UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Geologic Effects of Flooding From Teton Dam Failure, Southeastern Idaho

by

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Open-File Report 77-507

1977

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards or nomenclature.

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Introduction

Shortly before noon on June 5, 1976, the recently completed Teton Dam failed, and 0.3 km^3 (240,000 acre-ft) of water spilled down Teton River to the Snake River Plain over a period of about 8 hours (Ray and Kjelstrom, 1977). The flood inundated 240 km^2 (93 mi^2) along Teton River and Henrys Fork as far downstream as Menan Buttes. The greatest previous flood (February 1962) had inundated about 45 km^2 (17 mi^2) (Thomas and Lamke, 1962). Farther downstream along the Snake River, flooding was widespread near Roberts but became more confined near Idaho Falls. Below Idaho Falls, flooding occurred near Firth and Blackfoot.

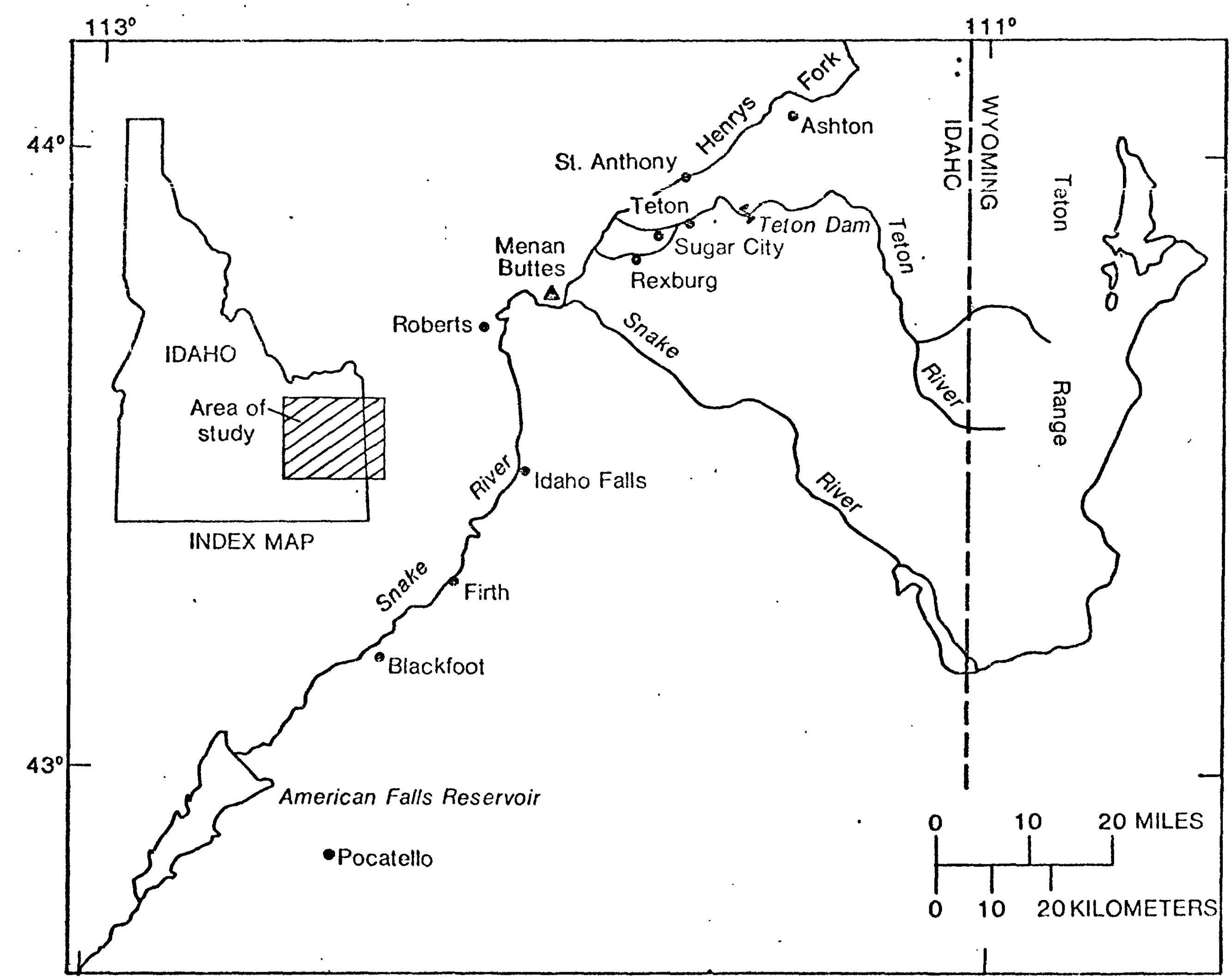

Figure 1.--Location map showing Teton Dam and areas referred to in text.

The flood was finally contained by American Falls Reservoir, 250 km (155 mi) downstream from Teton Dam (fig. 1). This report describes the effects along the flood path from Teton Dam as far downstream as Menan Buttes (pl. 1).

Fourteen deaths were attributed to the flood and estimates of flood damage range from $400 million to $1 billion (Independent Panel to Review Cause of Teton Dam Failure, 1976). Almost 800 houses were destroyed, and 3,000 more were damaged (The Blackfoot News and The Standard Journal, 1976). Damage to farm buildings, equipment, and irrigation systems was severe.

The magnitude of the flood at the destroyed stream gage near St. Anthony was probably more than 100 times greater than the flood of 1962, the largest during 62 years of record from 1890 to 1970. Hence, its geologic effects provide perspective for comparison with the effects of exceptionally large floods in the geologic past, such as those caused by failure of natural dams formed by moraines, glaciers, or landslides.

Erosion and sedimentation

The flooded area is divisible into three areas that had contrasting patterns of erosion, sedimentation, and destruction of manmade structures. The first, a canyon area, extends from Teton Dam 7 km (4.5 mi) downstream to the former bridge north of Newdale. This area experienced deep, fast flows, and the few manmade structures in the canyon (a powerhouse, bridge, flume, and several small buildings) were either buried or destroyed. The second area begins at the canyon mouth and extends westward 5 km (3 mi) to the towns of Teton and Wilford. Here, the flood spilled over a low basalt scarp to the flat alluvial fill of the Snake River Plain and spread over an area 4.5 km (2.8 mi) wide. The leading edge of the flood was a wall of water as high as 5 m (16 ft). Damage to buildings ranged from water damage in basements at the shallow fringes to nearly complete destruction near the center of flow at Wilford where 110 of 154 houses were swept away. Of the remaining houses, 20 were heavily damaged and 24 were slightly damaged (The Blackfoot News and The Standard Journal, 1976). Thirdly, the Sugar City-Rexburg area extends from Wilford to Menan Buttes and was inundated by an advancing sheet of water as wide as 11 km (7 mi), but less than 5 m (16 ft) deep in most places. In this area damage to buildings was variable, and was influenced by differing depths of flow, proximity to the main path of flow along the North Fork of Teton River, and local topography. In the towns of Sugar City and Rexburg, from 1.5 to 5 m (5-16 ft) of floodwater caused severe damage to many houses and commercial buildings.

Canyon area

The canyon below Teton Dam is steep-sided and narrow, ranging from 200 to 300 m wide (650-980 ft). The north wall is composed of welded ash-flow tuff and the south wall, besides the welded tuff, is formed of basalt that came from sources to the south (Prostka and Hackman, 1974). The canyon is 93 m (305 ft) deep at the dam and about 12 m (40 ft) deep at the mouth.

Because the dam failed quickly, maximum flow through the breach occurred soon after failure. Thus peak flow was reached when the head of water behind the dam was high, a circumstance that resulted in deep flow in the canyon downstream. The map shows approximate minimum depths of flow in the canyon ranging from 24 m (80 ft) near the dam to 13 m (43 ft) at the canyon mouth. The actual mean depth in a given cross section at the places marked was probably several meters deeper than the indicated depth (see map explanation under depth of flow). In places the depths were greater on the outside of a bend than on the inside. This suggests there may have been a rise in the water surface of several meters across canyon bends. Precise leveling of high-water marks is needed.

Flood discharge in a cross section about 4 km (2.5 mi) below the dam was indirectly estimated at 65,000 m^3/sec (2.3 x 10^6 cfs) (Ray and Kjelstrom, 1977). The average velocity was about 12 m/sec (40 fps), which is comparable to flow velocities estimated for catastrophic floods in the geologic past (Malde, 1968; Baker, 1973). Obviously the flood flow had the power to accomplish a great deal of geologic work in a short time.

The deep, fast flow through the canyon eroded talus and bedrock from the canyon walls and scoured cobble gravel and finer sediments from the canyon floor. Bedrock and talus were especially eroded from bedrock projections and from the outsides of canyon bends (hachured areas on map). The amount of bedrock erosion is generally difficult to determine, but amounted to at least 10 m (33 ft) in places. A survey by the U.S. Bureau of Reclamation indicated removal of about 30 m (100 ft) of welded tuff at one point on the north abutment of the dam where flow was constricted to a width of 100-150 m (330-500 ft) (R. J. Farina, oral commun., 1977).

Floodwater in the canyon destroyed the cottonwood forest that had grown along the canyon floor. These trees, stripped of bark and limbs by the turbulent flow, acted as battering rams against manmade structures downstream, together with other trees that had been floating behind the dam.

Nine pendant bars (Malde, 1968; Baker, 1973) ranging in length from 500 to 1,100 m (1,600-3,600 ft) were deposited in the canyon downstream from bedrock projections and on the insides of canyon bends. These bars define the present channel of Teton River; the difference between the old course and new course is evident on the map by the overlap of flood deposits on the former channel. The individual bars typically change in grain size in a downstream direction, from bouldery cobble gravel or boulder gravel at their heads to sand or cobble and pebble gravel and sand at their lower ends.

The large angular boulders of welded tuff and basalt that were eroded from bedrock and talus are as large as 11 by 8 by 4 m (36x26x13 ft) and weigh as much as 810 tonnes (890 tons) (fig. 2). Although most commonly the boulders are about 0.5-2 m (1.5-6.5 ft) on a side. Most of the boulders are concentrated at the heads of bars within 500 m (1,600 ft) of their presumed source, namely the bedrock outcrops and talus immediately upstream. Only a few boulders are scattered over the lower parts of bars, indicating that probably only a few of the boulders were transported farther than about 500 m (1,600 ft).

The largest boulders that were transported are larger than would be predicted by the estimated velocity of flow. Baker (1973, fig. 14), for example, reviewed the relation between flow velocity and intermediate particle diameter, as determined empirically by Peterka, Ball, and Martin (1956). By this relation the largest boulders that were transported in the canyon moved at flow velocities less than those predicted. This suggests that movement of the boulders may have been initiated by falling from the canyon walls rather than solely by tractive force under prevailing flow velocity (Fahnestock, 1963; Baker, 1973). The boulders were probably dislodged when slopes were undercut thus permitting large joint blocks to slide out into the flow. The larger blocks would have been dropped a short distance downstream, if only because the velocity of flow near the canyon floor must have been no more than 70 percent of the mean flow velocity, and the competence would have been inadequate for further transport (Baker, 1973). Baker (1973) also reviews the effects of macroturbulent flow which, in addition to rockslide, may cause the transport of particles larger than those estimated from traction-transport relationships.

The thickness of the flood deposits is generally indeterminate. The thickness depends on the depth of scour in the preflood surface, which is rarely exposed. However, a report that all but a corner of the powerhouse was buried indicates a minimum thickness of about 12 m (40 ft) for the bar nearest to the dam (R. J. Farina, oral commun., 1977). Downstream, the minimum thickness probably ranges from 3 to 12 m (10-40 ft).

Large-scale asymmetric ripples as much as 3 m (10 ft) high and 50 m (165 ft) long are commonly displayed on the pebbly cobble gravel sections of the bars. The exaggerated asymmetry of some ripples and their length in relation to height give the appearance of thin overlapping sheets of gravel. The gravel came from the outer zones of the dam as well as gravel on the former canyon floor, which, prior to the flood, probably was from 10 to 30 m (33-100 ft) thick and stood as high as several meters above the level of Teton River. The gravel in the bars consists of basalt, welded tuff, quartzite, limestone, and crystalline rocks of Precambrian age. Its sorting ranges from good in openwork pebble-cobble gravel to moderate in gravels with medium to coarse sand matrix. Angular boulders of basalt and welded tuff as much as 2 m (6.5 ft) in maximum diameter are scattered on the bars, often associated with shallow scoured depressions immediately downstream.

A few small deposits of sand and pebbly sand as thick as several meters are found in sheltered areas or at the distal ends of bars. Some of these deposits also display small- and large-scale asymmetric ripples. The sand came from the same sources as the gravel.

Area near the canyon mouth

When the flood reached the mouth of the canyon, the floodwater overflowed a shallow canyon cut in basalt and spilled westward across low saddles in the basalt onto gravelly alluvium of the Snake River. Floodwater also surged northward up a tributary valley.

The erosion and deposition within the shallow canyon of this area, a trough as deep as 15 m (50 ft), was similar to the effects in the canyon upstream. In places, floodwater eroded the basalt walls and deposited gravel bars, one having a small concentration of basalt boulders on its upstream end. Cobble and pebble gravel and sand were transported as far as 4 km (2.5 mi) westward onto the plain from the canyon mouth. These flood deposits are as thick as several meters but more commonly are less than 0.5 m thick and cover about 2.5 km^2 (1 mi^2) of formerly arable lands. They display large-scale asymmetric ripples. Scattered basalt boulders from 1 to 1.5 m (3.3-5.0 ft) in intermediate diameter were carried as far as 1.5 km (1 mi) from their nearest possible source (fig. 2), indicating competent bottom flow velocities on the order of 4.5 to 6 m/s (15-20 fps) (Peterka and others, 1956, in Baker, 1973, fig. 14). Along the Teton River between the canyon and Teton, some banks and levees oriented more or less perpendicular to the floodflow were scoured. The eroded material, mostly gravel, was deposited locally. For several weeks following the flood, areas near the channel remained flooded because the return of floodwater to the channel was prevented by levees and gravel deposits.

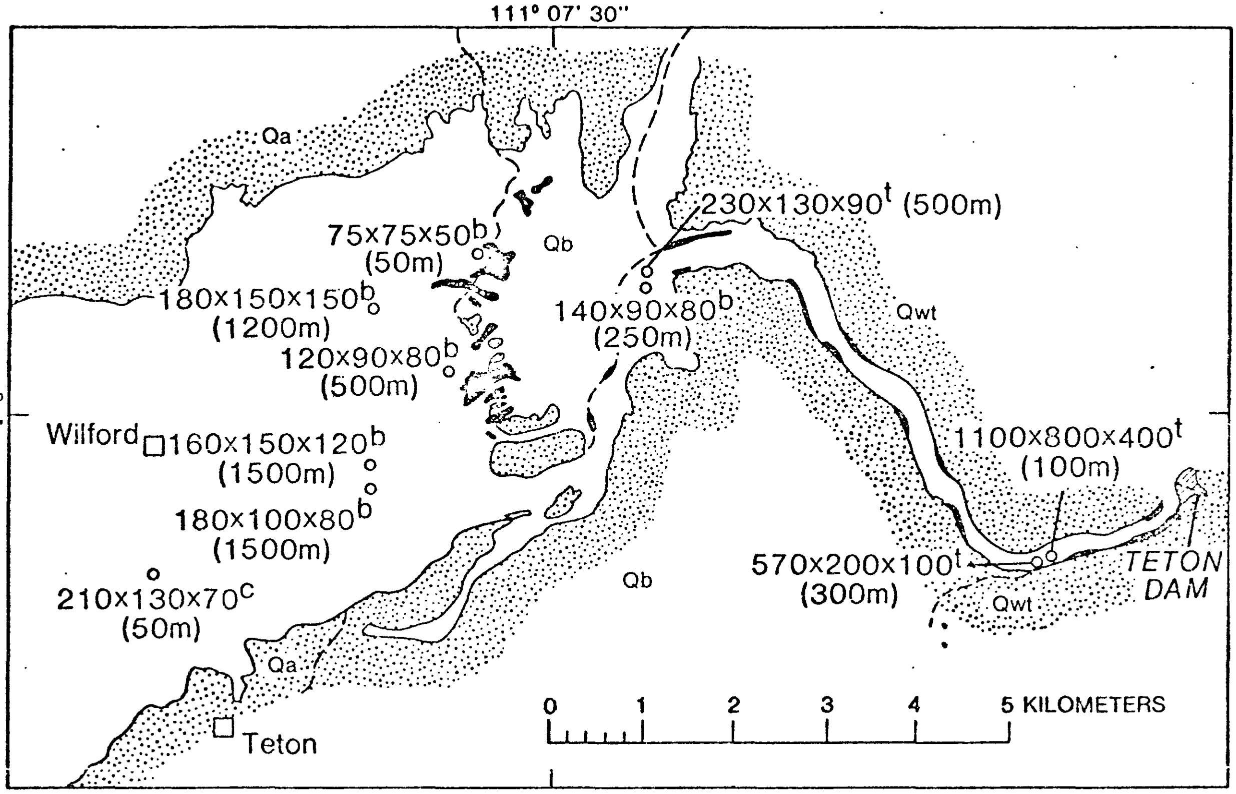

Figure 2.--Map of canyon and area at canyon mouth (flooded area outlined by stipple pattern) showing dimensions (in centimeters) of boulders transported during the flood. Symbol at upper right refers to the following lithologies: b, basalt; t, welded tuff; c, concrete. Minimum distance of transport in meters shown in parenthesis. Areas where erosion of bedrock occurred are hachured. Qa, gravel alluvium; Qb, basalt; Qwt, welded tuff.

The tributary valley that joins Teton River from the north near the canyon mouth was nearly filled by a surge of floodwater about 12 m (40 ft) deep at the confluence. The surge moved upstream 5.5 km (3.4 mi) and partly destroyed three roadfills that crossed the valley. It deposited as much as 1 m (3 ft) of fine sand, silt, clay, and locally, gravel, although thickness was generally less than 30 cm (1 ft). The gravel was covered everywhere by a thick layer of fine sediment. Floating debris was trapped in large amounts in areas of slack water. A smaller alcove south of the canyon mouth was also flooded. It contains similar deposits of sand from one to several centimeters (0.5-2 in.) thick, which alternate with silt beds less than 1 cm (0.5 in.) thick. This sediment was probably deposited by sedimentladen water that surged up the alcove, the sand being transported and deposited as bedload, and the silt being deposited from slack water at times between surges. This silt and sand came from the compacted silt and sand core of Teton Dam and from fine-grained flood-plain deposits that covered the gravel fill of the canyon floor.

Some of the most spectacular erosion caused by the flood occurred where floodwater flowed westward over the rolling loess- and sand-covered basalt north of Teton River and onto the gravel-covered plain. Gravel from the canyon was carried 1.5 km to a height of 8 m (26 ft) above the river on the rising slope that leads to the loess-covered basalt. In low places, loess was eroded down to basalt or down to a resistant buried caliche horizon. Where the loess was removed the basalt was eroded as well. Downstream from saddles in the basalt bench where flow was deepest, the floodwater flowed onto the gravel plain where it formed plunge pools as deep as 10 m (33 ft). The eroded gravel and basalt boulders now cover about 2.5 km^2 (1 mi^2) adjacent to the bench. This is the area of greatest damage to croplands. Fields were locally denuded of topsoil near the bench and were otherwise covered with from 20 cm (8 in.) to as much as 1 m (3 ft) of gravel.

A triangular-shaped terrace remnant, 1 1/2 km (1 mi) east of Wilford and 3-4.5 m (10-15 ft) above the general level of the plain, was only thinly covered by floodwater. Deep flow along the sides of the terrace scoured the terrace scarp, primarily on the north side, and deposited gravel as thick as 1 m (3 ft) over nearby fields. Merging of the floodwater at Wilford formed a flood 3-5 m (10-16 ft) deep, which destroyed or heavily damaged most structures.

Near the canyon mouth, most roads, which had been built from local gravel as embankments about 1 m (3 ft) above surrounding fields, were severely eroded. Irrigation canals were similarily damaged. Photographs taken during the flood show riffles over bed irregularities formed by road and canal embankments. Plunge pools as deep as 3 m (10 ft) were formed on the downstream sides of roads and the eroded gravel was deposited in adjacent fields as distant as several hundred meters, although usually the gravel was carried no further than 50 m (165 ft). The gravel deposits diminish in thickness from about 30-80 cm (1-2.5 ft) near the roads and canals to one to several pebbles thick at the edge of the deposits. Most of the deposits are nearly flat topped and have a lobate shape; the lobes in places having steep fronts of 20-30 degrees and are 10-30 cm (4-12 in.) high. The presence of crossbedding suggests that the lobes were deposited as waves of gravel that advanced from the embankments. Near Teton River, where the embankments were higher and floodwater was deeper, the erosion was greatest; in places, road embankments were entirely removed. At bridge crossings, where the flood was constricted by abutments and roadfills, thus causing an increase in velocity, banks were greatly eroded, bridges were destroyed, and channels were widened 2-3 times their former width.

In fields beyond the area of severe damage, the damage was variable depending in part on conditions of use before the flood. Before the flood use of the fields varied from pasture with good ground cover, to fields of young grains and alfalfa cultivated with shallow furrows (less than 8 cm (3 in.) deep), to fields of potatoes having deep (25 cm (10 in.)) and wide furrows and little, if any, ground cover. Generally, potato fields fared worst during the flood because their surface relief increased turbulence and scour; in some fields plantings of seed potatoes were destroyed. Still other potato fields, where the flood was shallow were only slightly scoured, and these were in bloom during July. Most fields of hay, alfalfa, and grain were undamaged, except for the damage from standing water, deposits of floating debris, mangled machinery, and buildings, and lack of irrigation water while irrigation systems were being repaired. A month after the flood, hay and alfalfa were being cut in many of these fields. However, as much as 20 cm (8 in.) of silt and fine sand was deposited in swales and where roads or canals ponded water. Locally these deposits were thick enough to destroy pasture and crops.

Sugar City-Rexburg area

Between Wilford and Menan Buttes, an area that includes Sugar City and Rexburg, the flooded area was as wide as 11 km (7 mi), but the depth and velocity of flow decreased. No measurements of flow were made here, but discharge and velocity were probably considerably less than at Wilford. According to Ray and Kjelstrom (1977), the rate of advance of the leading edge of the flood wave decreased by about 50 percent between Wilford and Sugar City. At the Teton-Wilford-St. Anthony road, flood discharge was about 30,000 m^3/sec ($1x10^6$ cfs) (Ray and Kjelstrom, 1977). A concrete foundation slab with an intermediate diameter of 1.3 m (4.2 ft) (fig. 1), which was moved by the flood, indicates a local competent bottom flow velocity of 4.5-6 m/sec (15-20 fps) (Peterka and others, 1956, _in_ Baker, 1973, fig. 14). Near Sugar City 6.5 km (4 mi) west of Wilford, the largest transported particles were boulders of welded tuff 75 cm (2.5 ft) in intermediate diameter that were eroded from the foundation of a building. These indicate competent bottom velocities on the order of 3-4.5 m/sec (10-15 fps). The distribution of flood deposits suggests that the flow was concentrated along the route of the North Fork Teton River through Sugar City to Henrys Fork, a path aligned with the direction of flow from the canyon. Thus, Sugar City suffered much more destruction than Rexburg, even though they are about the same distance from the canyon mouth.

The effects of flooding in this area, although variable, were directly related to depth of flow and the proximity to the main flow path along the North Fork of Teton River. Depths were greatest along flood plains of the North Fork and South Fork of Teton River, but probably were nowhere deeper than 4-5 m (13-16 ft); large areas were flooded by 1-2 m (3.5-6.5 ft) of water.

Road and canal embankments and terrace scarps were sites of considerable erosion, as near the canyon mouth, whereas flat fields were eroded little, if any. The terrace scarps along Henrys Fork and Teton River were gullied, primarily where flow was concentrated along recesses in the terrace scarps. These gullies are broad and shallow; in places they merge to form broad eroded embayments in the scarps. At several places where the depth of floodwater could be estimated, the floodwaters flowed over scarps at depths of about 1-1.5 m (3.5-5 ft), thus disrupting the turf cover and initiating headward erosion of gullies. Slumping and ravelling of unconsolidated sand and gravel of the terraces, in the presence of the great width of flow over the scarps, probably prevented the development of narrow, steep-sided gullies.

In contrast to the large areas at the canyon mouth, where sand and gravel were carried several kilometers, sand and gravel carried by the flood in this area was deposited close to its source, usually within a few hundred meters. However, north of Sugar City, various gravel deposits from railroad and highway embankments and from a shallow abandoned channel of Teton River were transported as much as 3 km (2 mi). The deposits are rarely thicker than 1 m (3.5 ft) and are typically less than 30 cm (1 ft) thick. The deposits are as thick as 1.5 m (5 ft) at the base of eroded terrace scarps.

Widespread flood deposits of fine sand and silt occur in this area along the flood plains of the North Fork and South Fork of Teton River and Henrys Fork. Such deposits are also found in fields surrounded by levees, roads, or canals and in swales. Generally these deposits are discontinuous and less than 20 cm (8 in.) thick. These are typical of fine-grained flood-plain deposits elsewhere. The sand and silt were derived from the dam core, from the eroded flood-plain deposits on the canyon floor, by shallow erosion of plowed fields (in most places less than a few centimeters (1 in.)), and from the fine-grained fraction of sand and gravel embankments. Fine-grained flood deposits are especially abundant along the flood plain of Henrys Fork. Their presence is probably due to deposition in slack water formed by hydraulic damming of floodwater at a 2-km (1.2-mi)-wide constriction between Menan Buttes and the fan of the mainstream of Snake River.

Sugar City and Rexburg, although not the location of major geologic change during the flood, suffered the greatest property damage in the flooded area. Sugar City, by its proximity to the path of major flow, was hit by a wall of water in the same way that Wilford was overwhelmed. Floodwater armed with floating logs, machinery, and buildings swept several rows of houses on the upstream (east) side of town off their foundations and smashed them into other houses. The central and downstream parts of Sugar City were subjected to lesser forces, the brunt having been absorbed by the east side. Rexburg did not suffer comparable impacts except for areas near the South Fork of Teton River, where trailers and homes were swept away and several businesses were destroyed. Nevertheless, flooding by as much as 2.5 m (8 ft) of water caused much damage to residential and commercial property.

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