# 6. Minnesota River Valley Landslides

## Deep-seated slope failures along the Minnesota River valley and tributaries

Deep-seated, large slides are located primarily along the Minnesota River valley and its tributaries. They are entirely within the glacial sediment sequence. An understanding of the specific surfaces where failures occur, the location of springs, as well as the history of valley formation helps understand slide locations and future occurrences. Although these are large, they are typically the slowest form of failure. Geotechnical investigations prior to development and wise land uses that protect the slopes from reactivation are prudent approaches.

## Methods

Existing surficial geology maps of the Twin Cities Metropolitan Areas *(Hobbs et al., 1990; Patterson, 1992; Meyer and Patterson, 1999)* and those updated during this project *(Steenberg et al., 2018)* provided pertinent regional geologic data that helped understand the geologic setting of deep-seated landslides. Water well logs, Minnesota Department of Transportation boring records, and Giddings-hole and rotary-sonic-core logs drilled for the Minnesota Geological Survey map project provided site-specific information of units that were potentially involved in landslide events. The depth to the failure surface estimated using hillslope expression on the mapped slides combined with kilometer-spaced cross-sections through the surficial deposits (*Berthold, 2018*) helped identify the geologic units that were likely involved in the landslides. Field work conducted in the summer and fall of 2018 focused on verifying these interpretations through the materials exposed in the slide area, as identified by the shape of the scarp and deposit. Watershed districts in Hennepin County provided information on the locations of known erosion sites within their watersheds. Spring horizons mapped by Minnesota Department of Natural Resources geologist Dr. Greg Brick *(MnDNR, 2017*) were correlated with map units.

## Geologic Background

Glacial deposits, including those of meltwater streams and lakes, cover all of Hennepin County. The valley now occupied by the Minnesota River is the most recent, indirect feature of glaciation. Glacial floodwaters emanated from the very large glacial Lake Agassiz and shaped the valley over a few thousand years. The creation of the valley now occupied by the Minnesota River was a destabilizing event for the entire basin. Adjustments to valley profiles and the creation of new tributaries are ongoing. Steps or knickpoints in the tributary-stream profiles record where adjustment is occurring, and they can be observed migrating upstream on human time scales. It is the continuous evolution of stream profiles that creates the freshest and most susceptible slopes, but even the older steep slope areas can become active with changed hydrology, vegetation or land use.

## Glacial History

The youngest glacial-age units in Hennepin County are meltwater stream deposits found at the surface, paralleling the modern Minnesota River but lying over 200 feet above the modern river valley. There, sand and gravel were deposited by meltwater streams as the ice retreated (units Qts, Qts1, Qts2 on the cross sections shown in Figure 6.4). These deposits are over 100 feet thick in Eden Prairie along Purgatory Creek. There are a few areas in

Bloomington with thick deposits as well (Figures 6.1, 6.2, and 6.3). Because of the great thickness and porosity of this unit, it is generally dry where it is exposed next to the deep river valleys. However, farther back from the bluff face it may be saturated. One would therefore expect a steeply sloping water table surface that may intersect the bluff face at low elevation, or even in the bed of the Minnesota River, where groundwater would emerge as springs.

**Figure 6.1 — Terrace Sand and Gravel Deposits**

Meltwater stream deposits along Purgatory Creek deposited as ice retreated from the region. These sand and gravel layers are never saturated near deeply incised streams because of their thickness and permeability. Photo by Mary Presnail.

The next youngest event to affect Hennepin County was the advance of the Grantsburg sublobe that emanated from the northwest, bringing loamy to clay-loamy glacial sediment that was deposited in hummocky, stagnant-ice terrain. This unit forms the surface of most of the county *(Johnson et al., 2016 and references therein)*. As the Grantsburg sublobe entered the county from the west, it crossed older morainic topography of the underlying Superior lobe and proceeded to flow into the area recently occupied by it. The Grantsburg sublobe till is therefore highly variable and its classification depends on how much of the visibly different, red, sandy loam glacial sediment of the Cromwell Formation of the Superior lobe was incorporated (*Johnson et al., 2016 and references therein)*. In some places the till resembles sediment of the Des Moines lobe before it crossed the St. Croix moraine, mapped as Villard (Qv) and Heiberg (Qh) members of the New Ulm Formation. Where it admixed more of the Superior lobe material, it is mapped as the Twin Cities Formation (Qt). Despite the color variation, the overall differences are subtle and based on minor changes in texture and lithologic composition.

Prior to the Grantsburg sublobe advance, the Superior lobe advanced into the region from the northeast and deposited the reddish-brown till of the Cromwell Formation (Qc). Lake sediment composed of alternating layers of reddish clay and gray silt (Qcl) accumulated as Superior lobe ice retreated. This lake is referred to as "Early glacial Lake Lind" and is a significant unit in the subsurface (*Berthold, 2018*). These events are depicted in sequence (Figure 6.2).

Even older glacial sediment from previous glaciations is found at depth, and thick layers of glacial sediment and stream sediment have accumulated in lows in the bedrock (Table 6.1). Dark gray, clay loam to loam glacial sediment is exposed in places in tributary valleys to the Minnesota River and has been identified as two members of the Lake Henry Formation (*Johnson et al., 2016 and references therein; Berthold and Lively, 2018*).

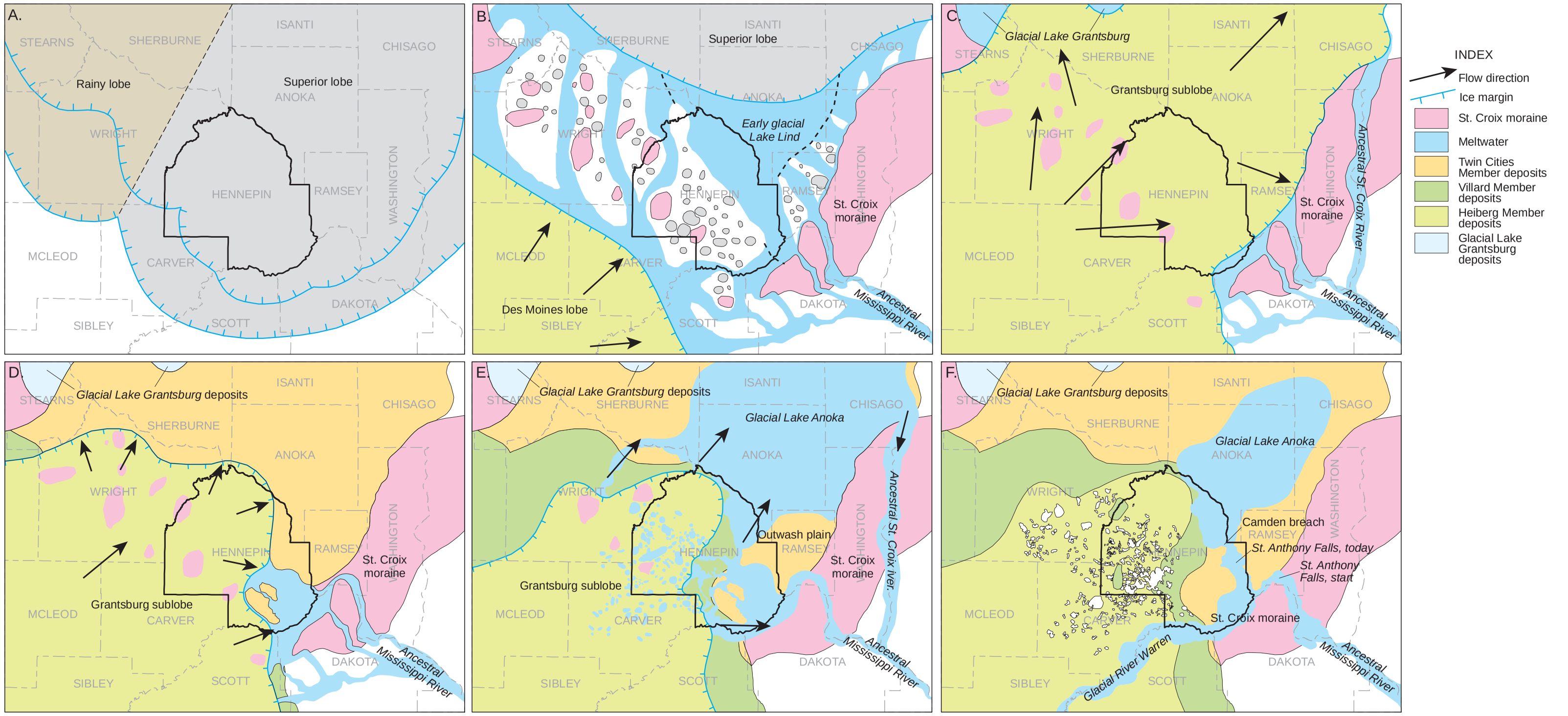


**Figure 3.** A schematic depiction of the late Wisconsinan glacial history of Hennepin County and surrounding areas.

**A.** The Superior lobe first advanced into Hennepin County during the Emerald phase from the northeast (Superior provenance) and deposited sediment of the Cromwell Formation (gray). It likely advanced contemporaneously with the Rainy lobe, which flowed into Minnesota from the north–northeast (Rainy provenance) and deposited sediment of the Hewitt Formation (brown; southern ice margin). The position of the dashed line separating the two ice lobes is based on the existence of the Hewitt Formation sediments in adjacent Wright County. The Superior and Rainy lobes then retreated back to the northeast and north, respectively. The Superior lobe readvanced into Hennepin County during the St. Croix phase, including into territory formerly occupied by the Rainy lobe, and deposited the St. Croix moraine (northern ice margin). This readvance ice margin is marked by thrust-block uplifts (hill-hole pairs) identified within the Lake Minnetonka basin, and is interpreted to be contemporaneous to the Powder Ridge Winter Recreation Area ski hill, another thrust-block uplift in Stearns County (Knaeble, 1998). During this phase, it is also likely that the portion of the Minnesota River on the southern border of Hennepin County formed as an ice-marginal meltwater channel.

**B.** After the St. Croix phase, the Superior lobe retreated back toward the Lake Superior basin. Proglacial meltwater, following the paths of former tunnel valleys, dissected recessional Superior-lobe deposits and eventually coalesced toward the ancestral Mississippi River. Some of the meltwater ponded behind these recessional deposits and formed an early phase of glacial Lake Lind (dashed lines). This ponding was also controlled by the Stacy basin, a bedrock low. Numerous ice blocks (gray) were left behind on the recently ice-free landscape, with a high concentration in Hennepin County. Meanwhile, the Des Moines lobe advanced into Minnesota from the northwest (Riding Mountain provenance) and contributed meltwater to the area.

**C.** As the Des Moines lobe continued to advance into Minnesota, an offshoot branched to the northeast from the central core of the lobe, forming the Grantsburg sublobe. This offshoot of ice flowed radially over the ice-cored, dissected, and patchy terrain of the Superior lobe and as a result incorporated sediments of Superior provenance. Grantsburg-sublobe meltwater in this area followed the existing channels cut by Superior-lobe meltwater and also flowed toward the Mississippi River. This advance generated the Twin Cities Member of the New Ulm Formation, particularly evident along the margins of the Grantsburg sublobe. A central axis core of Villard Member till was also deposited at this time in Hennepin County. Glacial Lake Grantsburg, a proglacial lake to the north, was active at this time.

**D.** The Grantsburg sublobe actively retreated from its maximum position at the Pine City moraine to the position shown. It continued to flow radially, generating arcuate washboard moraines marking annual recession. Meltwater channels emanated from the ice margin, cutting into recently deposited Twin Cities Member sediments. This recessional position also exposed deposits of the Villard Member of the New Ulm Formation on the southwestern side of the area delineating the St. Croix moraine. Because ice in this area did not cross the moraine, it is not of mixed provenance. Glacial Lake Grantsburg had drained by this time.

**E.** Active recession of the Grantsburg sublobe ceased and the ice stagnated, exposing more sediments associated with the Villard Member of the New Ulm Formation. Numerous meltwater channels emanated from this last ice margin, progressively dissecting recently deposited material. Some of this meltwater followed existing channels in southeastern Hennepin County, but the rest flowed to the northeast into the Stacy basin, forming glacial Lake Anoka. Within the stagnant ice, ponds of meltwater formed on the ice surface, generating ice-walled stagnation plains.

**F.** The stagnation of the Grantsburg sublobe generated the extensively ice-cored topography associated with the Heiberg Member of the New Ulm Formation in Hennepin County. Glacial Lake Anoka eventually drained through the Camden breach in north Minneapolis, cutting large terraces and delineating the modern path of the Mississippi River. Glacial Lake Agassiz in northwestern Minnesota also drained, forming the large glacial River Warren valley currently occupied by the Minnesota River. This deluge of meltwater also generated St. Anthony Falls.

Figure 6.2 — Ice Advances Affecting Hennepin County

Superior lobe advance and partial retreat and lake formation is followed by advance of an ice lobe from a different direction. Broad meltwater streams deposited sand and gravel in southern Hennepin County as the ice in the interior of the county stagnated before the Minnesota River valley formed (from *Berthold, 2018*).

## Valley Formation Exposed and Destabilized Sediment Layers

The Minnesota River valley was created by the draining of Glacial Lake Agassiz approximately 13,400 years ago. Immediately after valley formation, the valley walls would have been highly unstable. This is the likely time that the largest landslides occurred. If landslide activity was concurrent with the river occupation, the deposits would have been swept away by the glacial lake flood waters. If they occurred after the flow subsided, landslide deposits should be visible unless they have been buried by the sediment that has accumulated in the Minnesota River valley since it was formed.

The valley cut 230 feet (70 meters) deep into the landscape. This created waterfalls or steep reaches (knickpoints) at the mouths of the tributary streams. These knickpoints have been migrating upstream as tributaries continue to adjust to the base-level fall. In this way, over the last several thousand years, the lower few miles of tributary valleys have incised deeply enough to reach equilibrium with the elevation of the Minnesota River valley floor. However, the tributary valley walls are young and upstream areas are continuously being destabilized as knickpoints continue to migrate and new knickpoints form in the tributaries. The deep reaches of these valleys will continue to expand upstream until the entire basin has adjusted its gradient. Where incision has happened most recently, near the knickpoints, the slopes are most vulnerable to failure.

Tributaries in the process of adjustment, and therefore carrying as much sediment as they can handle, deliver it to the Minnesota River that is not effective at carrying it away. Major tributaries have built fans at their mouths that contribute to the overall aggradation of the valley floor. Modern sedimentation rates on the floodplain are on the order of a centimeter or two per year (under an inch) and much of the valley is filled with over 50 feet (15 meters) of sediment *(Jennings et al., 2018)*. This is the process that has the potential to bury or obscure early landslide deposits.

## Failure Style in the Minnesota River Valley and Tributaries

The largest failures in the Minnesota River valley are deep rotational failures with deposits that show some evidence of liquefaction and flow. They are primarily located along the Minnesota River valley in Bloomington. The lake sediment associated with the Superior lobe (Qcl) is present in the subsurface in these areas (Figure 6.4). Layered clay and silt impedes the downward movement of water, allowing it to build up porewater pressure on top of the unit and within the silt beds.

Springs emerge from the bluff at different elevations and indicate the horizons where water is accumulating and able to move laterally. Along the slopes of the Minnesota River valley below East Old Shakopee Road and above Long Meadow Lake in Bloomington, there is a double spring line. The upper spring line, at an elevation of about 770 feet above sea level (ASL), is depositing iron. The lower spring line, at about 720 feet ASL, is depositing tufa, a form of calcium carbonate (*Brick, 2018*). These two distinct spring lines most likely emerge from contacts between units with different chemistry. The upper, iron-rich spring horizon may demarcate the top of the Cromwell Formation lacustrine clay and silt (Qcl). The lower calcareous horizon is more consistent with the Meyer Lake Member of the Lake Henry Formation (Qh2). However, the Meyer Lake Member seems to be more deeply buried here. An alternative explanation for the difference in spring chemistry might be the variability in the Twin Cities Formation layers. Whatever the source of the springs, these hillsides have the largest rotational failures in the Minnesota River valley. The springs remain active, and arcuate cracks on the surfaces above the bluffs in this area are indicative of deep-seated landslides of unknown age that extend 650 feet (200 meters) into the flat area beyond the bluff edge (Figures 6.5a, 6.5b and 6.5c). The different glacial units involved in the slides are interpreted from slide locations and nearby cross sections produced by the MGS (Table 6.2, Figure 6.4).

# Table 6.1

## Glacial and Postglacial Stratigraphic Units in Hennepin County

(in order of ascending age)

### Post-glacial

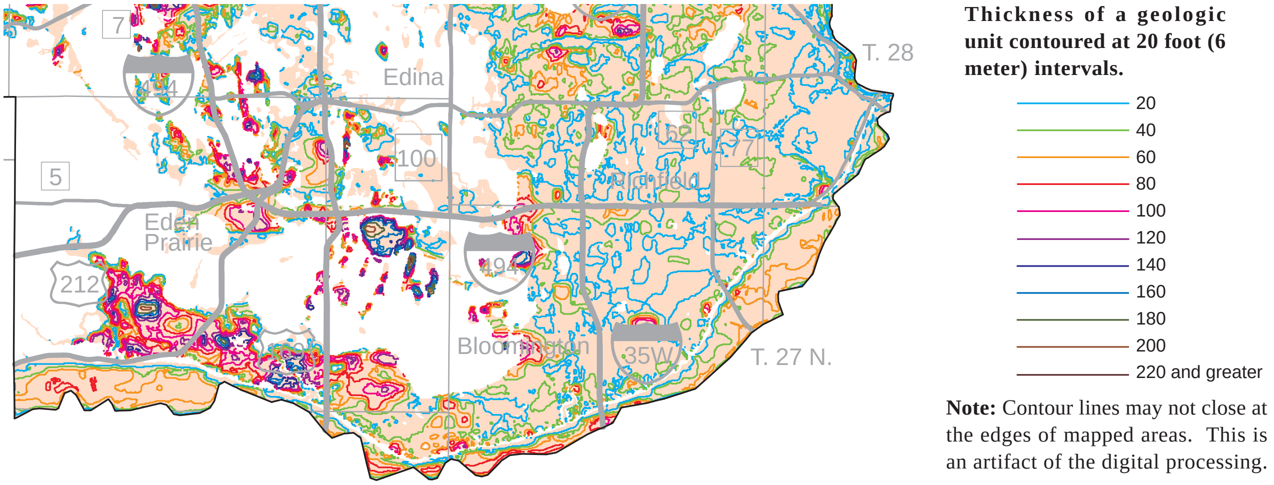
| | |
|---|---|
| Afhl | Artificial fill over Holocene lacustrine |
| Aftci | Artificial fill over Twin Cities ice-contact |
| Afsi | Artificial fill over Superior ice-contact |
| Ql | Holocene lacustrine |
| Qas | Fine alluvium |
| Qag | Coarse alluvium |
| Qc | Colluvium |
| Qat | Terrace sand |
| Qlt | Lacustrine under terrace sand |
| Qnd | New Brighton delta |
| Qnb | New Brighton sand |

### Pre-last glacial units

| | |
|---|---|
| Qh1 | Sauk Centre outwash |
| Qsc | Sauk Centre till |
| Qf1 | St. Francis outwash 1 |
| Qsf1 | St. Francis till 1 |
| Qh2 | Meyer Lake outwash |
| Qml | Meyer Lake till |
| Qf2 | St. Francis outwash 2 |
| Qsf2 | St. Francis till 2 |
| Qwo | Old Rainy outwash |
| Qwt | Old Rainy till |
| Qeo | Elmdale outwash |
| Qet | Elmdale till |
| Qvo | Old Superior outwash |
| Qost | Old Superior till |
| Qsu | Quat sand below old Superior-provenance till; unnamed |
| Qu | undifferentiated sediments |

### Glacial

| | |
|---|---|
| Qno | New Ulm outwash |
| Qts | Twin Cities sand (the surficial version of TC sand) |
| Qhl | Heiberg lacustrine |
| Qhi | Heiberg ice-contact (changed it to Heiberg; was Villard ice-contact on surficial map) |
| Qsh | Heiberg stagnation |
| Qht | Heiberg till |
| Qvs | Villard sand |
| Qtc | Twin Cities colluvium |
| Qtl | Twin Cities lacustrine |
| Qst | Twin Cities stagnation |
| Qvt | Villard till |
| Qts2 | Twin Cities sand within (not surficial) |
| Qti | Twin Cities ice-contact |
| Qtt | Twin Cities till |
| Qts1 | Twin Cities sand below till (Hillside sand equivalent) |
| Qms | Moland sand |
| Qmt | Moland till |
| Qsi | Cromwell ice-contact |
| Qs1 | Automba phase outwash |
| Qca | Cromwell till — Automba phase |
| Qcl | Cromwell lacustrine |
| Qs2 | St. Croix phase outwash |
| Qcs | Cromwell till — St. Croix phase |
| Qs3 | Emerald phase outwash |
| Qce | Cromwell till — Emerald phase |

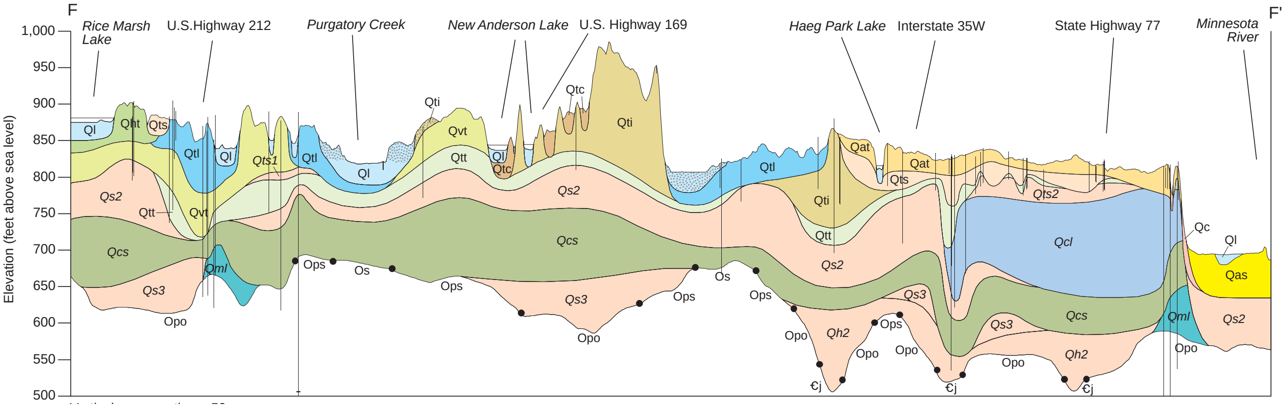


**Thickness of a geologic unit contoured at 20 foot (6 meter) intervals.**

**Note:** Contour lines may not close at the edges of mapped areas. This is an artifact of the digital processing.

## Figure 6.3 — Presence and Thickness of Sand and Gravel

Sand in a terrace position at the surface as mapped (Qat) and contoured total thickness (*Berthold and Lively, 2018*).



## Figure 6.4 — Representative Cross Section

A portion of cross section F-F' from Plate 4, Hennepin County Atlas *(Berthold, 2018)* shows the stratigraphy in the area of large landslides along the Minnesota River in Bloomington in the eastern portion of the section. Unit Qcl appears to be involved in destabilizing the slope.

Figure 6.5a — Springs in Eroded Traces of Arcuate Depressions

In Bloomington, iron-rich springs emerge where sands overlies lake clay of the Cromwell Formation and where numerous, deep-seated landslides have been mapped.

Figure 6.5b — Arcuate Depressions at the Head of a Landslide Area

Three, arcuate, downhill-facing depressional features are present in the area where numerous, deep-seated landslides have been mapped.

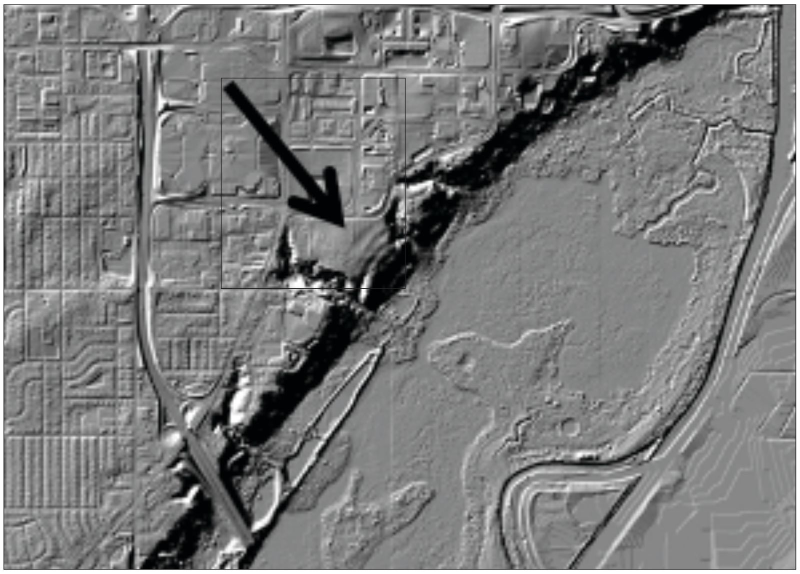
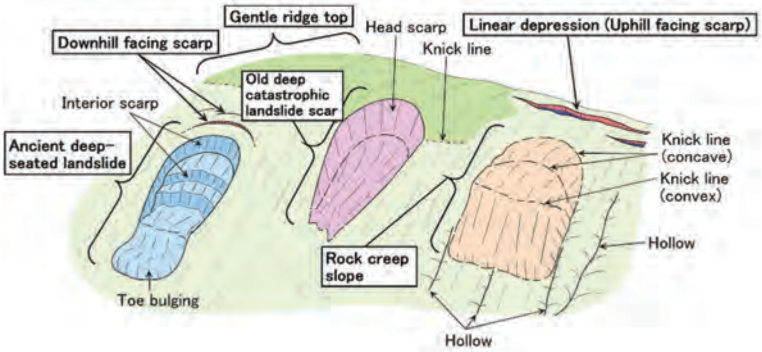


Figure 6.5c — Downhill-facing Scarps are Indicative of Ancient, Deep-seated Landslides

From *Uchida et al., 2011*.



## Table 6.2 — Cross sections, Units Involved in Failure and Area Affected

| Line number | Possible failure units | Area |
|---|---|---|
| 102 | qts, qcl, qvt | Western edge of County |
| 102 | qts2 | Eastern edge of County |
| 102 | qvt, qts2 | Nine Mile Creek |
| 104 | qat, qts | Western edge of County |
| 104 | qts, qtt | Eastern edge of County |
| 101 | qts, qtt, qcl | Eastern edge of County |
| 101 | qts, qts2, qtt | Nine Mile Creek |
| 101 | qts | Purgatory Creek |
| 101 | qts | Western edge of County |
| 100 | qts, qvt, qcl | Western edge of County |
| 100 | qts | Purgatory Creek |
| 100 | qts1 | Nine Mile Creek |
| 100 | qts1, qcl | Eastern edge of County |
| 103 | qcl | Eastern edge of County |
| 103 | qcl, qts2 | Nine Mile Creek |
| 103 | qvt, qcl | Western edge of County |
| 105 | qts | Western edge of County |
| 105 | qts | Eastern edge of County |
| 99 | qvs, qvt | Far western edge of County |
| 99 | qts, qts1, qvt | Western edge of County |
| 99 | qts | Purgatory Creek |
| 99 | qts, qst | Eastern edge of County |
| 99 | qat | Nine Mile Creek |
| 98 | qcl, qcs, qts | Eastern edge of County |
| 98 | qts | Nine Mile Creek |
| 98 | qvt, qts | Purgatory Creek |
| 98 | qts, qas | Riley Creek east |
| 98 | qts, qht, qvs | Riley Creek west |
| 98 | qht | Minnesota Bluff Trail |
| 97 | qht, qvs | Riley Creek far west |
| 97 | qht, qvs | Riley Creek west |
| 97 | qht, qvs, qts | Riley Creek east |
| 97 | qts, qvt | Purgatory Creek |
| 97 | qts, qcl | Eastern edge of County |
| 96 | qts | Eastern edge of County |
| 96 | qts, qtl | Purgatory Creek |
| 96 | qtc | Interior of County |
| 95 | qtc, qht | Interior of County |
| 95 | qts | Eastern edge of County |
| 94 | qts, qcl | Eastern edge of County |
| 94 | qht, qts | Interior of County |
| 93 | qts, qtt, qcl | Eastern edge of County |
| 92 | qtt, qcl | Eastern edge of County |
| 91 | qcs | Eastern edge of County |
| 90 | qts1, qcl, qcs, qs3 | Eastern edge of County |

# Recommendations

Landslide-susceptible areas like these deep-seated failures can be of two main types with differing failure mechanisms. The extent of area affected at the top and toe of the bluff and the rate of failure should both be considered when assessing the hazard. Infrastructure and buildings on top of or on a slope where springs are present, or where there are failure deposits and scarps, should be evaluated to determine if the site should be monitored to detect ongoing motion (e.g., using tensiometers or inclinometers). Setbacks from the bluff top in these settings are overly simplistic approaches that do not work well with deep-seated features. Guidelines need to be tailored to the geotechnical needs specific to each region.

To reduce the likelihood of failures in the thick, dry sand deposits along the Minnesota River valley, preserving the slope angle is of critical importance. Slope erosion can be reduced by protecting the toe of the slope, controlling runoff above or onto the slope, avoiding cuts into the slope without the use of engineered retaining walls or other mitigation measures, and keeping slopes properly vegetated.