

FLOODS IN MINNESOTA

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•DURING the summer of 1972, Minnesota recorded rainfalls unprecedented in number, intensity, total rainfall, and area covered.

The mean annual total precipitation in Minnesota is 25 in., and the normal monthly total is 3.2 in. in July. The previous record 24-hour rainfall occurred in 1909 and totaled 10.8 in. The National Weather Service (NWS) indicated that a 5-in. rainfall in 12 hours has a return frequency of 100 years in central Minnesota.

The recorded 1972 storms that exceeded a 100-year return frequency are given in Table 1.

The 10 major storms experienced in Minnesota during summer 1972, in terms of total damages and fortunately in lives lost, were not so catastrophic as those in Rapid City or Pennsylvania. However, there were no mountains to trigger these storms, nor were they the result of hurricanes. The storms experienced in Minnesota could occur in any state that experiences summer thunderstorms.

According to the state climatologist, relating the number of large rainstorms that occurred in Minnesota in 1972 with respect to previous years is not possible, the reason being a recent change in the number of recording stations. The NWS has 200 official recording stations in Minnesota. Prior to 1971, unless heavy rainfall fell in the area of one of these stations, it was not recorded. In 1971, to supplement these stations, NWS began a new program with the Future Farmers of America called "Operation Rain Gauge." This program is under the technical guidance of the NWS and is administered by high school agricultural instructors. Already 1,500 gauging stations have been established in this program. The ultimate goal is to locate one station in every township. In years to come, Operation Rain Gauge will vastly improve the documentation of the location, magnitude, and frequency of these large storms in Minnesota.

The largest recorded storm in Minnesota history occurred on July 21, 1972, in central Minnesota. The storm was roughly 45 miles wide and 140 miles long, encompassing an area of 6,300 square miles. About 3,500 square miles or 55 percent of the storm area received a rainfall greater than 5 in. in the 8- to 10-hour storm duration; 178 square miles received more than 13 in. of rain.

A detailed map of this storm was prepared by NWS with data from 245 reporting stations including 215 reports from Operation Rain Gauge. These reports make this the most thoroughly documented heavy rainstorm in Minnesota's history. The storm caused the greatest monetary losses ever experienced in the state for a flash flood. Total damages are estimated at \$20 million. Of this total, \$5.9 million were damages to the road system, and \$3.1 million of this involved damages to the federal-aid system.

Timely weather reports and forecasting coupled with actions of local, county, and state law enforcement agencies, civil defense, state and county highway departments, and private citizens saved many persons from hundreds of road washouts across the heavy rainfall area. One fatality resulted from a car being driven into a road washout. All 17 major trunk routes traversing the storm area were washed out for periods ranging from 3 to 16 days, leaving many towns isolated. Only Interstate 35 running along the extreme eastern edge of the storm area remained open. Over 4 ft of water covered the highways in many locations. There were 20 major washouts on the trunk highways, ranging from 200 to 400 ft long and 10 to 20 ft deep. In several instances, local authorities cut trenches through the highway to relieve ponding on the upstream side. In at least one instance, someone, undoubtedly on the downstream side of the highway, plugged the inlet of a culvert under the highway by making a flap gate out of a highway sign. This action contributed to a washout at the next culvert crossing downstream.

Table 1. Large rainstorms in Minnesota in 1972.

Date	Location	Rainfall (in.)
May 26	Renville County	6
May 26	Steele County	7
June 7	Martin County	8 ^a
July 11	Fergus Falls, Melrose	4 to 7
July 19	Red Lake, International Falls	4 to 6½
July 21	Central Minnesota	4 to 13 ^b
July 27	Aitkin and Crow Wing Counties	4 to 6
July 31	Fillmore County	4 to 5
Aug. 15	Two Harbors	5
Aug. 16	Duluth	3 to 4
Aug. 20	Duluth	3 to 4 ^c
Sept. 20	Duluth	4 to 5.5 ^d

^a7-hour storm. ^c2-hour storm.
^b8- to 10-hour storm. ^d10-hour storm.

The events that occurred at Clarissa, Minnesota, during this storm are examples of the type of problem involving highways and a village during a 13-in. rainfall. Clarissa is a typical small-town community with a population of 599. US-71 passes through the town in a north-south direction. Eagle creek has a 50-square-mile drainage area upstream from Clarissa and flows southerly along the north and east edges of town. Along the west side of town is a small draw draining about 1 square mile. US-71 crosses Eagle Creek on a bridge north of town and crosses the draw south of town on a 17-ft high embankment over a 4- by 6-ft box culvert and a 6-ft cattle pass. During the storm, Eagle Creek left its banks

approximately ½ mile north of Clarissa, and the overbank flow entered the small draw causing the drainage structures under US-71 to head up 17 ft until flow over the road occurred. Backwater inundated a considerable portion of the town upstream, and the flow over the road threatened a home on the downstream side of the highway. The threat to the home was aggravated because a sight distance safety improvement project on the highway in 1960 had unfortunately moved the low point of the highway from directly over the culvert to a location 400 ft north, directly in front of the house. The highway eventually collapsed at this low point and destroyed the home.

Shortly after the storm had passed, the highway department maintenance crews delivered a 72-in. culvert to the location of the washout in order to reopen the highway. Irate townspeople demanded that the highway department construct a bridge to replace the 4- by 6-ft culvert at this location. At a meeting with the townspeople, the highway department agreed to make a hydraulic analysis of the situation and determine what the reasonable drainage needs were at this high-risk location. It was decided that a 100-year frequency discharge, including an allowance for overbank flow from Eagle Creek and proper headwater elevation controls, would be reasonable. This resulted in the selection of a 169-in. span concrete arch culvert that provided a fourfold increase in waterway opening. A public meeting with the townspeople was held to explain the reasoning for the design, which they accepted.

As in the Clarissa situation, culvert inadequacies caused major damage to both public and private property in other areas during this storm. Highway bridges over major streams and rivers generally passed the flows with minor damage. Minnesota bridge design standards provide a freeboard above the 50-year frequency design discharge. The freeboard was probably the primary factor in minimizing damage to bridges. Also it is apparent that the ponding effect of culverts and the numerous lakes and swamps in the area slowed runoff to the major streams. Examples of indirect flow measurements taken at three culvert sites receiving a 13-in. rainfall are given in Table 2. All three locations had major highway washouts.

The culvert problems resulted in the highway department receiving much unfair criticism in the news media from public officials who had requested the highway department to blow open the highways to relieve upstream ponding. The highway department

has subsequently issued a written policy on this problem allowing such action provided downstream damage possibilities are assessed prior to such an action.

During August and September of 1972, three large thunderstorms struck the City of Duluth, a metropolitan area of 100,000

Table 2. Indirect flow measurements at three culvert sites.

Size and Type of Culvert	Maximum Flow Through Culvert (cfs)	Maximum Flow Over Roadway (cfs)
10- by 6-in. concrete box	705	219
36-in. diameter reinforced concrete pipe	80	135
4- by 6-ft concrete box	400	2,150

people. The storm on August 20 dumped 2 to 4 in. in 1½ hours. This storm covered 162 square miles and resulted in the most damaging flash flood in the history of Duluth, causing an estimated \$12 million in damage. The severity of the washouts of the streets can be attributed to the Duluth topography, an 800-ft rise from the elevation of Lake Superior in a mile. The high velocities of flow from overflowing inadequate city storm sewers down the steep grades caused tremendous erosion. This situation was further aggravated when another storm struck on September 20 and dumped 4 to 5 in. in 10 hours. This storm caused 2 deaths and another \$1 million in damage. Damage to state trunk highways in the Duluth Storms was surprisingly light except where the highways were routed over city streets.

In an effort to improve the reliability of flood flow characteristics from small (less than 50-square mile) watersheds, the Minnesota Highway Department has, for the past 14 years, been cooperating with the U.S. Geological Survey in a stream gauging program. Several of these gauge sites were in the area of the large storms. Thus, peak discharges could be computed. The gauging data recorded vary tremendously in annual peak discharges for the small number of years of record, which makes it difficult to determine a reasonable design discharge.

In conclusion, the purpose of this presentation is to attempt to illustrate the dilemma faced by the highway engineer. His task is to properly assess the public benefit versus the high economic cost factors involved in designing drainage structures for passage of runoff from large storms without adequate research information on the probable frequency, magnitude, duration, and location of these storms.

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