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EROSION ON THE SHEYENNE RIVER DELTA, NORTH DAKOTA[1/]

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Member

ABSTRACT

Catastrophic rainstorms occur every year somewhere within the continental United States. These events, aside from creating serious short-term damages on-site and downstream, play a major role in the continuous reshaping of the landscape; they can effect a tremendous re-distribution of soil, extend channels and form new ones, and even initiate new erosion patterns. The areas affected may be only a few square kilometers and the rainfall, runoff, and other hydrologic forces are seldom recorded or measured. Therefore, the severe rainstorm and subsequent runoff and gully erosion near Fargo, North Dakota, in 1975, which were recorded and measured, are of special interest to scientists. Although channels existed prior to European settlement of the region in the late 19th century, the 52-cm rainfall which occurred June 28 to 30 extended existing channels and carved new ones through both cultivated fields and virgin grasslands. From a single 1300-hectare drainage basin near Leonard, a 1070-meter-long branching gully excavated 174,000 m^3 of soil. Ninety-nine percent of soil eroded from the gully was deposited within 2 km of the gully outlet.

INTRODUCTION

Many researchers are concerned about the erosive influence that severe rainstorms exert on the landscape. They often cause excessive sheet and gully erosion rates (including widespread dissection and denudation of upland fields) and troublesome sediment deposits at downstream locations. These destructive events and the resultant erosion patterns must be understood to better cope with them. The severe storms of June 28 through July 2, 1975, in the Red River Valley of North Dakota provided an opportunity for measuring and evaluating landscape evolutionary processes.

Costa (1974), reporting on tropical storm Agnes, noted that large floods caused slope failures in the Blue Ridge and Appalachian Plateau Provinces and thus were active modifiers of topography. Conversely, he

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1/ Contribution of the Watershed Research Unit, Agricultural Research, Science and Education Administration, U.S. Department of Agriculture, Columbia, Missouri.

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stated that the large floods in the Piedmont during this storm played a minor role in shaping the landscape, because only a few slope failures occurred. These were in lowlands along main channels where channel width increased 20 to 160 percent. Fisher et al. (1966) reported that most sediment in the Eel River is transported by flood flows during a small percentage of the time--80 percent of sediment in about 4 percent of the time. Brown and Ritter (1971) reported that 180 tonnes per hectare (t/ha) or 80 English tons/acre (t/a) from the 8,030-km^2 (3,100-mi^2) drainage area of the Eel River was transported past their gaging site in 30 days in December 1964. At Treynor, Iowa, Spomer et al. (1971) reported that heavy rainfall in June 1967 eroded 1,270 tonnes (1,400 tons) of soil from each of the two gullies that drain 30- to 33-ha (75- to 83-a) agricultural watersheds in western Iowa. Soil lost through sheet-rill erosion from these watersheds was an additional 168-224 t/ha (75-100 t/a).

Rainfall in the Red River Valley of North Dakota from June 28 through July 2 produced unusual flooding and erosion in an area where land slopes are 0 to 2 percent. Flooding on the Red River of the North is common when spring rains and snowmelt combine to produce large runoff rates over frozen ground, but a Soil Conservation Service Report (1975) stated that flooding from summer thunderstorms over a large drainage area such as the Red River of the North is unusual.

Erosion was widespread in two areas of excessive rainfall near Fargo, North Dakota. The result was severe gully erosion in an area southwest of Fargo adjacent to the Sheyenne River, a tributary of the Red River. To understand how and why gully erosion was severe, it is necessary to examine the geology, soils, and topography of this area.

GEOLOGY AND SOILS

The central part of the Red River drainage system occupies a broad, gently sloping, low-relief basin originally formed by an immense late-glacial freshwater body, Lake Agassiz. During the early history of the lake, the Sheyenne River, a major western tributary, deposited deltaic-lacustrine sediments over about 1,950 km^2 (750 mi^2) of the basin (Figure 1). The geology of this area, generally called the Sheyenne Delta, has been discussed in detail elsewhere (Upham, 1895; Leverett, 1932; Brophy, 1966; and Baker, 1967) and will only be summarized here.

The Sheyenne Delta as originally formed about 13,000 B.P. was a fan-shaped, low-relief landform with a low gradient from west to east. The sediments of the delta range in thickness from about a meter (3 ft) at the west to about 46 m (150 ft) at the eastern margin. The textural distribution of these sediments is rather complex, with sands and gravels in the west grading eastward into laminated deposits of very fine sand, silt, and clay.

After the initial formation of the delta, the level of Lake Agassiz dropped from its early elevation of 326 m (1,070 ft) MSL to the Campbell Stage--about 300 m (990 ft). Wave attack at this stage created a northeast-facing escarpment, part of which is shown in Figure 2 (labeled shoreline of Lake Agassiz). Also during this and later stages, the Sheyenne River, responding to the lowered lake level, extended its course across the delta and entrenched itself to its present level about 30 m (100 ft) below the delta surface.

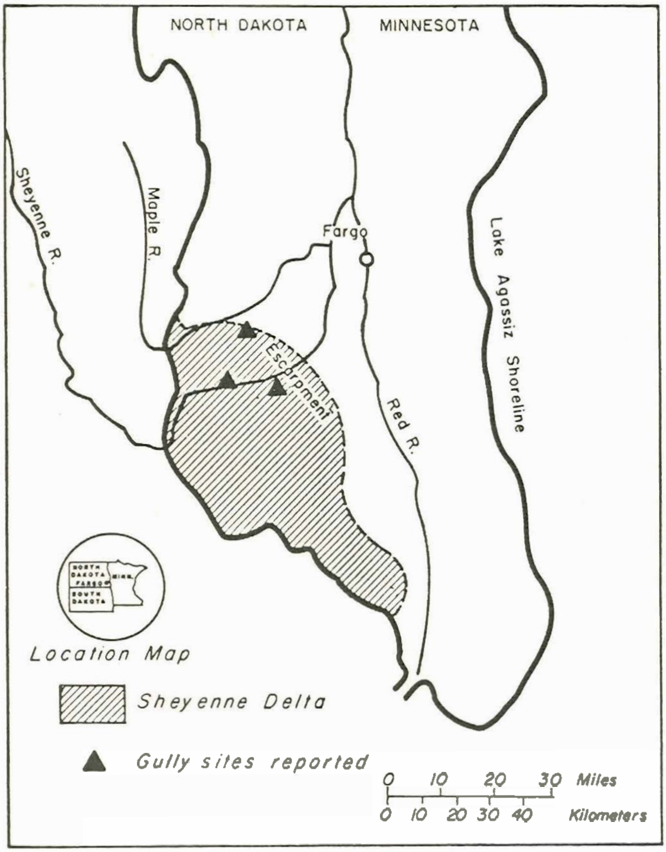


Figure 1. Location of Sheyenne Delta, present course of Sheyenne River and shoreline of prehistoric Lake Agassiz.

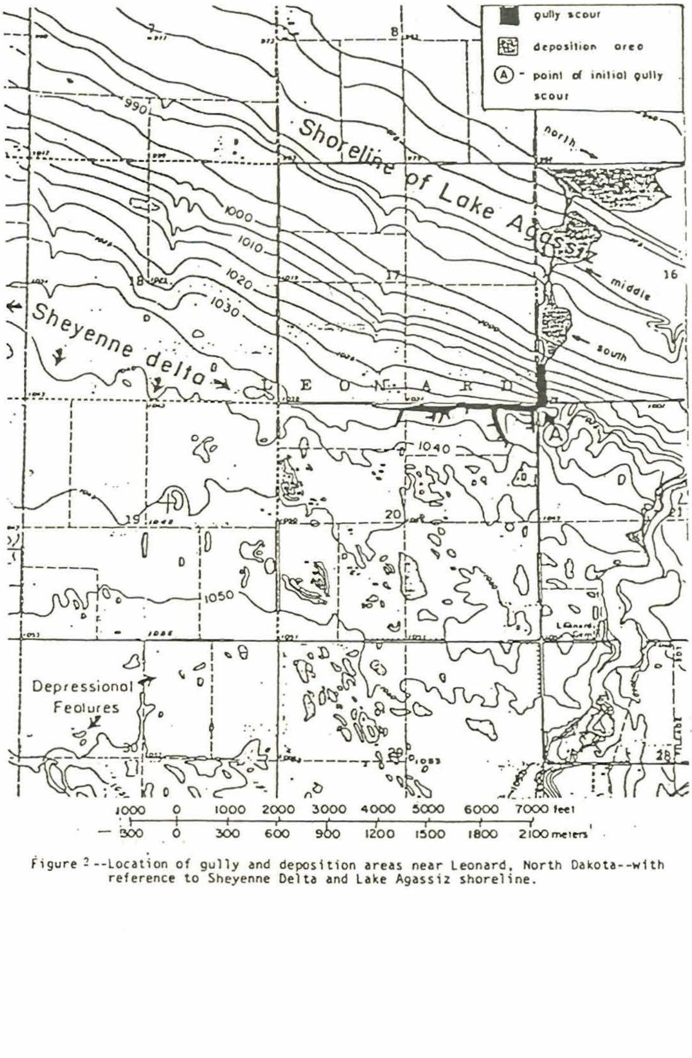


Figure 2--Location of gully and deposition areas near Leonard, North Dakota--with reference to Sheyenne Delta and Lake Agassiz shoreline.

Soils of the delta range from those with little or no profile development on recently deposited eolian sand to more mature types developed on long-stabilized eolian sand or on the deltaic-lacustrine beds. Most are classified as Haploborolls and are of the following soil series: Embden, Glyndon, Egeland, Hecla, Hamar, Ulen, and Maddock (Omodt et al., 1966). Soil surface textures are sands, loamy sands, sandy loams, and loams.

The natural drainage of the delta upland was poor before the area was settled and farmed. It consisted of a few short tributaries to the Sheyenne and Maple Rivers and some rather widely spaced shallow gullies dissecting the escarpment. This initial drainage pattern has been modified by construction of many section-line roads flanked by drainage ditches. In addition, intensive cropping of wheat, barley, oats, corn, soybeans, alfalfa, and sunflowers has led to construction of many field drains emptying into the road ditches.

Considering the nature of the drainage net, the existence of a high water table, the presence of steep slopes in the high dunes along the Sheyenne trench and along the escarpment, and the presence of easily erodible surface sediments, one could expect occasional episodes of severe erosion. One such event occurred in the early summer of 1975.

RAINFALL AND RUNOFF

Between June 28 and July 2, 1975, a series of intense thunderstorms occurred in a band from southeastern North Dakota to northwestern Minnesota. Two areas of heavy rainfall were defined by a "bucket" survey conducted by the National Oceanic and Atmospheric Administration, Bureau of Reclamation, Corps of Engineers, and the Minnesota State Office of Climatology. In the first area, near Leonard, North Dakota, rainfall was an estimated 52.3 cm (20.6 in.) from June 28 to 30; 3.2 km (2 mi) north of Leonard, a 14-cm (5.5-in.) gage overfilled twice during these three days (see Figure 3). In the second area, northeast of Fargo in the Felton, Minnesota, area, 25 to 36 cm (10 to 14 in.) of rain fell during the same period. The heavier rainfall shifted to northwestern Minnesota on July 1 and 2.

Showers over the area on June 26 provided wet antecedent soil-moisture conditions before the heavy thunderstorms began on June 28. As the heavy rains continued, excess water was concentrated on the Sheyenne Delta. Field drains constructed on the delta in recent years accelerated the process. Excess water concentrated in borrow areas (road ditches) and waterways as it moved toward the delta escarpment or to tributaries of the Maple and Sheyenne Rivers, which are the major drainageways for the delta area. These rivers flow in sharply incised, prehistoric valleys with stable valley walls and a dense grass cover.

Lindskov (1975) reported the flood stages and water discharges for these two rivers. The 1975 flood levels exceeded the maximum previously recorded at 18 of 47 sites with 10 years or more of records. Flood duration was long; the Red River was above flood stage for about 10 days at Fargo, Halstad, and Grand Forks, North Dakota. Hendrickson (1975) reported that the Red River and tributaries were flowing 8 to 13 km (5 to 8 mi) wide. On the Sheyenne River at West Fargo, North Dakota, where flood stage is 5 m (16.5 ft), a record flood crest of 6.8 m (22.2 ft) was observed on July 5; no discharge was given. The July 3 discharge at this site was 80.7 m^3/s (2,850 cfs) at a stage of 6.6 m (21.8 ft). Flooding was noted throughout the Sheyenne River

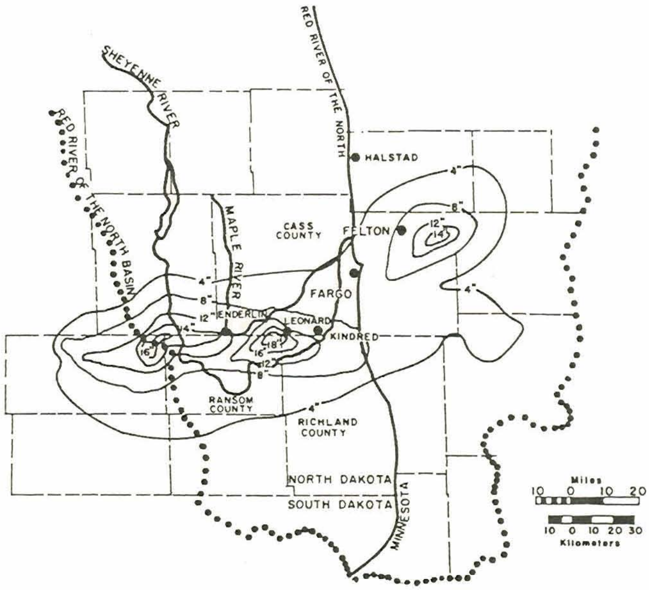


Figure 3. Isohyetal map of total rainfall (inches) during the period June 28-30, 1975 (based on data provided by National Oceanic and Atmospheric Administration and Minnesota State Office of Climatology). (cm = 2.54 x inches)

Valley, where roads and bridges were washed out. Flood stage on the Sheyenne River at Kindred, North Dakota, is 4.9 m (16.0 ft), and on July 6, a peak discharge of 133 m^3/s (4,700 cfs) and a 6.6-m (21.7-ft) flood stage were recorded. A record flood crest of 4.6 m (15.0 ft), 1.5 m (5 ft) above flood stage, was recorded on the Maple River near Mapleton, North Dakota, on July 2. The peak discharge was 329 m^3/s (11,600 cfs) with a recurrence interval of 50 years. On the Red River at Halstad, Minnesota, this record flood crest was 4.5 m (14.6 ft) above the 7.3-m (24.0-ft) flood stage, and a discharge of 1,160 m^3/s (41,000 cfs) was observed on July 10. The expected return period for this flood is 40 years.

CHANNEL EROSION

Erosion associated with runoff is usually of minor concern to Soil Conservation Service personnel in the Red River Valley of the North because most runoff occurs from snowmelt and spring rains while the ground is frozen. But this summer rainstorm revealed that an erosion hazard does exist and that damage to fields, roads, and bridges can be severe.

The Sheyenne and Maple Rivers have partially developed drainage channels that terminate abruptly within 1 mile of the rivers throughout the delta. These old channels probably developed before the area was settled and may predate the Indians. Relief changed sharply at their upstream terminus, and this change in relief provided the setting for renewed erosion during the heavy storms in 1975. In addition, the northwest to southeast gradient along the edge of the delta to the bottom of prehistoric Lake Agassiz is 3 to 4 percent at some locations. It was at these locations that channel erosion was initiated during the 1975 storms. Based on the study of eyewitness accounts, inspection of these rapid "washouts," and knowledge of the geology, the authors conclude that the erosion sequence was: (1) concentration of surface runoff along road ditches and natural drainageways, (2) incision at points of high gradient, with cutting of a knickpoint into the saturated fine sand below the water table, (3) upslope migration of the knickpoint as the consolidated upper soil profile was undercut by a combination of groundwater outflow and plunge pool action of water flowing over the knickpoint, (4) development of laterals with advancing knickpoints (these often developed parallel to corn rows), and (5) seepage flow from vertical banks of new gullies, which resulted in undercutting and slumping of channel walls.

Well data show that very fine sand deposits, 5 m (16 ft) thick, are located at the Leonard, North Dakota, gully site (Figure 4), and rest on clay-silt deposits. This is significant for two reasons: (1) the clay-silt unit provided a resistant layer that limited downward erosion, and (2) the water table probably was perched on the clay-silt unit, which inhibited downward infiltration. Also, the heavy rains coupled with slow infiltration below the 5-m (16 ft) depth contributed to the rapid saturation of the sand, thus raising the water table to the surface, and causing the high rate of runoff.

The largest channel, approximately 5.2 m (17 ft) deep, 30 m (100 ft) wide, and 1,067 m (3,500 ft) long, developed in Cass County, 2.4 km (1.5 mi) northwest of Leonard (Figure 2). The drainage area for this gully was 13 km^2 (5 mi^2). Initial cutting of the gully began at the edge of the delta (see Figure 2) near a T county road

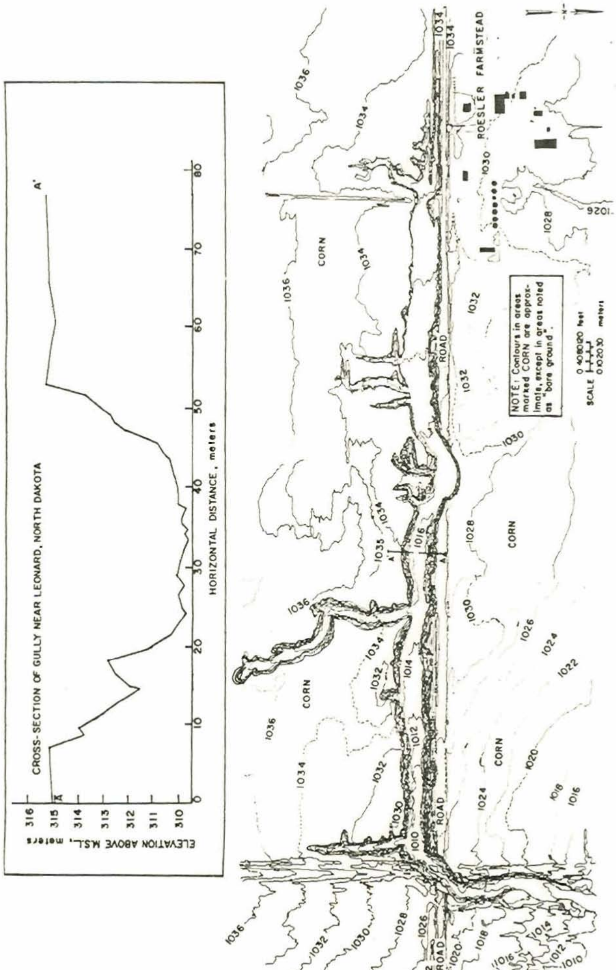


Fig re 4--Topog aphic map showing gully erosi n and djacent farml nd near Leonard, North Dakota with a representative cross section.

intersection. A small 0.8-m (2.5-ft) corrugated culvert under the intersection was inadequate for flood flow. According to Kent Roesler, who owns and farms this land, the 5.3-ha (13-a) gully developed in 36 hours with a rapidly advancing overfall. Using low-altitude aerial photographs taken at 366 m (1,200 ft) and photogrammetric techniques to compile topographic maps (Figure 4), we determined that the volume voided by the main gully and principal lateral gullies was 174,000 m^3 (228,000 yd^3). The figure also shows a representative cross section of the gully. Gradient of gully bottom was 0.005, which is much steeper than the 0.5-m/km (2.5-ft/mi) (0.0005) grade that the Soil Conservation Service considers as stable for channels in this soil. There is a threat of further erosion until the channel can be stabilized.

Another large incised channel developed in Richland County about 11 km (7 mi) southwest of Kindred, (Figure 3). It had an 8-km^2 (3-mi^2) drainage area. Initial incisement was at the head of an old, stable channel, a stub tributary to the Sheyenne River, and the gully advanced through a field parallel to a road. The gully destroyed cropland and parts of the road and removed an estimated 76,000 m^3 (100,000 yd^3) of soil. A second active gully was initiated downstream in this previously stable tributary. A 2-m (7-ft) overfall advanced upstream to within 70 m (200 ft) of the original channel head.

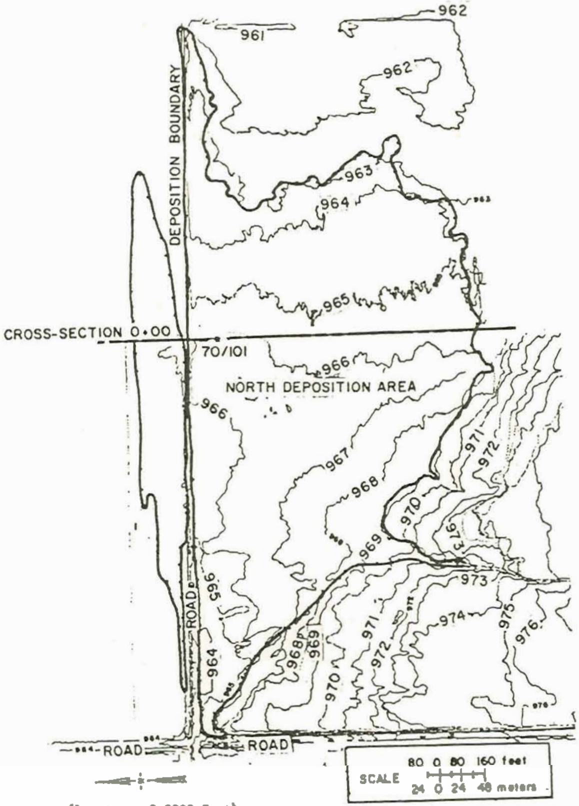
Another large gully developed in the U.S. Forest Service grassland reserve in northeastern Ransom County. The soil at this location is classified as a member of the Serden series (mixed, frigid Typic Udipsamments). It has a combined silt and clay content of less than 10 percent. This gully is about 300 m (1,000 ft) long, 3 to 6 m (10 to 20 ft) deep, and 25 m (75 ft) wide. It developed between existing sand dunes in the area, and it outlets into an old channel.

The Soil Conservation Service has located 12 major incised channels (or gullies) and numerous smaller gullies in the eroded areas. Numerous gullies also developed parallel to roads. Formation of the gullies caused considerable damage to fields, crops, and roads.

SEDIMENT DEPOSITION

Soil eroded from the many newly formed gullies was deposited almost immediately downslope because of the relatively level topography and the lack of a well-defined drainage network. Many open-surface drains constructed by the Soil Conservation Service to drain agricultural land were filled with sediment after this storm event.

Figure 5 shows a deposition area downstream of the Leonard gully. Measurements at several locations 1.6 km (1 mi) downstream from the gully showed that the maximum sediment depth was 1.2 m (4 ft). Figure 6 shows representative cross sections of the deposits in the three distinct deposition areas. The depth of sediment deposits was determined by coring on a 60-m (200-ft) grid. The surface configuration of the deposits and cross section end points were determined from contour maps. Aerial photos show that deposits from the July storms covered more than 28 ha (70 a) in three clearly defined areas. The measured volume of these deposits was 173,000 m^3 (226,000 yd^3). Therefore, the sediment delivered to the Maple River several miles downstream probably is less than 1 percent of the 174,000 m^3 (228,000 yd^3) eroded.



(1 meter = 3.2808 Feet)

Figure 5--Topographic map of North Deposition Area, third of three, soil deposited was eroded from the gully near Leonard, North Dakota. North Boundary is 1.6 kilometers (1 mile) from gully origin.

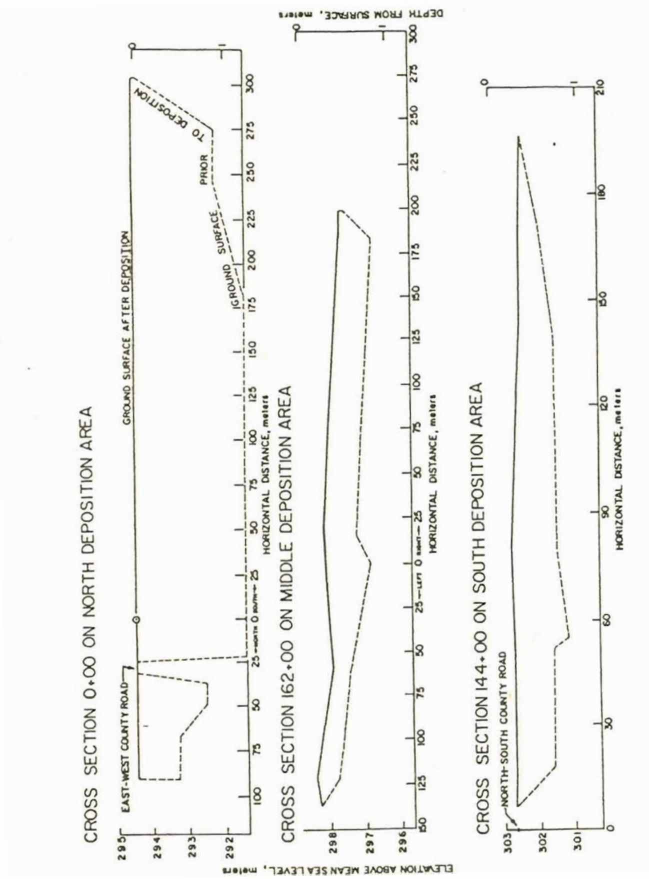


Figure 6--Representative Cross-sections for the three deposition areas.

Where gullies developed by extending old tributaries, the sediment was carried into the Sheyenne or Maple rivers and deposited downstream. A visual check at the confluence of the Maple and the Sheyenne rivers and at the confluence of the Sheyenne and the Red rivers revealed little sediment deposition on the adjoining flooded farmland or in the river channels. This would indicate that most of the sediment from these sandy soils was deposited between its origin on the delta and Fargo.

DISCUSSION

Gaps of knowledge in sedimentation processes are of interest to engineers, geologists, and fluvial morphologists. These include (1) the role of the severe storm in changing the landscape and the entire drainage system; (2) the quantities of sediment that severe storms erode and transport as compared with the usual storms; (3) the extreme forces acting because of increased boundary shear, high velocities, seepage pressures, and erosional stresses on soil that cannot otherwise be observed or measured; and (4) increased conveyance by added channelization, which can raise the "erosion level" of the region--after a severe storm, more sediment can move through stream systems than before if no remedial action is taken.

We determined the volume voided by the Leonard gully and surveyed the sediment deposits. The resultant sediment delivery was 99 percent. The Maple River drains the area where the gully formed but is 8 km (5 mi) from the deposition area. Mapleton is another 18 km (11 mi) downstream, where Lindskov (1975) reported a peak daily sediment discharge of 3,420 tonnes with a concentration of 120 mg/l (ppm) on July 3. Open surface drains had been constructed to drain excess runoff into the Maple River from upstream, where no defined waterways previously existed. The low-velocity flows in these open drains would permit additional deposition, but it is difficult to measure or observe all of this deposition. The only other sediment data available was reported by Lindskov for July 3 on the Sheyenne River near Kindred. Sediment concentration was 822 mg/l (ppm) and sediment discharge was 8,470 tonnes and sediment concentration on the Red River of the North at Fargo on July 3 was 141 mg/l (ppm) and discharge was 4,330 tonnes. At Kindred, the Sheyenne River emerges from the delta area and enters the level bottom area of glacial Lake Agassiz. These low sediment concentrations and discharges indicate that most of the soil eroded from the delta area was deposited before it reached the river sampling sites. This would be expected, since the high sand portion of the soil would not be transported in streams with low gradients and low velocities. The higher sediment concentration and discharge of the Sheyenne River at Kindred would be expected, because this sampling site is close to an area of excessive gully erosion. Our conclusion is that sediment discharge in the main rivers in the area was small as compared with the excessive gully erosion on the upland.

The Soil Conservation Service is studying the soils, drainage, and water table to determine what structures will stabilize the new gullies. The extremely sandy soil and high water table make stabilization difficult. A more difficult question is what measures can prevent or reduce gully formation during future severe storms. Returning the delta area to grass would not be acceptable to farmers in the area, nor are farmers likely to accept some form of runoff-retarding structures, for example, terraces, where land slopes are 0 to 2 percent. Shallow drainageways constructed by the farmers are desirable for utilizing farmland, but draining low areas to increase farmland probably should be supervised to avoid concentrating runoff in areas where the gully erosion hazard is high. Maintaining grassland along the delta escarpment should help to reduce gully erosion. Excess runoff should be transported from the upland into surface drains of increased capacity. Larger road culverts, grassed waterways or conduits, and concrete chutes or drop structures at sites with large relief also may be necessary. Roads also tend to concentrate flow, so their influence on runoff patterns should be considered.

In retrospect, we noted that two of the three gullies studied are extensions of an existing drainageway. The prestorm channels seemed stable with grass cover, but some of them developed an incised, raw channel with an advancing headcut. The topography is still dynamic, and periods of excessive rainfall can cause erosion and dramatic topographic modifications.

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