

9. Weather and Climate Correlation

Weather Correlation

Rainfall-induced landslides are the most frequent and widespread damaging landslides that occur in the United States, according to U.S. Geological Survey. These slides are associated with prolonged wet periods followed by an episode of particularly heavy rainfall. Typically, rainfall-induced landslides are shallow, small and fast-moving. Most Hennepin County landslides are rainfall-induced. Understanding weather and soil conditions that lead to Hennepin County landslide events enables hazard assessments to identify specific indicators that should be monitored. Weather data also help to identify seasonal landslide-risk periods as well as longer term climate-influenced activity.

Introduction

June 2014 was Minnesota's wettest June; in fact it was the wettest of all months in the modern record. The state-averaged monthly rainfall total for June 2014 was 8.03 inches with some areas in the Twin Cities receiving more than 13 inches. This total easily exceeded the previous record of 7.32 inches set in 1897 and again in June 1914.

The year prior to June 2014 was already wet in Hennepin County. Rains in late April produced landslides on an engineered slope along the Interstate 494 corridor in Eden Prairie on April 29. Two main rainy periods occurred in June 2014. The first 7-day rainy period ended on June 4, and three failures were documented as part of this event,

including one that forced the abandonment and demolition of a home in Eden Prairie. Contributing to this slide was a human trigger of stormwater infrastructure that failed while under repair.

The widespread rains of this first June event may have established the antecedent moisture conditions for the subsequent failures that occurred in association with the second rainfall event. The second period brought more widespread failures. The second round of storms hit southern Minnesota particularly hard.

Critical infrastructure in Hennepin County, including two major hospitals, were threatened by either slope failure or flooding during the extraordinary rains of June 2014. Suspending patient services at two large metropolitan hospitals, even if temporary, would have had serious impacts across the entire region. The landslide below Fairview Riverside Medical Center in Minneapolis was the most expensive individual event of the disaster, and it directly led to the inclusion of Hennepin County in the federal disaster declaration (*FEMA, 2014*).

Hennepin County was motivated by the events of 2014, as well as the tragic fatalities of 2013 in neighboring Ramsey County, to develop a tool to better understand and predict landslides in the local environment. Precipitation appeared to be a principle driver of landslides in this area, which warranted further study. Craig Schmidt of the National Weather Service's office in the Twin Cities assessed rainfall events as part of this landslide assessment.

Background

Excess soil moisture reduces the internal friction between sediment grains and can decrease the resistance to gravitational failure. In the absence of soil-moisture measurements, precipitation records can approximate soil-moisture conditions. Soil moisture is usually gauged by looking at precipitation in a period leading up to the slide (antecedent moisture) and the intensity of rainfall in a shorter period immediately preceding the slide.

Precipitation also results in enhanced spring flow that can lag behind peaks in soil moisture but also lead to slope instability, either through reduction in friction or from freezing and thawing. Storm water runoff creates new ravines, deepens and widens existing ravines and destabilize slopes.

Typically, moderate to intense rainfall causes failure to occur (Coe *et al.*, 2014). However, the antecedent rainfall prior to the intense event is also important because if soils do not have time to recover to a normal moisture state, they are more vulnerable. Antecedent rainfall not only controls the initial moisture content of the sediment or rock but affects the subsequent rate and depth of wetting. Rainfall intensity, cumulative precipitation and the timing of rainfall all have a role in slope failure.

Methods

For well-dated landslide events found during the initial inventory of historic slides (Jennings *et al.*, 2016), rainfall totals for those days as well as the cumulative totals from two weeks prior to the event were recorded. The stations closest to the slides were used. If nearby stations did not have long enough records, those in Minneapolis or St. Paul that had data that went back to the date of the slide were used.

Monthly precipitation data from every year dating back to about 1880 between March and September were reviewed to find relatively high totals (upwards of 9 inches). Within those months, dates or a set of dates that had high rainfall totals were focused on when searching newspaper archives to search for news of landslide events.

Results

Reported slides occurred in Hennepin County between April and September with peaks in the months of May, June and August. These are the months that typically have more convective storms and larger rainfall totals. Wetter periods in the last century and a half had more reports of slides. Some of this distribution may be affected by the quality of records and the ease of searching electronic databases versus paper or microfiche records. The apparent recent increase is certainly affected in

part by the use of online search tools and digital news sources.

The initial report (Jennings *et al.*, 2016) attempted to identify the critical rainfall intensity and recovery interval for slope failure by accumulating local data and comparing the region to similar settings (e.g., Guzetti *et al.*, 2007, 2008). These expectations were shaped by work done by the United States Geological Survey (USGS) in Seattle where a robust relationship was found between 15-day antecedent precipitation and 3-day precipitation (Godt *et al.*, 2006). Unfortunately, the differences in topography and rainfall patterns between the Pacific Northwest and Minnesota preclude a direct comparison. Heavy rainfall in Seattle occurs over multiple days from large-scale storms that are enhanced by mountain-range effects. Heavy rainfall in Minnesota is driven by intense, smaller scale convective storms that can drop heavy rainfall in a short time over small areas, reducing the predictability of soil response.

Discussion

The Standardized Precipitation Index (SPI) assesses long-term weather patterns and may provide an approximation for the antecedent soil moisture conditions that might set up the conditions for slope failure. If a SPI threshold were to be determined, then forecasts of short-term (1–3 day) precipitation that might trigger an event in saturated sediment could be anticipated.

Three different July failure events that had SPI data were compared, and the SPI increased markedly as the event time was reached on the 6- and 9-month timescales. The SPI was very positive for two of the events, but not for one that occurred in a very extreme, short-term rainfall event. There was not always an obvious short-term triggering rainfall event. The SPI and trigger idea deserves more study as additional slides are documented in the region.

The British Geological Survey found that rainfall deviating from long-term average was important and typically considered a period 7–90 days prior to the slide and considered the triggering high-intensity rainfall in the 7 days prior to the slide. They also found that even though rainfall might exceed a threshold, failure was not likely if there had been dryness in the preceding 18 months.

However, smaller rain events might lead to a slide if the previous three to four months had been wet (Pennington et al., 2014).

The Norwegian Government simulates soil saturation and provides this in real time through an interactive website (www.varsom.no/en) and compares landslide days to no-landslide days to better constrain their threshold events (Krøgli et al., 2018). This is an assessment that Hennepin County could conduct for the most recent wet year of 2019 that has not produced the number of slides comparable to the wet year of 2014.

Another approach is to put the rainfall in historical context using the National Oceanic and Atmospheric Administration (NOAA) Atlas 14. (Table 9.1). For the events since 1975 that were dated in Hennepin County, Dr. Kenneth Blumenfeld made the following notes, as reported in Jennings et al., 2016:

- July 18, 1975 (FID 39). I do not see any recent precipitation associated with this event. The station they pulled had no measurable rain for over 10 days, and even MSP had been dry since the 9th. A mini heat wave was in progress, with highs in the low-mid 90s and lows in the mid-upper 70s. No heavy precipitation had fallen in the area since the very end of June. June 1975, however, was a very wet month, with about 8 inches at MSP.
- July 20-21, 1987 (FID 40). This was the first event of the two shown below which dropped between 3.5 and 9 inches of rain on Eden Prairie. Heavy rains fell from around 6 p.m. to 2 a.m., with the highest intensities from 7 p.m. to midnight in the northeastern parts of Eden Prairie.
- July 23-24, 1987 (FIDs 42-44). The infamous “superstorm,” ... with widespread 6-10” values across the central and southwestern TC area. Heavy rains fell from 7 p.m. to 1 a.m., with highest intensities from 7–10 p.m. Three-hour totals of 7.58 inches were right around 500-year threshold for 3-hour rainfall, from NOAA atlas 14.

Table 9.1 — Historical Context of Rainfall Related to Landslides Since 1975

Slide location	Slide date	24-hr rainfall amount (in)	24-hr recurrence interval	4-day rainfall	4-day recurrence interval	10-day rainfall amount	10-day recurrence interval	30-day rainfall amount	30-day recurrence interval
FID_0	6/19/2014	2.71	1 or 2 year	3.44	1 or 2 year	4.8	1 or 2 year	7.64	1 or 2 year
FID_36	5/21/2011	3.03	2 or 5 year	3.27	1 or 2 year	4.21	1 or 2 year	6.87	1 year
FID_36 (2)	5/22/2011	1.82	<1 year	5.09	5 or 10 year	6.03	5 or 10 year	8.53	2 or 5 year
FID_37	6/1/2014	2.76	1 or 2 year	4.25	2 or 5 year	4.37	1 or 2 year	7.24	1 or 2 year
FID_39	7/18/1975	0	<1 year	0	<1 year	0	<1 year	6.03	1 year
FID_40	7/22/1987	11.05	500 or 1000 year	14.75	500 or 1000 year	15.01	500 or 1000 year	17.56	500 or 1000 year
FID_41	6/19/2014	1.82	<1 year	2.43	<1 year	3.71	<1 year	9.02	2 or 5 year
FID_42	7/24/1987	4.31	5 or 10 year	11.88	500 or 100 year	11.97	200 or 500 year	13.82	50 or 100 year
FID_43	7/24/1987	8.02	100 or 200 year	10.43	200 or 500 year	10.54	100 or 200	13.46	50 or 100 year
FID_44	7/24/1987	0	<1 year	11.05	500 or 1000 year	15.01	500 or 1000 year	17.34	500 or 1000 year
FID_107	7/24/1987	0	<1 year	11.05	500 or 1000 year	15.01	500 or 1000 year	17.34	500 or 1000 year
FID_110	7/24/1987	0	<1 year	11.05	500 or 1000 year	15.01	500 or 1000 year	17.34	500 or 1000 year
FID_111	7/24/1987	0	<1 year	11.05	500 or 1000 year	15.01	500 or 1000 year	17.34	500 or 1000 year

- July 26-27, 1999 (FID 47). This was a late night event associated with a slow-moving thunderstorm complex, and it dropped 2–4 inches in about 1.5–2 hours.
- May 21–22, 2011 (FID 36). This was a 2-headed event. On the evening of the 21st, an isolated severe thunderstorm sat over northwestern Hennepin County, producing very heavy rains for a few hours. Additional storms in the late morning and early afternoon of the 22nd produced heavy rainfall, over a shorter duration, however, 2-day totals in parts of the county were 4–5 inches.
- June 12, 2014 (FID 37). This was only a minor rainfall event on the 11–12th, with totals well under 0.50" in Eden Prairie (and the rest of Hennepin County, for that matter). There had been heavier rains ending on the 1st, but the heaviest totals would come later in the week, after this landslide event.
- June 19, 2014 (FID 0, 41). This was a very heavy rainfall event that occupied most of the morning and early afternoon, with a report of over 5 inches in Eden Prairie, and many 3–5" reports around the county. Heavy rains of 1–2" affected the area June 14–15 also, so the ground would have been very wet.

Rain event contour maps available by date. For further detail consult: www.dnr.state.mn.us/climate/summaries_and_publications/mega_rain_events.html.

In conclusion, the data do not currently support a robust conclusion on rainfall thresholds. There are still questions regarding:

- What window of time is needed to capture the long-term deviation from the average;
- If there is a better way to estimate soil moisture, such as gridded soil moisture modeling;
- If there are better records of rainfall intensity near slide locations, including radar data; or
- If there are other things that should be considered.

Hennepin West Mesonet

The Hennepin West Mesonet (HWM) is a dense network of sensors that provide critical local environmental information in near real-time. This information allows emergency officials to monitor for indications and make risk and impact-based alerts and warnings for responder and public safety.

Sensors especially useful for landslide situation monitoring are rain gauges; soil moisture and soil temperature sensors from the surface to 4 feet depth (124 cm); and frost profile tubes to a depth of 10 feet (305 cm). Station distribution is shown in Figure 17.3. Data can be accessed at www.hennepinwestmesonet.org.

Climate Considerations

The collection of more data regarding rainfall and landslide timing is warranted because climatologists report a clear continuing trend towards more annual precipitation as well as more intense precipitation events in Hennepin County. This suggests that precipitation-driven landslides may become more common occurrences in the county until hillslopes stabilize under a new climate regime. Other likely impacts of climate change in the Twin Cities region may include rising ground and surface water levels, as well as changes in stream flow. The instances of freeze-thaw cycles are also likely to increase in number during future winters in Hennepin County. These factors may have the potential to affect landslides and rock fall activity in the county as well.