LANDSLIDES THROUGH TIME:

ACTIVE AND DORMANT LANDSLIDES IN EASTERN NORTH DAKOTA

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North Dakota is commonly associated with having a gently undulating landscape, so many people do not think of landslides having an impact on the state. However, nearly 50,000 landslides have been mapped statewide by the North Dakota Geological Survey (NDGS) since 2003. These landslides occur in many locations statewide (fig. 1) with most of them being in waterway systems (Red River, Sheyenne River, etc.), the Pembina Gorge (failing Pierre Shale), and the badlands in western North Dakota (Bullion Creek and Sentinel Butte Formations). Historically, the NDGS used an inventory style of mapping to map landslides, meaning all identifiable landslides were mapped. There was no distinguishing between an active or dormant type of slide.

At the NDGS, Phase I of landslide mapping began in 2003 and went through 2017 which included the publication of nearly 300 landslide maps (Maike and Moxness, 2022), using 1:20,000 aerial photographs from the 1950s and 1960s. These photos were looked at with a stereoscope, which gives a three-dimensional effect to the viewer. Over time, higher resolution satellite data became available along with Light-Detection and Ranging (LiDAR) and beginning in 2017, the NDGS used LiDAR and the satellite imagery in conjunction with stereopairs to continue mapping landslides across the state. The landslide maps using these products would now be known as Phase II. LiDAR is a remote sensing technology using lasers from an aircraft to create a digital elevation model of Earth's surface (Maike, 2016). LiDAR data was a game changer for interpreting landscapes for slides and failures. Through computer modeling, vegetation could be removed from the digital elevation models, allowing geologists to observe the "bare-earth." This vastly increased the number of landslides mapped by the NDGS (Moxness, 2019, 2022; Maike, 2021; Maike and Moxness, 2022). Currently, the Geological Survey is nearing completion of the Phase II landslide mapping program. The NDGS began Phase III landslide mapping on the eastern side of the state in 2021.

Phase III landslide mapping brings the 21st century into the mapping world. Phase III utilizes two North Dakota LiDAR datasets collected in the same area, typically 8-10 years apart (the current data availability). The second raster is subtracted from the first raster to calculate the elevation change. Negative values would signal erosion or net loss whereas positive values would signal accretion or net gain. Over a period of 8-10 years there may be many reasons for positive or negative displacement besides landslides. The interpretation for Phase III landslide mapping needs to be conducted by an individual with a great amount of experience with satellite imagery, LiDAR interpretation, and slope stability.

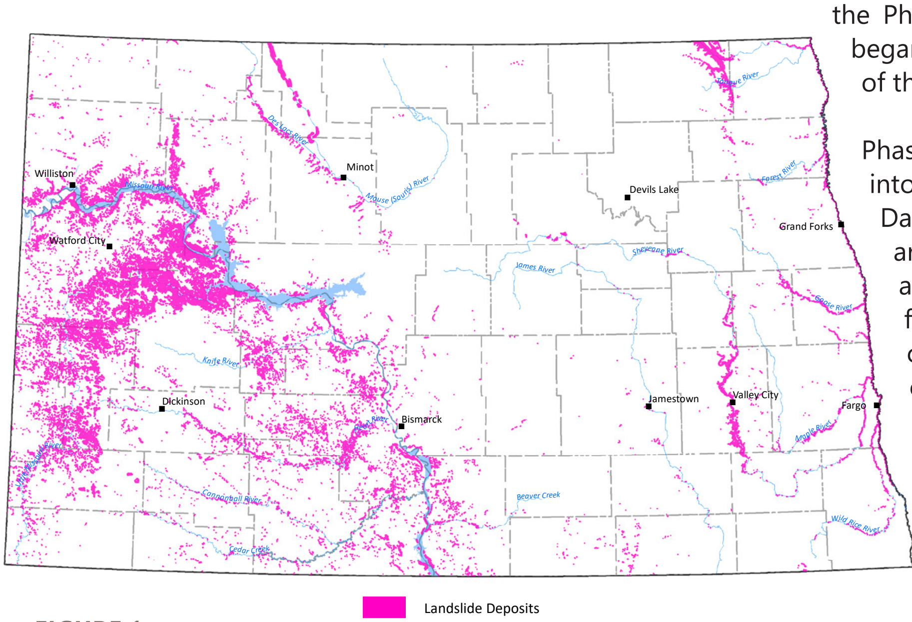

FIGURE 1.
Locations of landslide deposits throughout the state of North Dakota.

Comparing previously mapped Phase II landslides to the newly mapped Phase III landslides can reveal how active or dormant landslides are. This article highlights the 1:24,000 quadrangles that contain new landslides in areas previously free of slope failure as well as failed slopes that have recently become dormant in the Red River and Pembina Gorge areas. Most of the landslides found in these regions are rotational and translational slides, which occur when exposed rocks or sediments fail and move along a curved or planar surface of failure. Visible evidence of these types of slides includes tilted trees or other features rotated along with the rotational block (Schwert, 2003). Though the mechanics are similar, there are other factors that influence landslide development. Flooding in the Red River creates a positive hydraulic pressure and saturates the soil along the river banks. The increased soil moisture in the riverbanks can lead to premature failure (Schwert, 2003). The Pembina Gorge has steeper slopes compared to the Red River Valley which result in more failure prone slopes. As Phase III progresses across the state, new datasets have become available for analysis. This information can be advantageous to city, county, and state planners to know how active slopes are in their area. As mentioned above, LiDAR has been used to identify landslides in North Dakota since 2017. While it is useful to know the location of failure prone areas, it is also useful to know how long an area has been active, or conversely, how long it has been dormant.

This new way to look at the Phase II and Phase III mapping in the state has given us new values to represent the activity of slopes in each respective quadrangle. The first dataset was Phase II landslides by quadrangle in the Red River and Pembina Gorge regions. The second dataset was Phase III landslides in the same quadrangles mentioned previously. From these two datasets, we created two new datasets for a total of four landslide datasets for this comparison: Phase II, Phase III, dormant, and newly active landslides. The remainder of this article will focus on the latter two datasets in more detail.

DORMANT LANDSLIDE AREAS

The dormant landslide area dataset was created by taking the Phase II landslides and removing any overlap by Phase III. The resulting areas represented landslides that were identified as to have occurred before the mapping of Phase II, but have not shown any movement since. Areas that are dormant can indicate where the slopes have stabilized, but can also mean that it should be easier to see signs if the slope has become active again. It is important to note that identified dormant landslides were dormant between Phase II and Phase III mapping (typically an 8–10-year time span). The landslides could have been dormant a day before Phase II mapping, or a hundred years before. Landslide dormancy can be affected by many factors including meander cutoffs/oxbows and preventative efforts such as planting

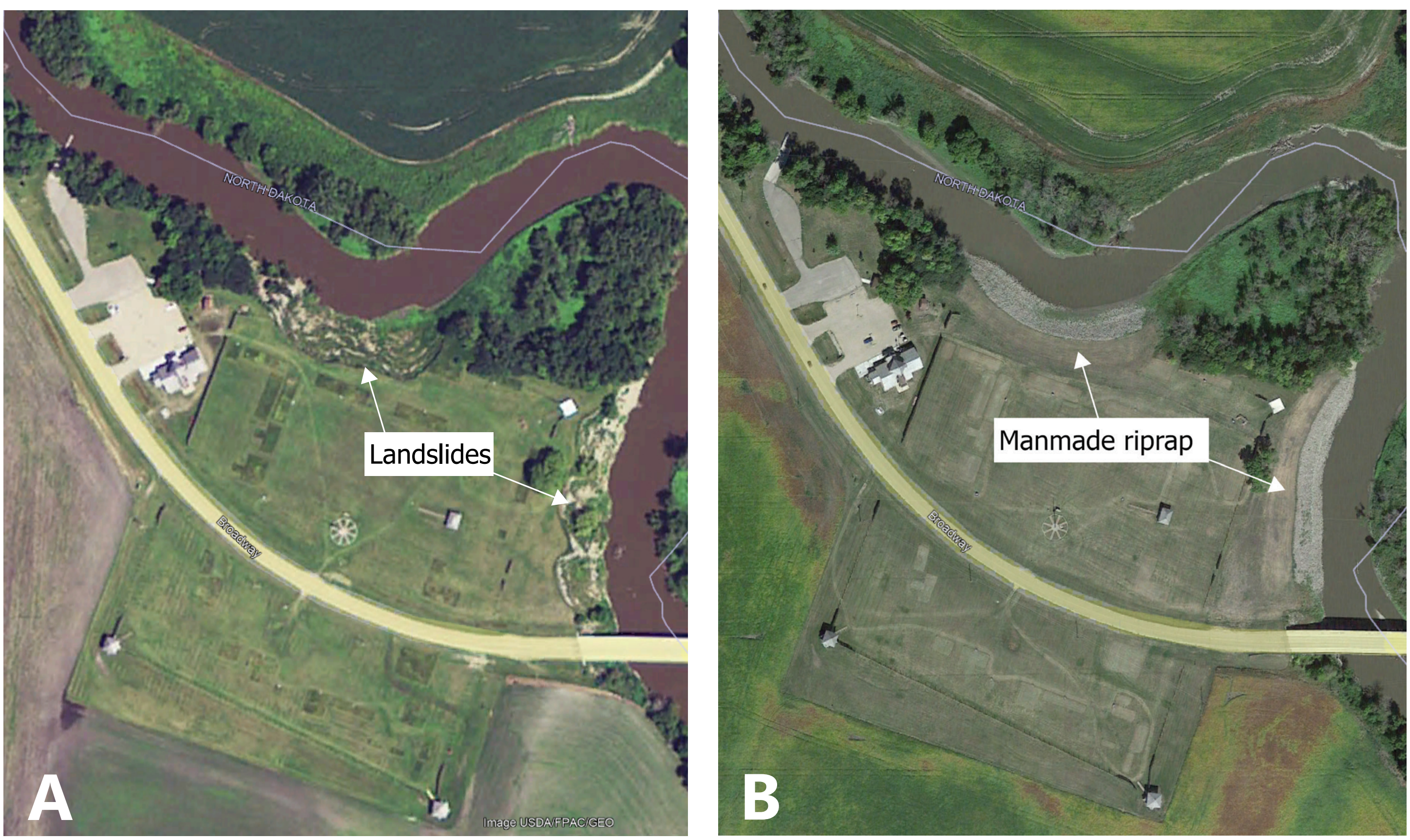

FIGURE 2.
(A) Imagery taken in April 2011 at Fort Abercrombie State Historic Site showing significant landslides approaching the site's structures, and (B) the same location in September 2013 showing landslide mitigation in the form of rock riprap.

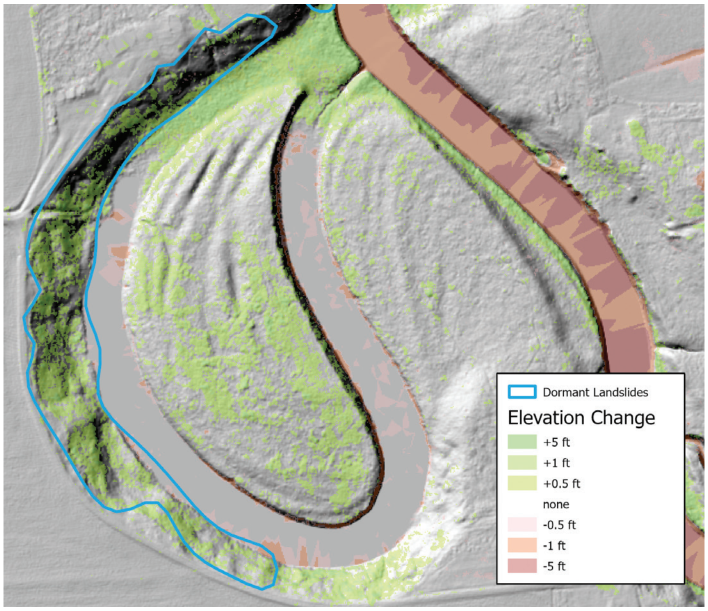

FIGURE 3.
This oxbow lake found south of the town of Oxbow, ND is an example of once active landslides, that once separated from the influence of the river, have become dormant. The blue outline indicates the current dormant landslides.

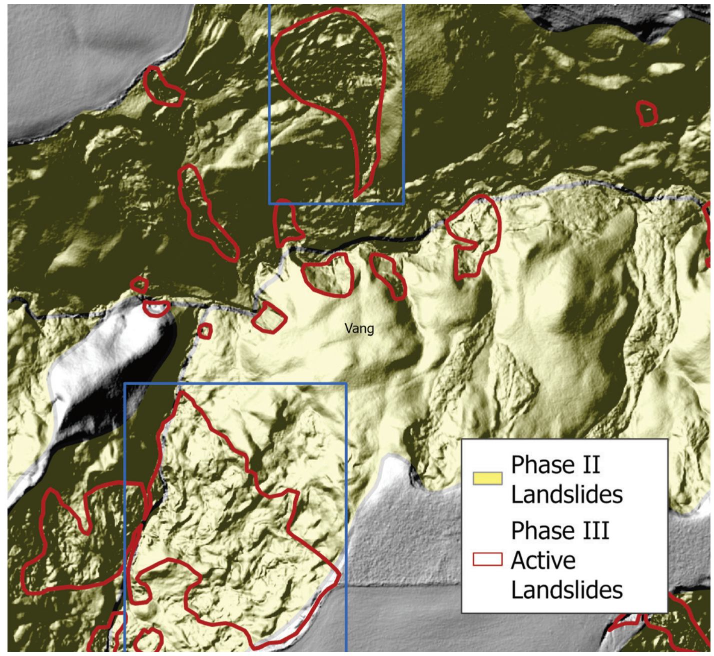

FIGURE 4.
Located in the Pembina Gorge, west of Walhalla, ND, the blue rectangles highlight two examples of active landslides mapped in Phase III that have failed on previously failed slopes. The highlighted landslides look "fresh" with rougher topography that has not smoothed out due to erosion.

vegetation or adding riprap as seen at Fort Abercrombie State Historic Site (fig. 2). In the Red River Valley, the Red River and other tributaries can cut off a section of the river and create an oxbow (fig. 3). There is no longer flowing water, except during a flood, and as a result the previously failed landslides along the banks begin to stabilize. In the Pembina Gorge, almost every slope has failed at some point, so much so that entire lengths of slopes along valleys are comprised of previous landslides (fig. 4). Many of the slopes in the Pembina Gorge have stabilized and become dormant as of the time of mapping, while new landslides mapped in Phase III occurred almost exclusively on already failed surfaces (fig. 4).

NEWLY ACTIVE LANDSLIDE AREAS

Like the dormant landslide area dataset, the newly active landslide area dataset was created by taking the Phase III landslides and removing any overlaps with Phase II. The resulting dataset represents landslides that have occurred in areas that had no visible evidence of past landslides. These types of landslides usually occur on the edge of Phase II landslides indicating that the affected area is just expanding rather than entirely new landslides forming. There, landslide expansions comprise most of the newly active landslide area in the Pembina Gorge and the Red River Valley. Occasionally you will see sliding in areas that previously had no failed slope, which is easily picked up on the elevation difference raster mentioned above (fig. 5). Landslides in areas that were historically dormant or stable can take landowners by surprise, cause infrastructure damage, or even force homeowners to move their dwellings.

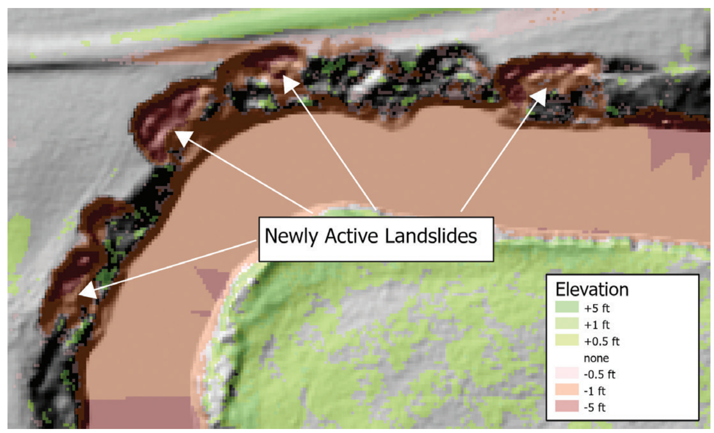

FIGURE 5.
Differential elevation raster overlain on a directional hill shade raster of some landslides north of Abercrombie, ND. The landslides indicated in the image have an iconic concave shape and extend into a previously stable landscape.

LANDSLIDE ACTIVITY

Table 1 demonstrates that most of the previously mapped landslides in the Red River area are dormant. This implies that for at least 8-10 years many of the previously failed slopes have not moved enough to be mapped in Phase III. This is not to say that they will be dormant for the next 8-10 years. Also in Table 1, the overall low number of newly active and high numbers of dormant landslide areas in the quadrangles, indicates that the river meandering may have remained somewhat stable, and the same areas of activity remained active. Likewise, higher active landslide numbers, paired with high dormant landslide numbers, could indicate a shifting in areas of failure, such as meanders getting cut off or landslides occurring on previously stable reaches of the river. It is also interesting to note that the quadrangles with some of the highest dormant area values are near larger cities, which might be explained by the increase of planned slope stabilization and landslide mitigation. In Table 2, which includes the quadrangles for the Pembina Gorge, it is apparent that almost every major slope has failed at some point and now only a few small areas are active, and even fewer areas have newly active landslides occurring on previously stable slopes.

Rivers are a major source of landslides as they are often associated with steeper slopes, and their power to alter the landscape in dramatic ways. Both in the Red River Valley and the Pembina Gorge, most landslides are almost exclusively found along waterways. Landslides can occur gradually or suddenly and take landowners and city planners by surprise. What might have been considered a stable slope along a riverbank might be a dormant landslide that can reactivate at any time when the right conditions are met. As new LiDAR comes out, geologists at the NDGS plan to continually update landslide mapping throughout the State of North Dakota to keep the public well-informed.

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TABLE 1.
Area in square meters for quadrangles that intersect the Red River. The area of the "Dormant landslide area (sq. m)" is calculated by removing the overlap between the Phase II and Phase III landslides and tabulating the area of the remaining Phase II landslides. The "Newly active landslide area (sq. m)" is calculated in a similar way, but instead tabulating the area of Phase III after any Phase II overlap was removed. The two percentage columns are simply the newly tabulated area columns divided by their respective Phase II or III area.

Quadrangle Name	Phase II Landslide Area (Acres)	Phase III Landslide Area (Acres)	Dormant Landslide Area (Acres)	Newly Active Landslide Area (Acres)	% Landslides Remained Dormant
Abercrombie (MN)	35.9	24.6	16.3	5.0	45%
Big Woods (MN)	5.3	4.1	2.4	1.3	46%
Big Woods NE (MN)	1.9	-	1.9	-	100%
Big Woods NW	139.5	95.7	62.9	19.1	45%
Big Woods SW	91.3	119.0	25.6	53.3	28%
Bowesmont	49.2	9.3	39.9	-	81%
Bygland (MN)	372.4	51.7	326.6	5.9	88%
Christine	44.6	23.6	29.8	8.9	67%
Climax (MN)	196.7	99.2	125.2	27.8	64%
Climax NW	357.4	129.0	248.7	20.3	70%
Climax SW	12.0	3.8	10.1	1.9	84%
Drayton	131.1	26.5	110.0	5.5	84%
Dwight	6.4	-	6.4	-	100%
Eldred (MN)	-	0.5	-	0.5	x
Fargo North	289.5	46.5	250.2	7.2	86%
Fargo South	321.0	22.8	305.9	7.7	95%
Georgetown (MN)	436.3	123.4	328.4	15.5	75%
Grand Forks	240.0	70.5	175.6	6.2	73%
Halstad (MN)	231.7	99.3	150.2	17.8	65%
Hickson	197.1	65.8	153.5	22.2	78%
Joliette	143.5	73.8	71.2	1.4	50%
Manvel	6.7	1.0	6.7	1.0	100%
Mattson (MN)	82.4	32.6	52.8	3.0	64%
Oslo	126.2	117.6	40.1	31.5	32%
Oslo NE (MN)	-	2.2	-	2.2	x
Oslo SE (MN)	206.5	89.8	126.4	9.7	61%
Pembina	199.3	45.0	157.1	2.8	79%
Perley (MN)	217.7	55.5	170.5	8.3	78%
Shelly (MN)	185.1	76.7	131.8	23.4	71%
Thompson	34.5	4.8	33.3	3.6	96%
Wahpeton (MN)	-	1.8	-	1.8	x
Wolverton (MN)	10.8	8.7	3.2	1.1	29%

TABLE 2.
Area in square meters for quadrangles in the Pembina Gorge. The area of the "Dormant landslide area (sq. m)" is calculated by removing the overlap between the Phase II and Phase III landslides and tabulating the area of the remaining Phase II landslides. The "Newly active landslide area (sq. m)" is calculated in a similar way, but instead tabulating the area of Phase III after any Phase II overlap was removed. The two percentage columns are simply the newly tabulated area columns divided by their respective Phase II or III area.

Quadrangle Name	Phase II Landslide Area (Acres)	Phase III Landslide Area (Acres)	Dormant Landslide Area (Acres)	Newly Active Landslide Area (Acres)	% Landslides Remained Dormant	% Newly Active Landslides
Hanks Corner	942.2	69.8	885.2	12.9	94%	18%
Olga	3,284.7	503.8	2,861.4	80.5	87%	16%
Olga NW	5,447.8	721.5	4,738.9	12.6	87%	2%
Olga SW	61.0	19.0	55.2	13.2	90%	69%
Vang	7,095.3	796.8	6,353.8	55.3	90%	7%
Walhalla	580.7	161.9	434.3	15.5	75%	10%