7. Mississippi River Gorge Landslides

Landslides on near-vertical faces in the Mississippi River Gorge

Slides on near-vertical bedrock-dominated slopes along the Mississippi River gorge were field-checked to better map and understand them. Layers within the Platteville Limestone are prone to failure by undercutting and when they fail, the rock slabs fall, releasing material above them. Events are difficult to time and can be sudden.

Methods

Trails along the Mississippi River gorge provided access to bedrock slopes during the summer of 2018, and again in winter 2018 when springs and seeps were evident owing to ice formation. The Mississippi Watershed Management Organization (MWMO) provided information on erosion-prone areas. Julia Steenberg of the Minnesota Geological Survey (MGS) provided photographs of bedrock faces that were taken between 2009 and 2011 during a fracture-mapping project (*Runkel et al., 2015*). Dislodged rock, rocky colluvium and glacial sediment that had accumulated at the toe of the slope were used to identify particularly active portions of the bluff face.

Geologic Background

The Mississippi River gorge, from the confluence with the Minnesota River to St. Anthony Falls, is a post-glacial valley created as the waterfall retreated from the confluence to its current position. This retreat took approximately 11,000 years to cover a distance of 8.5 miles (Figure 7.1), for an average rate of 3.5′/year (Table 7.1).

Table 7.1 — Approximate Position of St. Anthony Falls

Using the average retreat rate, the position of the falls over time was approximated in years ago and years before the common era (BCE) *(adapted from Alexander et al., 2011).*

Bridge	Miles	Year
Stone Arch Midpoint	0.21	1766
Stone Arch Downstream End	0.27	1680
Interstate 35W	0.65	1100
No. 9 Railroad	0.87	800
Washington Avenue	1.43	70 BCE
Interstate 94	2.18	1,200 BCE
Franklin Avenue	2.55	1,800 BCE
Greenway RR Bridge	3.29	2,900 BCE
Lake Street	4.23	4,300 BCE
Summit Avenue	4.60	4,900 BCE
Ford Bridge	6.34	7,500 BCE
Hidden Falls	7.15	8,700 BCE
Fort Snelling	8.50	11,000 BCE

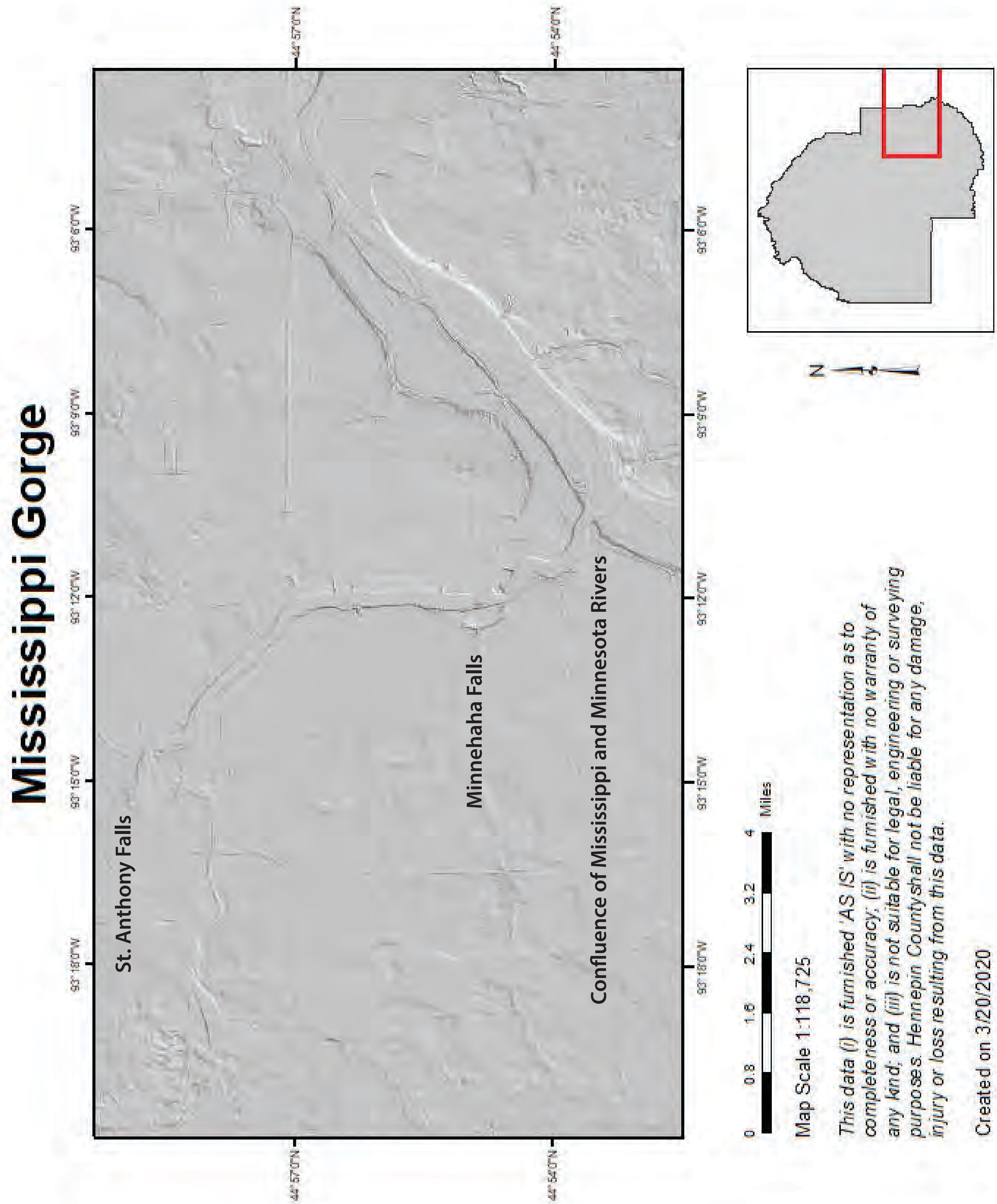

Figure 7.1 — Mississippi Gorge

The Mississippi River gorge begins at the confluence with the Minnesota River. It was created as a waterfall and retreated to its current position at St. Anthony Falls. This retreat took approximately 11,000 years to cover 8.5 miles for an average rate of 3.5'/year.

The tributaries have waterfalls that are still very close to the gorge, many of which are modified by urbanization and stormwater infrastructure. The most notable falls are Minnehaha Falls, Hidden Falls and Shadow Falls (Figure 7.1).

The bedrock exposed by waterfall retreat in the Mississippi River gorge and the short, deeply incised reaches of tributaries includes flat-lying to gently dipping sedimentary rock layers formed in a marine setting as water levels fluctuated. The Platteville Limestone forms the uppermost unit in most places because it is the most resistant to erosion. However, remnants of a higher layer of soft shale, the Decorah Shale, crops out in places and restricts water movement.

The Platteville is subdivided into field-identifiable layers or Members (Figure 7.3). The spacing and nature of their fracture planes help distinguish them. The high density, vertical to sub-vertical fractures in the Magnolia Member give it a blocky appearance. The widely spaced, vertical fractures of the Mifflin Member cause it to break off in large, tabular slabs. The Hidden Falls Member has high density, curvilinear fractures (*Runkel et al., 2015*). Underlying the Platteville is another thin shale layer, the Glenwood Shale, and beneath that the buff-colored, weakly cemented St. Peter Sandstone.

Figure 7.3 — Bedrock Sequence The Magnolia Member is 7–10′ thick and has a blocky appearance. The Hidden Falls Member is 4–6′ thick and has curvilinear fractures. The lowermost Mifflin Member is 11–13′ thick and breaks off in large, tabular slabs. Springs emanate predominantly from Magnolia/Hidden Falls contact (48%) and Hidden Falls/ Mifflin contact (25%). Seeps along bedrock layers exposed above the Ford Dam can be identified by ice. *(Runkel et al., 2015)*

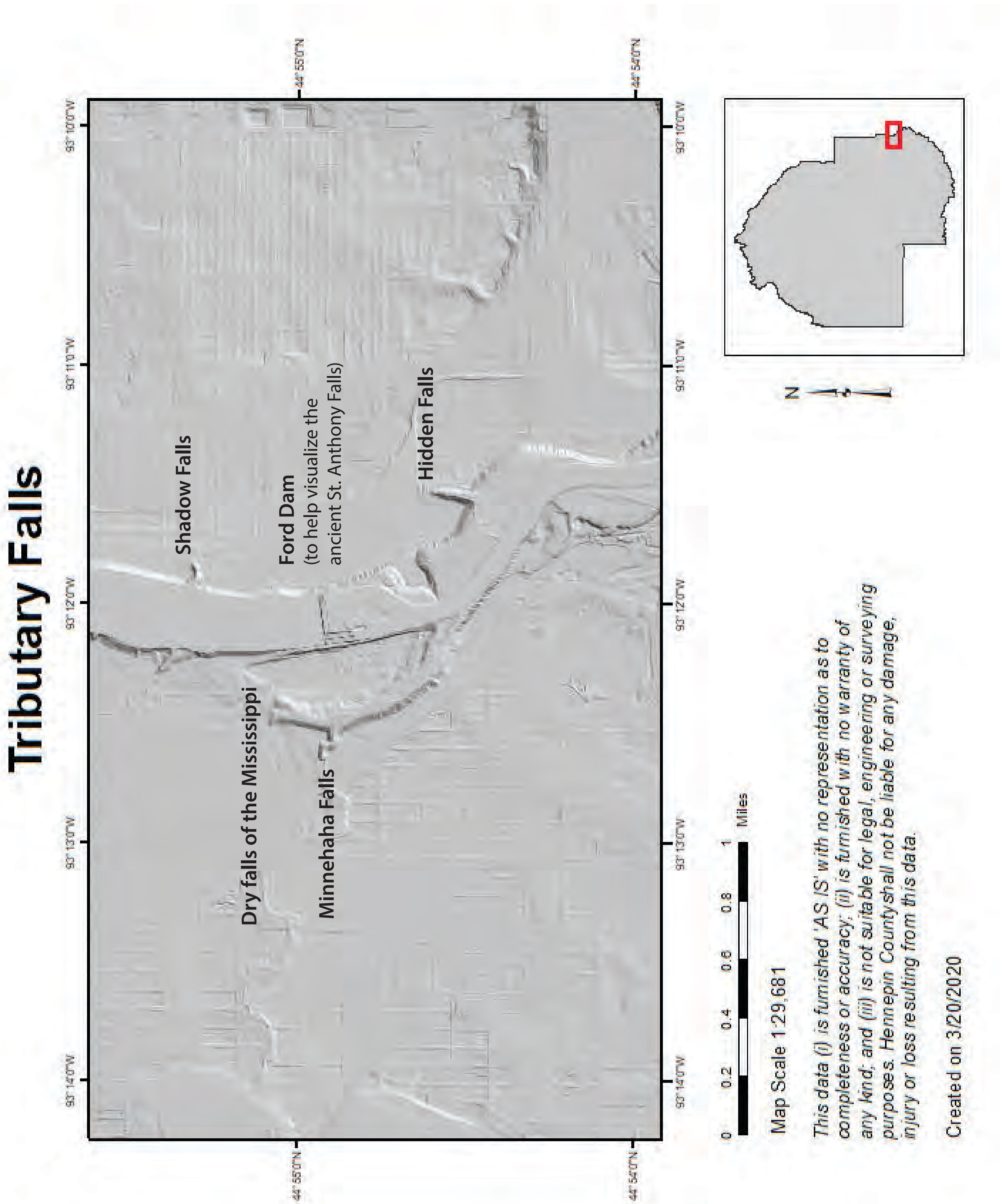

Figure 7.2 — Tributary Falls

Tributaries to the gorge have waterfalls including Minnehaha Falls and a dry waterfall near it, Hidden Falls, Shadow Falls and Bridal Veil Falls (not shown but just N of east side of the Franklin St. Bridge). The Ford Dam is lower than the former St. Anthony Falls but helps to visualize the expanse.

Springs

Springs and seeps discharge at predictable horizons within the Paleozoic bedrock layers, typically where water perches above an impermeable horizon *(Brick, 1997; MnDNR, 2017)*. The vertical and horizontal hydraulic conductivity of the layers above control how much and how quickly water is conveyed (*Runkel et al., 2015*). The springs in the state are being inventoried by the DNR (Figure 7.4). From highest to lowest, the spring lines exposed in the Mississippi River gorge are:

1. glacial sediment-Decorah Shale contact; e.g., springs near the Lake Street Bridge
2. glacial sediment-Platteville Limestone contact
3. within the Platteville Limestone
   - a seam of ash weathered to clay in the Platteville Limestone; e.g., Cold Spring near Fort Snelling, and Chalybeate Springs below St. Anthony Falls in Pillsbury Park, and downriver at the location of the former Bohemian Flats community
   - the contact of the Magnolia and the Hidden Falls members
   - the contact of the Hidden Falls and the Mifflin members
4. at the Platteville Limestone — Glenwood Shale contact
5. where the water table in the St. Peter Sandstone intersects the valley wall

Springs and seeps have a bearing on landslide locations because they can create reentrants in the gorge wall by sapping (physically removing grains where they emerge) and enlarging fractures by dissolution, in some cases creating significant subsurface voids and sinkholes. Seeps are visible in winter by icy accumulations at distinct layers. Springs have a great enough flow rate that they do not freeze (Figure 7.5).

Figure 7.5 — Springs and Seeps

Immediately downriver from the Fairview Riverside Medical Center slide site, there is a combination of seeps (ice) and springs (wet, green and rusty) emerging from the Platteville Formation. Iron in the springs is oxidized when it emerges and the constant-temperature water supports mosses and other vegetation.

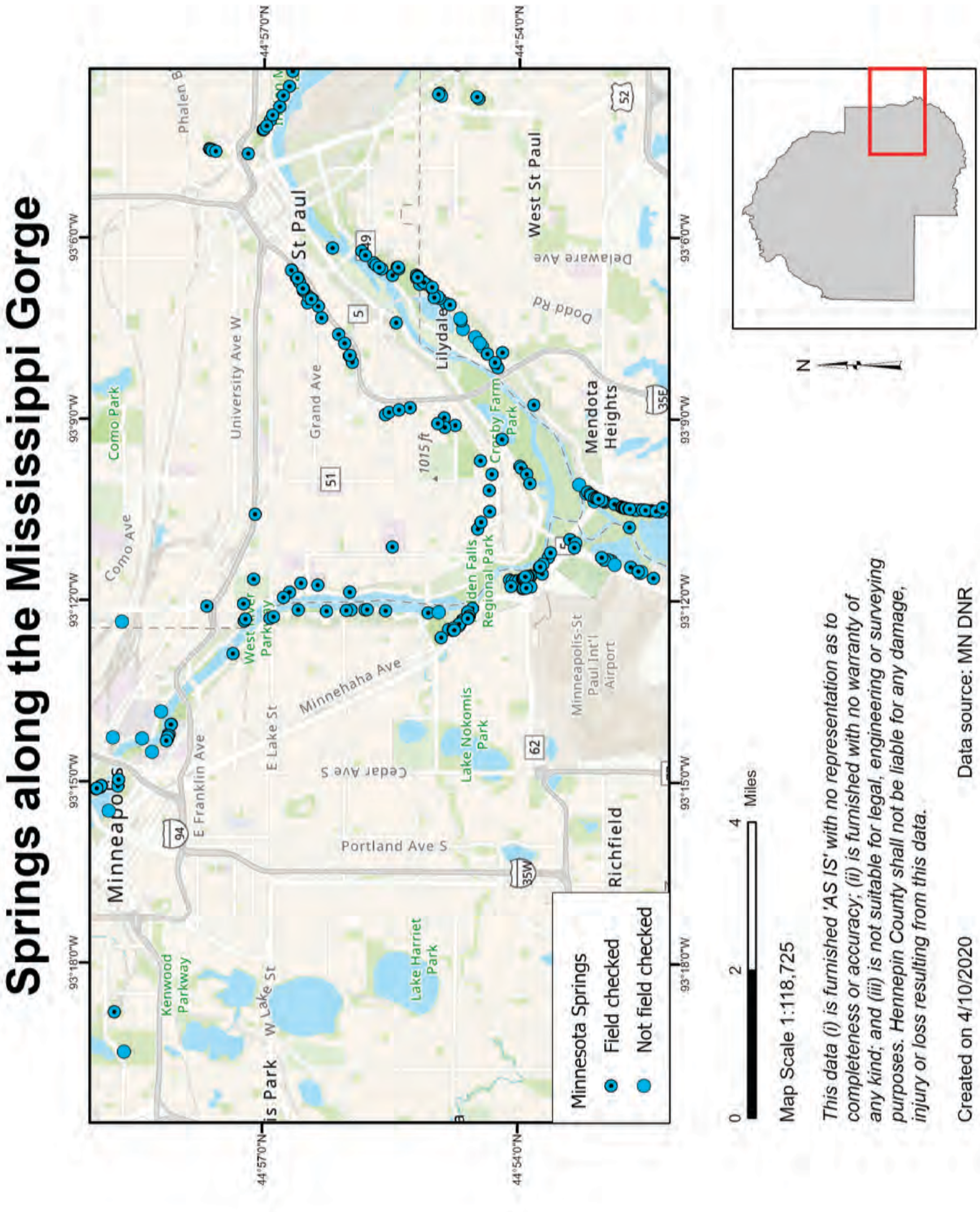

Figure 7.4 — Mississippi Gorge Spring Inventory

Dr. Greg Brick of the DNR has compiled spring locations in the state.
This portion of the map was accessed Dec. 17, 2018.
https://arcgis.dnr.state.mn.us/portal/apps/webappviewer/index.html?id=560f4d3aaf2a41aa928a38237de291bc

Failure Style in the Mississippi River Gorge

The primary style of bedrock failure involves block failure of a cantilevered or otherwise projecting slab of Platteville Limestone, typically the Mifflin Member. The underlying St. Peter Sandstone is more easily eroded and undercuts the limestone. This process is facilitated by springs and mechanical erosion. When the slab is ultimately destabilized and topples, it destabilizes the slope above it and can release significant amount of rock and loose glacial sediment. This is the main mechanism of retreat of tributary waterfalls and evidence for undercutting of the Platteville Formation is easily observed at Minnehaha Falls (Figure 7.6). Smaller blocks of the Hidden Falls and Magnolia members accumulate in talus cones on slopes prone to failure and can be a nuisance but are not as disruptive as the large blocks of Mifflin Member that fail, releasing everything above them.

The 2014 failure beneath Fairview Riverside Medical Center involved artificial fill (*Herbert et al., 2018*) and was related to saturation from rain and spring activity. It was the combination of the two that saturated and destabilized the fill that was obscuring the former location of a bedrock quarry.

Figure 7.6 — Overhanging Mifflin Member

At Minnehaha Falls, it is easy to see the reentrant in the slope that forms along the Glenwood Shale where springs emerge. This creates overhanging ledges of the Mifflin Member that break along joints. Fallen blocks can be seen on the slope (and in the pool below the waterfall, not shown here). Photo credit: Julia Steenberg, MGS.

Recommendations

The timing of this kind of slide is less predictable because spring activity lags precipitation by an unknown period and the direct link to precipitation events is less clear. Multi-season to years-long wet periods with punctuated intense events can create favorable conditions for failure. There may be a relationship with freeze-thaw cycles, but there are not enough rockfalls of known timing to make this anything more than anecdotal.

The fall-zone along the slopes on the Hennepin County side of the gorge is primarily occupied by trails but also includes portions of roadways north of Franklin Avenue. Remediating portions of the slope with the most activity above them or below them is prudent as is removing reasons for people to linger in these zones (e.g., benches, signage, view points). For example, the overlook at Fort Snelling History Center projects beyond the bluff face and is underlain by a vertical fracture in the Platteville with a seep (Figures 7.7a and 7.7b). Encouraging people to stand here should be carefully evaluated.

Critical areas could be monitored with trip wires, tensiometers or inclinometers to anticipate motion and issue road and trail closures to avert injury to those moving by. Where infrastructure like a bridge is positioned at the top of a slope that is threatened, carefully monitoring bridge changes would help to anticipate slope failure and avoid structural failure.

Monitoring change on near-vertical slopes requires low-angle or side-looking views, preferably in leaf-off conditions or using a method that can "see through" the vegetation, like Light Detection and Ranging (LIDAR). Structure-from-motion photography *(Westoby et al., 2012)* taken from the ground or using drones could create elevation models of bluff faces and could record changes where the slope is obscured by the vegetation. Side-scan LIDAR (*Day et al., 2013*) can be used to look through vegetation to map portions of the bluff faces.

Careful placement of stormwater infrastructure is important so as not to induce erosion, especially in the more easily eroded St. Peter Sandstone. For example, under the Highway 5 Bridge abutment (Figures 7.8a and 7.8b), erosion-control measures put in place have varying levels of permanence.

Ownership of the bluff corridor is complicated and may involve the city, state, city park authority, federal government, and railroad, among others. The entity responsible for the bluff face may differ from owner or maintainer of the trail or roadway being threatened below or on top of the bluff. Actions as small as trimming a leaning tree that is overhanging the bike trail can involve collaboration between multiple jurisdictions. A "vertically" coordinated approach, with all parties communicating about monitoring and remediating these sites, will have the best outcome.

Figure 7.7a — The Overlook at Fort Snelling History Center

People gather on a cement platform that projects beyond the bluff face and is underlain by a vertical fracture in the Platteville with a seep.

Figure 7.7b — Repair and Failure Below the Fort Snelling Overlook

The gabion wall baskets created below the overlook have begun to fail.

Figure 7.8a — Erosion of St. Peter Sandstone Near Infrastructure

Upriver side of Highway 5 Bridge abutment where repairs to the face of the St. Peter Sandstone have been made to protect it from undercutting.

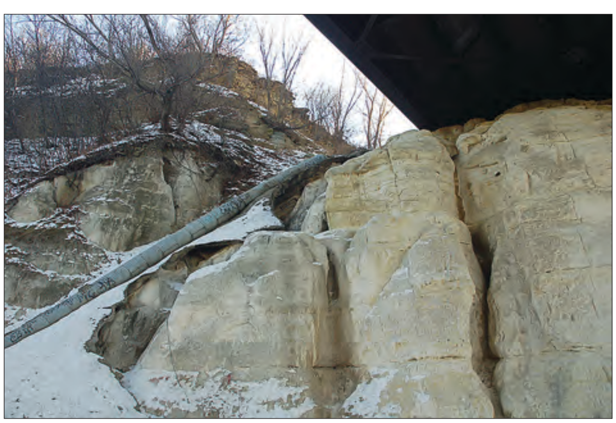

Figure 7.8b — Erosion of St. Peter Sandstone Downstream Side of Highway 5 Bridge

Downstream side of the Highway 5 Bridge abutment where repairs and a rerouted pipe were apparently put in place to protect the St. Peter Sandstone. Erosion is now occurring beneath the cement overlay.