Formation of the Madison Group. The Madison Group hosts one of Montana's most important aquifers, and the Little Rocky Mountains acts as a recharge area (Figure 13).

A gravel road was built decades ago between the creek and the canyon walls. The Mission Canyon Formation is karstic limestone with an abundance of natural bridges (arches) and caves (Figure 14). In 2011, floods scoured the canyon and removed the road, leaving it accessible only by foot. In Hays, the

Figure 12. The spillway for Fort Peck Dam is located away from the dam in terrain eroded into Bearpaw Formation sedimentary rocks.

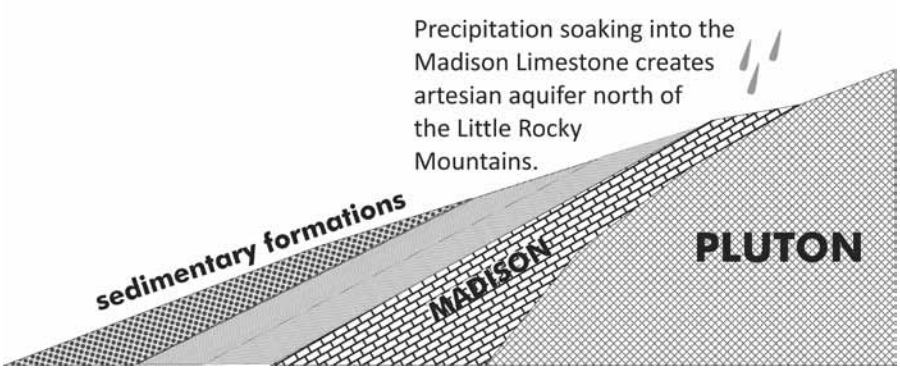


Figure 13. Cartoon cross section of the northwestern Little Rocky Mountains.

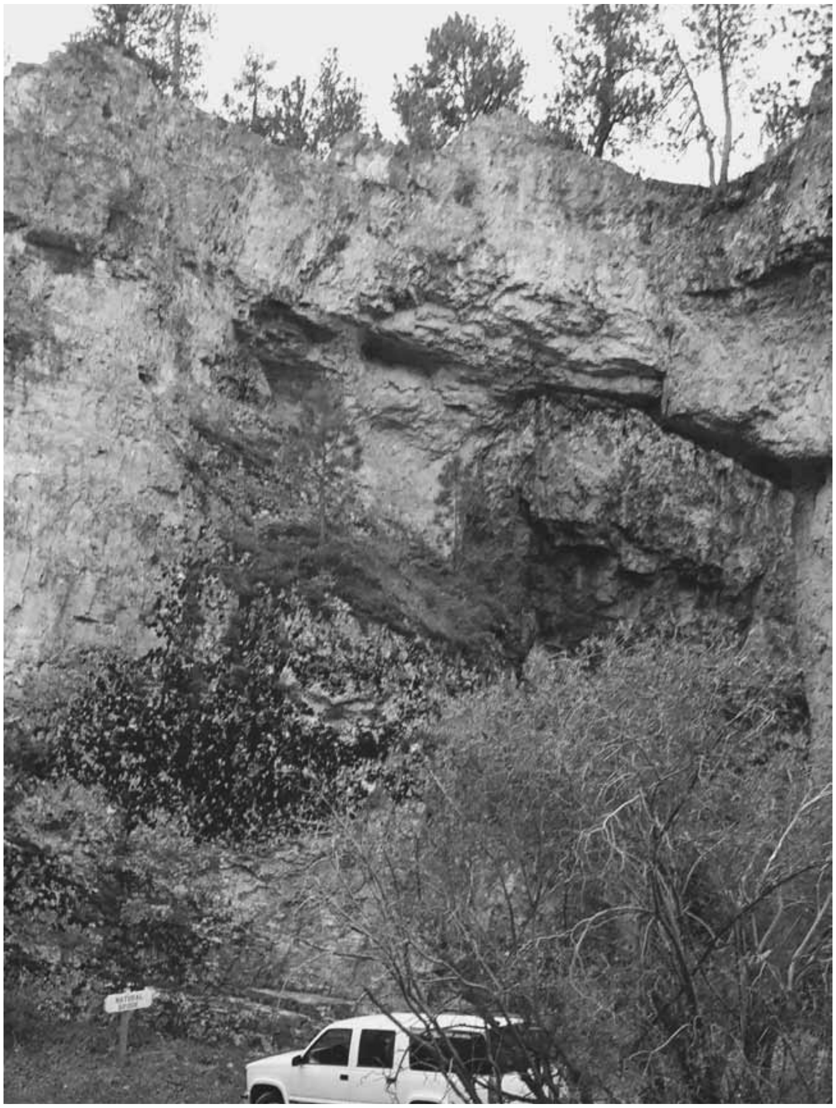


Figure 14. The best-known natural bridge in Mission Canyon, photographed in 1999.

flooding may have been the worst ever witnessed, certainly in recent memory. Slumps, earthflows, and various small landslides occurred on the valley walls, some of which blocked an irrigation ditch from the early 1900s (Figure 15). After the flooding subsided, Little Peoples Creek suddenly disappeared between the mouth of the canyon and Hays. At the same time, the mission water supply well began flowing. It had always been artesian, but had not had enough pressure head to flow at the surface, only enough to rise inside the casing. The well was not equipped to contain the increased pressure, and I was called back to Hays.

The solution to this mystery seemed straightforward enough. The flood had apparently scoured away low-permeability sediments and allowed the creek to sink into solution cavities in the limestone. This had increased the head to the well, causing it to flow. When I set about testing this hypothesis, it failed. The well was tapping into an aquifer below the Madison Group. The elevation at the wellhead was too high for the creek to provide the additional head. And walking the stream course, I found no evidence that fine-grained sediments had been scoured from the streambed. Diocese staff and I puzzled over this mystery for a considerable period of time. Then, in 2012, for no apparent reason, Little Peoples Creek began running again in its channel (Figure 16), and the well stopped flowing. Other hydrogeologists have found this as mysterious as I have, but the wet spring of 2011 obviously impacted both aquifers and streams.

Conclusions

Practical knowledge that has been gleaned from observation of floods and the geologic work they do include the following.

- These were "ordinary" effects in both type and scale but provided good

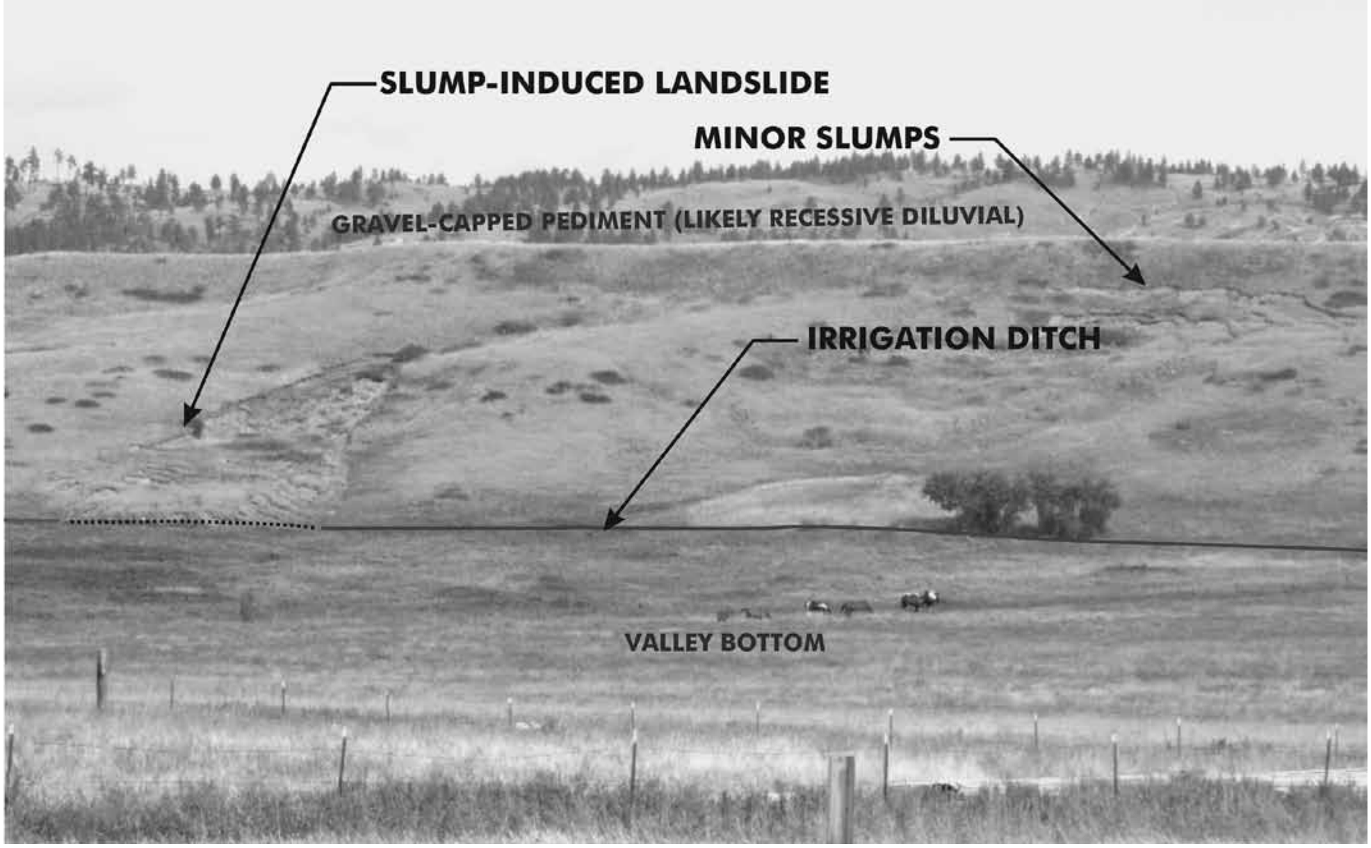


Figure 15. Mass wasting on valley slope east of Saint Paul Mission, Hays, Montana, in 2011 blocked an irrigation ditch from the early 1900s. Elevation difference between bench and valley floor is 48 m (160 ft.).

Figure 16. Little Peoples Creek at Saint Paul Mission after it began running again in 2012. Photograph courtesy Roman Catholic Diocese of Great Falls, Billings.

data for refinement of our understanding of flood-related geologic processes.

- The Judith River, a comparatively small and underfit stream, did considerable geologic work in 2011, including scouring to or nearly to bedrock (approximately 20 feet). The Judith River Trestle had been in operation for 99 years at that time with only four of the piers having been endangered by river scour previously.
- Large amounts of sedimentary bedrock were eroded from the spillway plunge pool at Fork Peck Dam in 2011. Similar rapid, flood-related erosion in soft and hard bedrock and in concrete has been observed elsewhere.

- Ground and surface waters often interact. A relatively straightforward hypothesis to explain sudden changes in ground water occurrence after the 2011 flood in Hays, Montana, was disproved. Ground water systems can be difficult to characterize, especially when interacting with floods or other catastrophic processes.

Acknowledgement

I thank Central Montana Rail, the Roman Catholic Diocese of Great Falls-Billings, and TD&H Engineering for permission to showcase these projects. They were fulfilling projects to work on. The City of Roundup permitted use of the 2011 flood images. Encouragement to become involved in paleohydrologic studies came particularly from creationist Michael J. Oard and anti-creationist David Baker, along with job-related observations that piqued my curiosity. *Deum laudo* (Psalm 29:10).

Reference

Holroyd, E.W., III. 1990. An introduction to the possible role of cavitation in the erosion of water channels. *Creation Research Society Quarterly* 27:23–32.