The Effects of Gully Plugs and Contour Furrows on Erosion and Sedimentation in Cisco Basin, Utah

Dee B. Thomas

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THE EFFECTS OF GULLY PLUGS AND CONTOUR FURROWS ON EROSION AND SEDIMENTATION
IN CISCO BASIN, UTAH

by

Dee B. Thomas

A thesis submitted in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE
in
Watershed Science

Approved:

UTAH STATE UNIVERSITY
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1975
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Dee B. Thomas
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ABSTRACT

The Effects of Gully Plugs and Contour Furrows on Erosion and Sedimentation in Cisco Basin, Utah

by

Dee B. Thomas, Master of Science
Utah State University, 1975

Major Professor: George B. Coltharp
Department: Range Science

Soil surface treatments consisting of gully plugs and contour furrows were constructed as a means of reducing erosion and holding sediment on site.

To measure the effectiveness of the gully plugs and furrows, angle iron stakes and profile transects were installed to measure soil loss and accompanying change in the soil profile. The profile transects gave a reliable measure of the change in the height of the soil surface in constructed pits and across contour furrows. Because of the shrinking and swelling of the soil, the change in height of the angle iron stakes was found to be much more than the reduction in soil surface caused by erosion.

High intensity thunderstorms, occurring mostly during July, August, and September, cause most of the erosion from this semi-arid land.

The gully plugs and contour furrows were effective in holding runoff and sediment on site, but the life expectancy of the treatments is only about fifteen years. (60 pages)
INTRODUCTION AND OBJECTIVES

Erosion has been a natural geologic process of nature since the beginning of time. Since the advent of man, erosion has been accelerated in many areas due to his activities. Only when man begins to be affected adversely does he look for a cause-and-effect relationship and seek for a solution to the problem.

The East Desert of Utah is similar to millions of acres of semi-arid desert land in the Western United States. Much of this area has scant vegetative cover and is eroding severely at the present time. Areas of this type have been termed "frail lands" by the BLM, the agency which administers much of this land (Turcott, 1966).

It has been estimated that this area contributes about 44 per cent of the transportable sediment but only 5 per cent of the water yield of the upper Colorado River, which drains the area (Coltharp, 1967). It has also been estimated that the annual sediment production from the 40 per cent of the upper Colorado River Basin administered by the BLM would cover the 69 square mile District of Columbia to a depth of 19 inches (Turcott, 1966). Most of the sediment originating from these lands is deposited in Lake Powell. Because of this rate of sedimentation the Bureau of Reclamation is interested in these sediment source areas. The BLM is also concerned about these deteriorated range lands because of the reduced forage yields and unstable watershed conditions.

The interest of these two agencies in seeking solutions to this problem resulted in a plan of action for treating some of the more active sediment source areas. The areas selected for treatment are
in the vicinity of Cisco, Utah (see location map, Figure 9).

To accomplish the goals of reducing sedimentation in reservoirs and improving watershed conditions of the "frail lands", the BLM constructed a number of contour furrows and gully checks (also known as gully plugs, check dams, bulldozer pits, and crescents). The general objective of this study was to evaluate the effects of these soil treatments on erosion and sedimentation in the study area. Specific objectives were as follows:

1. To determine the rate of soil loss for each area.
2. To determine the amount of sediment being trapped by the furrows and gully plugs.
3. To determine the life expectancy of the treatments.
REVIEW OF LITERATURE

Thousands of acres of land in the Colorado Plateau physiographic province contribute large quantities of sediment and very little water to downstream reaches of the Colorado River and its tributaries. This sediment yield and flash-type runoff not only perpetuates the low productivity of the rangelands, but damages farmland irrigation works, and flood-control projects downstream (Lusby, 1970).

Historical records show that many valleys that are now cut by deep arroyos contained shallow, perennial streams at the time of settlement by white man (Lusby, 1967). Judson and Ritter (1964) have determined the regional erosion rate to be 1255 tons per square mile per year or 6.5 inches per thousand years.

Soils in the area are poorly developed and generally consist of a shallow weathered mantle overlying the Mancos shale (Lusby, 1970).

Since 1958 the BLM and Bureau of Reclamation have cooperatively treated about 6,000 acres in the Cisco area. These treatments consisted of constructing approximately 25,000 gully plugs and furrows (Cox, 1972).

Osborn (1968) indicates that convective storms cause almost all of the annual surface runoff from small semi-arid watersheds in the intermountain areas of Southwestern United States. These storms occur as high intensity, short duration, widely scattered thunder storms principally during the months of July, August, and September (Fogel and Duckstein, 1969).

Lusby (1970) reported that runoff at Badger Wash, an area to the east of Cisco in extreme western Colorado, occurs almost wholly in re-
some runoff may occur during the winter. Snow generally does not accumulate enough to cause runoff in the spring.

Soils having high montmorillonite clay content are subject to extreme shrinking and swelling. Lucas (1972) reports that in Siskiyou County in northern California, the soil is a type of clay that expands when wet and contracts when drying. The soil moves and cracks severely when it dries. Cracks up to 3 inches wide and 4 or 5 feet deep appear. The soil rises and falls several inches in the course of wetting and drying and does so unevenly. This causes areas to develop high and low spots.

Soils at Badger Wash in western Colorado were found by Lusby (1970) to be subject to shrinking and swelling to such an extent that the soil surface was found to be higher in 1966 than in 1954 in two of the ungrazed watersheds. Gullies in grazed watersheds were found to have about twice as much erosion as those in ungrazed watersheds.

Over the past 35 years many types of land surface treatments have been applied as soil and water conservation measures. Over a million acres of pasture and range land were contour furrowed between 1934 and 1940 (Caird and McCorkle, 1964).

Biswell (1969), in reporting on range management practices to control surface runoff, states that small contour furrows, from 4 to 6 inches in cross-section, and spaced not more than 5 feet apart, are usually more effective than larger or more widely spaced furrows. He also states that range pitting is an effective water conservation practice in arid regions where rainfall is sporadic.

The manner in which treatments are constructed has a considerable
effect on the response of an area to treatment. Hubbard and Smoliak (1953), in Canada, indicated that furrows spaced more than 10 feet apart and only 4 to 5 inches deep were ineffective. The size and spacing of furrows would have an obvious effect on the longevity of the treatment. Caird and McCorkle (1946) found that listed furrows in Texas were effective for about 7 years. Brown and Everson (1952) reported that furrows were distinguishable after 10 years in southern Arizona.

Hickey and Dortignac (1965), working in New Mexico, found that soil ripping was highly effective in reducing surface runoff. No annual rate of decline of the effectiveness was determined. They found that soil pitting was not as effective in reducing erosion as soil ripping. Pitting had lost its effectiveness in 3 years. They also found that the pitting and ripping had, in some cases, penetrated the parent material (Mancos shale) and had thus initiated piping. This phenomenon of soil piping is described by Hasking (1967), Heede (1971), and Jones (1970). Since Cisco Basin is nearly all shallow soils over Mancos shale, the same phenomenon could easily occur.

King (1967) reports that gully plugs are quite effective in terms of catching and holding surface runoff and sediment. A small basin in south central Utah treated with gully plugs during 1954 significantly reduced runoff and sediment production during the following 10-year period.

Peterson and Branson (1962) found that earthfill dams (gully plugs) built in the 1930's soon failed by breaching, piping, or washing out of inadequate or poorly protected spillways. These failures were generally attributed to low construction standards which required
little or no moisture control or compaction.
DESCRIPTION OF THE AREA AND TREATMENTS

Location

The areas selected for study are located approximately five miles to the west and south of the village of Cisco, Grand County, Utah (see Figure 9). This area, known as Cisco Basin, is bounded on the north by the Book Cliffs and the south by the Colorado River. It is typical of the upper Colorado River Drainage basin of western Colorado and much of Carbon, Emery, Garfield, Grand, Kane, San Juan, Uintah and Wayne Counties in eastern Utah (Parker, 1965). Mean elevation above sea level is 1280 to 1340 meters (m) (4100 to 4400 feet).

Climate

The climate of the Cisco Basin is semi-arid, characterized by erratic precipitation occurring largely from thunderstorms during late summer and early fall, as shown by U. S. Weather Bureau records for Cisco, Utah. Precipitation important for vegetation growth comes during late winter and early spring but drops off to the driest months of June and July. Hancock (1968) summarized the precipitation reported by the Cisco Post Office station. Annual precipitation varied from a low of 4.11 centimeters (cm) (1.61 inches) in the year 1900 to a high of 35.53 cm (13.99 inches) in 1957. It is, therefore, obvious that the precipitation at Cisco is highly variable. Annual precipitation at Cisco based on 27 years of record is 15.59 cm (6.14 inches) (Hancock, 1968).
**Geology**

The geology of Cisco Basin has been summarized by Ibrahim (1963). This area is part of the Colorado Plateau Province which is characterized by an intricate system of highly dissected table lands of horizontal or slightly inclined sedimentary strata. Cisco Basin is located mainly on the top formation of Mancos shale, a thick formation of lead-gray marine shale which contains veinlets of gypsum.

Characteristic of the area are the remnants of three extensive pediment levels, sloping from the Book Cliffs, which indicate the different epi-cycles of erosion (Ibrahim, 1963). These pediment remnants have been incised and reshaped by many intermittent streams and gullies resulting from the local thunderstorms on the nearly bare soil.

**Vegetation**

Cisco Basin is in the shadscale zone which is dominated by different Atriplex species. There are four vegetation types in the Cisco Basin, each of which is an edaphically controlled climax community (Ibrahim, 1963). The shadscale-galleta grass (Atriplex confertifolia-Hilaria jamesii) community is found on the uppermost pediment remnants. Ground cover is more dense than in the other three communities and the soil is sandy loam in texture.

The other three plant communities are Nuttall Saltbush-galleta grass (Atriplex muttallii var. muttallii-Hilaria jamesii), saltsage-woody aster (Atriplex nuttallii var. gardneri-Aster xylorrhiza), and mat saltbush (Atriplex corrugata). These three plant communities are
developed on soils derived from the Mancos shale, which is less fertile than the soils of the shadscale-galleta grass community and they are highly erodible. The soil surface is 85 to 95 per cent barren, 4 to 5 per cent has vegetative cover, with the remainder being litter and rock (Coltharp and West, 1966).

Other important native plant species within the plant communities previously described include bud sage (Artemisia spinescens), winterfat (Eurotia lanata), and Indian ricegrass (Oryzopsis hymenoides). Ephemeral plants (Desert trumpet) Eriogonum inflatum and halogeton (Halogeton glomeratus) are conspicuous during part of the year. While these ephemerals are unimportant in the native plant cover, they may be extremely important when the soil has been disturbed by grazing animals or by surface land treatments.

Soil

The soils of the Utah East Desert are of the following three Orders: Aridisols, Entisols, and Vertisols. Parent material in the study areas is typically Mancos shale except for the shadscale-galleta grass community which is sandstone. These soils have been described fully by Ibrahim (1963). The soils are generally less than 10 centimeters (cm) deep and undeveloped, though the mat saltsage area has soil approximately 25 cm deep. Mancos shale and the soils derived from it are highly unstable in water and easily eroded. The soils in the mat saltsage area are especially susceptible to cracking and all areas are subject to soil swelling and shrinking as the moisture content of the soil changes, with maximum swelling occurring when the soils are wet. Soil texture varied from sandy loam on Area I to silty clay loam on Areas
II and IV, to silty clay on Area III.

Treatments

In 1958 the BLM, in cooperation with the Bureau of Reclamation, started doing surface land treatments in the Cisco Basin area to retard surface runoff and decrease erosion.

There are four areas which were used for study in this project (Figure 1). Study Areas I and IV were treated with contour furrows only, while Areas II and III were treated with both contour furrows and gully plugs. Study Area I is located in the shadscale plant community and was treated by the BLM in the spring of 1966. Area II was treated in the spring of 1964 and is in the Nutall saltbush community. Area III is in the mat saltsage community and was treated in the spring of 1962. Area IV, the saltsage-woody aster community, was treated in the spring of 1966 along with Area I.

At the time of treatment the areas were broadcast seeded to crested wheatgrass (Agropyron cristatum) and Indian ricegrass (Oryzopsis hymenoides) in an effort to provide a good protective plant cover, as opposed to the ephemeral plants which would otherwise come into the disturbed areas. Generally, only the crested wheatgrass became established around the treatments, although occasionally the native Indian ricegrass did well.

On study Areas II and III where dissection by gullies was most severe, indicating extreme erosion, both gully plugs and contour furrows were installed as a means of land treatment to reduce the accelerated rate of erosion. On Area II the gully plugs were installed at a density of 4.2 per hectare (per ha) while the contour furrows were installed at
Figure 1: Location of study areas.
a density of 1,650 meters per hectare (m/ha). On Area III the gully plugs were installed at a rate of 8.65 per ha and contour furrows were installed at a rate of 1,162 m/ha. See Figure 2 for a sketch of the contour furrows and gully plugs.

Study Areas I and IV are not nearly as dissected by gully patterns, hence it was decided that only contour furrows would be necessary to reduce the erosion. On Area I, which is located on the pediment top with a greater percentage of vegetative cover, sandier soil, and lower slope gradient than the other three areas, the density of furrows is only 440 m/ha. Area IV is more similar to Areas II and III, but it has lower slope gradient and slightly better ground cover and fewer gullies. The density of furrows on this site is 849 m/ha.

The basic objectives in applying these land treatments were to hold the overland flow of water on site, to reduce the erosion of the soil and, consequently, the deposition of sediment in Lake Powell, while at the same time increasing forage production for domestic livestock.

At each of Areas I, II, and IV, there was an area left untreated which was used as a control. As all of the land around Area II was already treated, there was no area in the immediate vicinity to use as a control. Consequently, an area was selected a few miles away, which had soil, vegetative type, and topography similar to that in Area III, to serve as the control for Area III.

**Contour Furrows**

The contour furrows for the study were constructed with a Holt trencher pulled behind a D-6 crawler tractor. This piece of equip-
Figure 2. Sketch of contour furrows and gully plugs.
ment has dual discs mounted one behind the other and slightly offset. The discs can be raised and lowered as desired to form short sections of furrows. A dam was formed at one end of a furrow section as the trencher was raised. The purpose for raising the trencher every 3 to 10 m was to form a series of catchments or detention storage basins across a hillside.

The furrows were designed for a zero gradient and are on the contour as much as possible. The actual furrow size when first constructed was about 0.15 m deep by 0.45 m wide by 3 to 10 m in length. The spacing of the furrows varied between areas according to slope, established gully or rill patterns, and infiltration capacity. These furrows were intended to intercept and hold surface runoff, thereby providing needed time for infiltration of the water and trap sediment on site. See Figure 3 for a view of constructed furrows.

Some of the problems associated with this treatment were: 1) the difficulty of following the contour stakes set out by the surveying crew when the contour lines curved excessively around a slope; 2) the trencher had a tendency to pull downhill, thus causing the furrows to have a slight slope. Even a slight slope of $\frac{1}{8}$ percent within a furrow is sufficient to result in early failure.

**Gully Plugs**

The gully plugs or checks were made by a D-7 bulldozer which pushed up a soil dam in a gully or on a side slope from the uphill side. The gully plugs in Area III were made by only a few pushes of the bulldozer. They averaged 3.4 m wide, 4 m long, and 0.5 m deep. The dam was pushed up so that it left a bank about 1 m above the
ground level. An example is shown in Figure 4. The gully plugs in Area II average 4.7 m wide, 5.3 m long, and 0.9 m deep and more oval in shape than in Area III. The dams were built more in the shape of a crescent and were compacted by the tracks during construction.
Figure 3. Furrows in Area II with pits showing in background.

Figure 4. Gully Plug with Pit Transect - Area III.
METHODS AND PROCEDURES

Various methods were used to evaluate the effects of land treatment on erosion rates. These methods identified as erosion transects, erosion stakes, pit stakes, and micro-watersheds will be described below. A standard 20.33 cm (8 inch) storage rain gage was placed in each study area and weighed periodically to measure the amount of precipitation received.

Erosion Transects

Erosion transects covered a 1.829 m (6 feet) span and 18 guide holes were equidistant along the transect. Measurements were made from a metal bar placed across the top of the end stakes. These measurements were taken by sliding a rod down through guide holes in the reference plane to the first contact with the soil surface (Figure 5). The distance from the soil surface to the top of the reference plane is read on a meter scale attached to a flattened side of the rod. Readings from these transects were taken in the fall, winter, spring, and then periodically during the summer season; particularly after storms producing overland flow of water.

Ten transects were placed across the furrows in each of Areas I, II, III, and IV; ten were located across small active gullies; and ten were placed in areas not affected by any treatment, to act as control, with the exception of Area I, where 13 were located. In addition to these transects in each of the four areas, an additional 30 transects were located in each of Areas II and III. Ten pits in
each area were selected for erosion transect measurements. In the bottom of these pits, three transects were located in the form of a T. These above described erosion transects were referred to as *furrow transects*, *gully transects*, *control transects* and *pit transects*. The transects were placed in representative locations to sample the furrows, gullies, control, and pits.

The purpose of the furrow transects was to measure the rate and amount of sediment being trapped in the furrows as well as the rate of sloughing of soil from the spoil bank. Gully transects were established to measure the rate of enlargement of the gullies. The purpose of the control transects was to measure the natural rate of soil loss from the area in general. The pit transects were established to measure the amount and distribution of sediment being trapped within the pits.

*Figure 5.* Control erosion transect - Area III.
Erosion Stakes

During the initial phases of this project the vegetation response resulting from the applied treatments was to be evaluated. To do this, many angle iron stakes approximately 75 cm (30 inches) in length were installed as corner markers for vegetative plots. As the second phase of this project got underway, it was decided that the same stakes used to mark vegetative plots could be used as point measurements for erosion determination. As the vegetation measurements were made only once each 5 years, there was no disturbance of the stakes except by the measurement of the stakes to determine soil loss. The stakes that were used for both purposes are referred to as erosion stakes.

The selection of location for the erosion stakes was made by a random sampling method. (Seventy transects were located in each of the treated and control portions of Areas II, III, and IV. Fifty-six transects were located in Area I treated.) Each transect consisted of 4 stakes, placed on corners of a rectangle 6 m by 15 m, providing a total of 280 stakes in each treated and each control part of Areas II, III, and IV; and 224 stakes in Area I treated.

The heights of these stakes were measured by means of rods with meter scales attached to one side and a 3.81 cm (1 1/2 inch) diameter round foot on the end of the rods. The foot is attached to an end of the rod with a ball and socket swivel to allow the foot to conform to the contour of the ground by each stake. A 90 degree pie-shaped wedge was cut out of each foot to allow a close fit and accurate measurement to be made at the outside corner of the angle iron stake (Figure 6). By reading horizontally across the top of each stake to the scale on
the rod, a precise measurement could be made of the height of each stake.

The stakes were measured in the fall, winter, spring, and periodically throughout the summer season. The purpose of measuring these stakes was to determine the change in stake height resulting from erosion or sedimentation.

Since the stakes were installed on a random basis, it is apparent that they would be scattered throughout the treatments. Some would be located in the furrows or pits, some on the top or sides of the spoil banks or gully plugs, some directly in the drainage system of the area, and most falling someplace between the furrows and gully plugs. Due to the wide distribution of stakes, the interpretation of the results of the average change in stake heights is made difficult. The average change of the stakes includes some of them showing deposition while

Figure 6. Measurement of erosion stake - Area IV.
most show a loss of soil. The total change of all the stakes in an area will be referred to as the net change. For the three areas with controls containing stakes, a direct comparison of treated and control portions can be made.

**Pit Stakes**

In each of Areas II and III, 40 pits were randomly selected. In each of the selected pits a steel fence post was driven into the ground in the lowest part of the basin and a measurement of the stake height was made (Figure 7). Measurements were taken during fall, winter, spring, and after summer storms. The stakes were measured by use of a steel carpenter's rule and the measurement taken from the top of the stake to the ground surface at the base of the stake. The purpose of

![Figure 7. Pit with pit stake - Area III.](image)
these stakes was to determine the rate at which the pits were being filled in with sediment so that total sediment trapped could be determined as well as life expectancy of the pit treatments.

**Micro-Watersheds**

Three small watersheds approximately 0.1 ha in size were selected for study in Area II. These were called micro-watersheds. Each watershed was a definitely identifiable area that drained into a gully plug. These watersheds were mapped so that the size of the drainage and collection area could be determined.

On the drainage areas of micro-watersheds 1 and 2, angle-iron stakes were systematically located to provide measurements of soil loss. In the pit bottom of micro-watershed 1, 10J stakes were installed in rows and measured periodically and after runoff producing storms to determine the amount of sediment deposited in the pit (Figure 8). The bottom of the pit on micro-watershed 2 was smoothed out, and a large sheet of plastic was placed to cover the bottom of the pit (Figure 9). The edges of the sheet were buried a few inches so that water entering the pit would not run under the plastic. After a runoff producing rain, the water was drained off and the sediment allowed to dry, after which it was collected, oven-dried, and weighed to compute the quantity of sediment deposited by the storm.

The pit on micro-watershed 3 was lined with plastic as described above, but stakes were not placed on the drainage area.

The purpose of these micro-watersheds was to measure more accurately, on a limited area, the amount of sediment moved and deposited in gully plugs by runoff producing storms. Stakes and plastic lining were
Figure 8. Micro-watershed 1.

Figure 9. Micro-watershed 2.
used to determine which method gave the most accurate measure of sediment collected.

On micro-watersheds 1 and 2 the stakes were placed on the watershed collection area for the purpose of measuring the amount of soil loss from the area and to compare this measurement with the quantity of sediment that was actually collected in the pits and measured either by a series of stakes or dried and weighed.
RESULTS AND DISCUSSION

General Discussion

A direct comparison of the results of erosion measurements cannot be made between the control erosion transects method and the erosion stake method. As noted from a comparison of results shown in Table 3 and Table 4 it can be seen that the control erosion transect method gave approximately twice the amount of soil loss as that shown by the erosion stake method. The explanation for this is that the control erosion transects were located in the most open, exposed sites so as to represent the greatest change possible in soil elevation. The erosion stakes, as explained earlier, were located at random and were, therefore, affected much more by the vegetation of the area, with the stakes in many cases being in spots of deposition and protection, rather than erosion. Not only could the stakes be located in spots where erosion would not be evident, but the stake itself could, in many cases, provide protection to the soils immediately at the base of the stake. An additional factor was also found to be important. Intense rains cause much soil splashing, due to raindrop impact, and this caused soil to be splashed up on the stakes to a height of approximately 10 cm. This soil splash could result in deposition of sediment at the base of the stake. Due to these factors it is concluded that no direct comparison could be made between the results of the two different methods of measurement of erosion. The main purpose of the erosion stakes was to compare the effects of treatment between the
treated areas and the control areas and also to evaluate the various
parameters thought to be significant in influencing erosion at the
stake. This was done by means of a stepwise multiple regression analy-
sis. When expressing soil loss, the results of the Control Erosion
Transect method was used, as this method showed more nearly the rate
of soil loss from the area in general.

It became obvious that there was a discrepancy between the amount
of soil measured as moving from the locations of the control erosion
transects and that which was actually measured in the furrows and pits.
There were several factors which appeared to contribute to this dis-
crepancy. First, the control erosion transects were located on the
area where the most severe conditions for erosion were present. These
locations were unaffected by vegetation and were located where the
gradient of the slope was the greatest. Second, as the transects were
located close to the tops of the small ridges, there was a considerable
area lower on the slope for sediment to be deposited in depression
storage before it would finally show up as sediment in a pit or furrow.
Third, as mentioned earlier, the cracks in the soil on Areas II, III,
and IV were able to trap a considerable amount of sediment as it moved
down slope as part of overland flow. Fourth, there are periods when
the wind acts as an erosive agent on these desert soils. This means
of soil loss was observed at times, but no determination was made of
the extent of wind erosion.

Analysis of Results

Data from this study is given as follows: 1) the changes in stake
heights between all measurement dates are shown as the mean change;
2) the changes in the contour furrow, control and pit transects are given as profile changes with the mean change of the transects in a given area computed; 3) a stepwise multiple regression analysis was used to show the significance of various factors influencing the change in elevation at the erosion stakes. This analysis is based on the classification of factors thought to influence erosion at the stake locations. These factors are: per cent of desert pavement, closest plant species, distance to nearest plant, direction from stake to nearest plant, distance to plant mounds, plant mounds live or dead, distance from nearest drainage, slope aspect at stake, direction the angle of the stake points, slope at the stake, position of the stake on the slope, and location of the stake in relation to treatments. All of these factors were evaluated in the analysis by means of the change in the stake height between the measurement dates of September, 1966 to September, 1969. A second analysis was made with the same factors, but between the dates of September, 1966 and September, 1968. September measurements were selected for comparison because soil moisture was generally at a minimum during this time. However, in September of 1969, the soils contained more soil moisture than in September of the preceding three years due to rains which increased the moisture content and thus caused the soil to swell. Because of this, the second analysis between September, 1966 and September, 1968 will be used in the results and discussion; 4) an analysis of variance was used to compare soil loss from treated and control plots. This analysis was made on data from erosion stakes.
Discussion of Area I

Area I is in the shadscale-galleta grass plant community. This plant community has a greater amount of ground cover than the other communities, also sandier and more productive soils. This area was contour furrowed in the spring of 1966. Since the area has slight relief, the linear density of the furrows is 440 m/ha. Soil texture analysis by the Bouyoucos method (Bouyoucos, 1962) showed the surface soil texture to be sandy loam.

When first constructed, the average width of the furrows was 0.73 m and the average depth was 0.10 m. The sandy texture of the soil allowed relatively rapid sloughing of soil from the sides of the furrow. The erosion transects were initially measured on July 10, 1966. Over the measurement period of September, 1966, to September, 1969, the furrow transects showed an average deposition of 0.42 cm in the furrow bottoms and an average decrease of 0.98 cm from the top of the spoil bank (Table 1). The deposition in the furrows amounted to a total of 5.7 metric ton (MT) of sediment caught per ha or an average of 1.9 MT/ha/yr (Table 2).

The furrows in this area remained intact better than in some areas because the infiltration capacity of the soil was greater, allowing more of the precipitation to infiltrate which reduced the total available for runoff. The furrows which crossed the natural drainages of the site were broken frequently by excessive runoff, thus allowing an unknown quantity of sediment to be lost from the site.

The average loss per year from the 13 control erosion transects was 0.09 cm. If this were an actual loss from the entire area, it
Table 1. Sediment deposited in furrows and soil loss from furrow throw September, 1966 to September, 1969.

<table>
<thead>
<tr>
<th>Area</th>
<th>Date treatments installed</th>
<th>Total (cm)</th>
<th>Average per year (cm)</th>
<th>Soil loss from throw Total (cm)</th>
<th>Average per year (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1966</td>
<td>1.26</td>
<td>0.42</td>
<td>2.94</td>
<td>0.98</td>
</tr>
<tr>
<td>II</td>
<td>1964</td>
<td>1.32</td>
<td>0.44</td>
<td>2.90</td>
<td>0.97</td>
</tr>
<tr>
<td>III</td>
<td>1962</td>
<td>1.46</td>
<td>0.49</td>
<td>1.87</td>
<td>0.61</td>
</tr>
<tr>
<td>IV</td>
<td>1966</td>
<td>2.56</td>
<td>0.85</td>
<td>4.63</td>
<td>1.55</td>
</tr>
</tbody>
</table>

Table 2. Furrow storage and life expectancy.

<table>
<thead>
<tr>
<th>Area</th>
<th>Total storage** (MT/ha)*</th>
<th>Effective storage*** (MT/ha)*</th>
<th>Rate of filling (MT/ha)*</th>
<th>Life expectancy (Yrs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>45.6</td>
<td>22.8</td>
<td>1.9</td>
<td>12</td>
</tr>
<tr>
<td>II</td>
<td>168.7</td>
<td>84.4</td>
<td>7.2</td>
<td>12</td>
</tr>
<tr>
<td>III</td>
<td>120.3</td>
<td>60.2</td>
<td>5.7</td>
<td>11</td>
</tr>
<tr>
<td>IV</td>
<td>82.8</td>
<td>41.4</td>
<td>6.0</td>
<td>6</td>
</tr>
</tbody>
</table>

*Metric tons per hectare
**Total storage is the volume of sediment the furrows could hold if they could be completely filled with sediment.
***Effective storage is the total volume of sediment the furrows are capable of holding due to the slight slope of the furrows.
would result in a loss of 12.8 MT/ha/yr (Table 3). This cannot be considered an actual loss, however, as the area has a fair ground cover; and the areas protected by plants, litter, and erosion pavement would protect the soil from erosion much more than in the bare areas where the erosion transects were located. Also, some of the soil lost from the erosion transects would be caught and deposited in depression storage and in the present ground cover and not be lost from the site. See Figure 10 for a plotting of the change in soil profile on a control erosion transect.

Table 3. Average soil loss from control areas, as determined by erosion transects.

<table>
<thead>
<tr>
<th>Area</th>
<th>2 Year average</th>
<th>3 Year average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sept. 66 to Sept. 68</td>
<td>Sept. 66 to Sept. 69</td>
</tr>
<tr>
<td></td>
<td>cm change</td>
<td>MT/ha*</td>
</tr>
<tr>
<td>I</td>
<td>-0.41</td>
<td>57.8</td>
</tr>
<tr>
<td>II</td>
<td>-0.32</td>
<td>40.3</td>
</tr>
<tr>
<td>III</td>
<td>-0.31</td>
<td>35.8</td>
</tr>
<tr>
<td>IV</td>
<td>-0.50</td>
<td>64.3</td>
</tr>
</tbody>
</table>

*Metric tons per hectare
-Erosion or shrinking
+Deposition or swelling

While the original storage capacity of the furrows seemed quite adequate to hold the overland flow, it soon became evident that due to sloughing of the upper bank and the lower spoil bank into the trench,
Figure 10. Plotting of the change in soil profile on a control erosion transect - Area II.

The storage capacity was soon reduced. It is likely the furrows in this study will continue to be effective in accumulating sediment until they are filled to one-half their capacity. This is due to the furrows not being installed exactly on the contour. Even a slight slope of ½ percent is enough to cause early failure of the furrows. The furrows that are overtopped due to slope will continue to trap sediment but not as effectively as furrows without any slope. The slope also reduces the total sediment that they are designed to hold, which in turn reduces the life expectancy of the furrows. The furrows in this area, filling at the rate of 0.42 cm/yr, will be filled to one-half their capacity in 12 years, which will be considered the life expectancy of the treatment (Table 2).
The erosion stakes were first measured on July 23, 1966. Since the stakes were installed on a random basis it is apparent that the stakes would be scattered throughout the treatments; some located in the furrows, some on top or sides of the spoil bank, some directly in the drainage system and most falling somewhere between the furrows. Due to the varied locations of the stakes, the interpretation of the average change in stake heights is difficult.

The average change in stake heights over the 3 year period (September, 1966 to September, 1969) was a decrease in surface elevation of 0.06 cm. Considering this to be representative, it would give a net soil loss of 8.5 MT/ha/yr. The average decrease in soil depth for the period September, 1966 to September, 1968 was 0.22 cm. If this is considered representative, the average soil loss per year would be 30.9 MT/ha/yr (Table 4).

As there are no control erosion stakes in Area I, there is no way to compare the effect of treatment on erosion rates through the erosion stake measurements.

Through the technique of stepwise multiple regression the factors affecting erosion at the individual stakes were examined (Table 5). The total of all factors combined resulted in an $R^2$ of 0.45. The ranking of the independent variables, in importance to the total contribution to the $R^2$, is shown (Table 5).

An examination of the stepwise multiple regression (Table 5) shows that all evaluated factors combined did not result in very good predictors of soil loss. This is evidenced by the low $R^2$ values obtained. There are, however, a few factors that show up as either being important or not important predictors. Location in relation to treatment
Table 4. Average change in soil surface elevation, as determined by erosion stakes.

<table>
<thead>
<tr>
<th>Area</th>
<th>2 Year average</th>
<th>3 Year average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sept. 66 to Sept. 68</td>
<td>Sept. 66 to Sept. 69</td>
</tr>
<tr>
<td></td>
<td>cm change</td>
<td>MT/ha*</td>
</tr>
<tr>
<td>Irt</td>
<td>-0.22</td>
<td>30.9</td>
</tr>
<tr>
<td>IIt</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>IIc</td>
<td>-0.66</td>
<td>7.6</td>
</tr>
<tr>
<td>IIIt</td>
<td>-0.10</td>
<td>11.6</td>
</tr>
<tr>
<td>IIIc</td>
<td>-0.20</td>
<td>23.3</td>
</tr>
<tr>
<td>IVt</td>
<td>-0.30</td>
<td>38.5</td>
</tr>
<tr>
<td>IVc</td>
<td>-0.26</td>
<td>33.4</td>
</tr>
</tbody>
</table>

*Treated  
*Control  
*Metric tons per hectare  
**Higher surface elevation than at beginning of study.  
+Deposition or swelling  
-Erosion or shrinking
Table 5. Ranking of independent variables in order of importance for predicting soil loss.

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Area I</th>
<th>Area II</th>
<th>Area III</th>
<th>Area IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T</td>
<td>T</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Per cent pavement</td>
<td>7</td>
<td>8</td>
<td>7</td>
<td>X</td>
</tr>
<tr>
<td>Closest plant species</td>
<td>9</td>
<td>11</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Distance to nearest plant</td>
<td>4</td>
<td>7</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Direction from stake to nearest plant</td>
<td>8</td>
<td>3</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Distance to nearest plant mound</td>
<td>3</td>
<td>2</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>Mound plant live or dead</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>X</td>
</tr>
<tr>
<td>Exposure of stake</td>
<td>2</td>
<td>9</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Direction angle of stake points</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Slope</td>
<td>1</td>
<td>12</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Distance to Drainage</td>
<td>X</td>
<td>5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Position on slope</td>
<td>X</td>
<td>10</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Location in relation to treatment</td>
<td>10</td>
<td>1</td>
<td>X</td>
<td>1</td>
</tr>
</tbody>
</table>

R²                                  | 0.45 | 0.29 | 0.26 | 0.29 | 0.42 | 0.26 | 0.27 |

T - Treated
C - Control
X - Not evaluated
was a good predictor on Areas II and III; however on Areas I and IV this variable was a poor predictor. Slope was a good predictor on Areas I, III control, and IV treated and control. Distance to nearest plant mound appears to be a pretty good indicator on most areas. Per cent pavement, closest plant species, and distance to nearest plant turned out to be poor predictors of soil loss in most of the areas. No other consistent patterns in the regression analysis are obvious in the rest of the independent variables.

**Discussion of Area II**

Area II is in the Nuttall saltbush plant community. The soil texture in this area is a silty clay loam. The area is highly dissected by small gullies and rills and has only 3 to 5 per cent ground cover (Ibrahim, 1963). The area had contour furrows and gully plugs installed in the spring of 1964. The contour furrows were installed at the rate of 1,640 m/ha and the gully plugs were installed at the rate of 4.2 per ha.

When furrow transects were first installed the average width and depth was 0.67 m by 0.10 m respectively. Furrows of this average size would provide a total potential storage of 168.7 MT/ha of sediment. This amount of sediment would completely fill the furrows and render them ineffective. The furrow transects showed an average deposition of 0.44 cm in the furrow bottoms and an average decrease of 0.97 cm from the top of the spoil bank. The deposition in the furrows amounts to a total of 21.6 MT/ha of sediment or an average of 7.2 MT/ha/yr. With the furrows filling at the rate of 0.44 cm per year, it will take 12 years for the furrows to fill to one-half of their capacity and
reach their life expectancy (Table 2).

Many of the furrows in this area have already failed because the detention storage has been reduced by sediment and this has resulted in failures at the low point of the furrow, which is usually at one end. As a result of furrow failure the sediment in many furrows is now being removed slowly and the furrows are no longer as effective as they were originally. The pits are, however, still effective in this area and are catching the sediment which is now being released as a result of furrow failure.

The control erosion transects in this area show an average yearly decrease in soil elevation of 0.16 cm. This is equivalent to 20.2 MT/ha/yr (Table 3).

The pits in this area are currently catching and retaining virtually all of the sediment which is moving on this area. There is evidence that some of the pits have been filled to the point of overflowing since their construction, but since the transects were installed there has been no storms which have resulted in overflowing of the measured pits.

The pits have an average width of 4.73 m and length of 5.34 m by 0.85 m deep which gives an average storage capacity per pit of 21.5 cubic meters (m$^3$) of sediment which is equal to 31.9 MT of sediment per pit, if the pits were completely filled. At the rate of 4.2 pits per ha this would give a total pit storage of 90.4 m$^3$ or 134.0 MT/ha of sediment.

Since the results from the pit stakes represent an average of 40 pits and the pit transect data is the average of 10 pits only, the data from the pit stakes will be used. The pit transects show
that the deposition is nearly uniform over the bottom of the pits.

The measurements of pit stakes over a period of four years from September, 1965 to September, 1969 shows an average deposition of 4.53 cm per year which is equivalent to 1.7 MT of sediment per year per pit or 7.1 MT/ha/yr (Table 6). At this rate of filling of the pits they would be expected to last for 19 years before being completely filled. This assumption is erroneous, however, since the pits remain capable of holding all of the overland flow resulting from storm runoff. Once the pits fill to the point that they cannot hold the runoff then the rate of sediment retention begins to decrease and total sediment is no longer retained on the area.

Table 6. Pit storage and life expectancy.

<table>
<thead>
<tr>
<th>Area</th>
<th>Pits per hectare</th>
<th>Effective storage MT/ha*</th>
<th>Rate of filling MT/ha/yr</th>
<th>Rate of filling cm/yr.</th>
<th>Life expectancy in yrs.**</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>4.2</td>
<td>100.0</td>
<td>7.1</td>
<td>4.53</td>
<td>14</td>
</tr>
<tr>
<td>III</td>
<td>8.6</td>
<td>60.5</td>
<td>1.8</td>
<td>1.12</td>
<td>33</td>
</tr>
</tbody>
</table>

*Metric tons per hectare.
**Based on filling to three-fourths pit capacity.

From observation of pits in the areas treated prior to the study (north of Cisco) it is apparent that when a pit fills with sediment to approximately three-fourths of its storage capacity that its life expectancy is reached (Figure 11). This is evidenced by the fact that
the pit is breached and its holding capacity is reduced. At this point very little additional sediment is trapped within the pit. Therefore, the useful life of the pit will be considered to be when the pit fills with sediment to three-fourths of its storage capacity.

![Figure 11. Pit filled to capacity (three-fourths full).](image)

With the pits in this area filling at the rate of 4.53 cm per year, it will take 14 years to fill to their useful capacity (Table 6). The total storage capacity of the furrows and pits in Area II is 367.0 MT/ha. At the present rate of sedimentation the structures are accumulating a total of 14.3 MT/ha of sediment per year.

The factors affecting erosion at individual stake locations on Area II control were evaluated by means of stepwise multiple regression (Table 5). It is obvious that even with all factors evaluated the amount of variance explained is very low. All factors together result
in an $R^2$ of 0.26. Table 5 also shows the factors affecting erosion on Area II treated. All factors together give an $R^2$ of 0.29. On Area II treated, the location of the stakes in relation to treatment, is shown to be the most important factor evaluated in contribution to the total $R^2$.

An analysis of variance was made to see if there were significant differences in soil loss between the treated and control portions of Areas II, III, and IV. The results of this analysis (Table 7) shows no significant difference in soil loss between the treated and control portions of Area II.

Table 7. Comparison of average yearly soil loss from treated and control plots based on 1966 to 1968 data.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>II</td>
</tr>
<tr>
<td>Treated</td>
<td>0.00</td>
</tr>
<tr>
<td>Control</td>
<td>0.66 cm</td>
</tr>
<tr>
<td>Difference</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Soil loss average per year.
*Significant at the 0.05 level.

Micro-Watersheds

The three micro-watersheds were located in Area II for the following reasons: 1) the pits receive more runoff as there are fewer pits
per hectare than Area III; 2) the soils in the area do not crack as much as the soils in Area III, therefore, more water reaches the pits; and 3) the watershed boundaries were easier to identify on the ground.

None of the area on the three micro-watersheds was treated with contour furrows; hence, the runoff and resulting sediment production should be typical of the area in general prior to treatment.

Micro-watersheds 1 and 2 were prepared for study with stakes and plastic on August 4 and 5, 1968. On August 13, a storm occurred which resulted in runoff and water was collected in the pits of the micro-watersheds. The storm produced 0.75 cm (0.3 in.) of precipitation. The duration of the precipitation and intensity were not known.

On August 15, the stakes on the two watersheds were measured and it was determined that on watersheds 1 and 2 the soil had raised 0.22 cm and 0.15 cm respectively. Instead of measuring the amount of erosion, as had been expected, the amount of soil swelling due to the increased moisture content of the soil was being measured. At this point, 10 soil samples were taken on each of the watershed areas to determine the percent soil moisture. The stakes were again measured on August 18, 20, 27, and September 2, and on each measurement date, soil moisture content was also determined. Figure 12 shows the change in soil moisture as the soil dried. It can be seen that after 12 days the soil had dried to minimum soil moisture without oven drying.

Figure 13 shows the soil also had shrunk back to nearly its original level. After the pits had dried the stakes in the pit for micro-watershed 1 were measured and the sediment from micro-watershed 2 was collected, oven dried, and weighed. Measurement of the pit stakes in
Figure 12. Soil moisture depletion curve.
Figure 13. Soil elevation response to soil moisture change.
micro-watershed 1 indicated 1.0 MT/ha had been deposited from the storm. The sediment collected and weighed from micro-watershed 2 amounted to 0.4 MT/ha (Table 8). During the remainder of the fall of 1968 the soil did not shrink to the level it was just prior to the storm.

Table 8. Sediment deposition measured in micro-watershed pits and evidence of soil loss measured by erosion stakes on micro-watersheds.

<table>
<thead>
<tr>
<th>Storm No.</th>
<th>Storm Date</th>
<th>Rain cm</th>
<th>Sediment Deposition MT/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Watershed 1</td>
</tr>
<tr>
<td>1</td>
<td>8-13-68</td>
<td>0.76</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>7-20-69</td>
<td>0.97</td>
<td>2/0</td>
</tr>
<tr>
<td>3</td>
<td>8-29-69</td>
<td>2.51</td>
<td>3.3</td>
</tr>
</tbody>
</table>

1/- Stakes indicated no soil loss.
2/- Pit stakes did not show any deposition.
3/- No stakes were installed in the watershed.
4/- This watershed was not installed for storms 1 and 2

This experiment supports the hypothesis that the measurement of stakes results in the measurement of swelling and shrinking of these
soils more than in the measurement of erosion. To further exemplify this, the loss of 0.10 cm of soil over one hectare of land would be equivalent to the loss of 10 m$^3$ or 14.7 MT/ha of sediment. With the equipment used, it was only possible to measure to the nearest 0.10 cm; hence, rounding off to the nearest 0.10 cm, the error could be as great as 7.4 MT/ha, even if erosion could be measured without any influence due to the change caused by soil moisture fluctuation.

It has been concluded, therefore, that the best way to use the stake measurement data thus collected in this research project is to compare data from the period of the year when soil moisture is at a minimum level. This was considered to be in September. This, however, can be quite variable from one September to the next.

The second storm which was monitored, occurred on July 20, 1969. The storm produced 0.96 cm (0.38 in.) of precipitation. No record of intensity or duration is available. No determination of sediment could be made on micro-watershed 1 by the measurement of stakes as the soil in the pit bottom had shrunk below the measured level prior to the storm. The sediment from watershed 2 was collected, oven dried, and weighed. Sediment deposited in the pit from this storm was equivalent to 0.6 MT/ha (Table 8).

The third storm which was monitored, occurred on August 29, 1969. By this date a third micro-watershed had been selected and prepared. Erosion stakes were not installed on this watershed. No record of rainfall was obtained from the site for this storm. It was noted, however, that the rainfall had been much more than for the preceding two storms monitored. Rainfall from this storm measured 2.51 cm
(0.99 in.) at Dewey, approximately 8 miles south of Area II.

Measurement of the pit stakes in micro-watershed 1 indicated that the equivalent of 3.3 MT/ha had been deposited in the pit. Sediment collected, oven dried, and weighed from micro-watersheds 2 and 3 was equivalent to 1.5 and 2.2 MT/ha respectively.

A comparison of the sediment collected in the pits with the results of the erosion stake measurements on micro-watersheds 1 and 2 (Table 8) showed that the erosion stake measurements indicated up to 15 times as much soil loss as was actually measured in the pits. This points out the degree of error that can result from the measurement of stakes only. It is concluded from this study that the most accurate method of measuring the rate of sedimentation is to actually collect or measure the sediment where it is deposited, such as in a pit or furrow.

Discussion of Area III

Area three is in the mat saltbush plant community. The soil texture in this area is silty clay with the subsoil being clay. The area is dissected with a well-established drainage pattern. The slope over most of the area is generally more steep than Area II. The soils, having a high clay content are subject to much cracking and also exhibit a high shrink-swell coefficient. The area was treated with contour furrows and gully plugs in the spring of 1962. The contour furrows were installed at a density of 1160 m/ha and the gully plugs were installed at a density of 8.6 per ha. The gully plugs were smaller and more numerous in this area than in Area II.
The average size of the furrows, when studies were first started in the area in June, 1966, was 0.72 m wide by 0.10 m deep. Furrows of this average size, if filled to capacity, would be able to hold a total of 120.3 MT/ha of sediment. The furrow transects showed an average deposition in the furrows of 0.49 cm and an average decrease of 0.61 cm from the top of the spoil bank. The deposition in the furrows amounts to 17.1 MT/ha of sediment caught and an average rate of 5.7 MT/ha of sediment per year (Table 2).

As in Area II, many furrows had already failed by the end of the study due to poor construction methods (furrows not on the contour). Severe cracking of the soil in this area caused many furrows to fail due to piping out through the cracks in the soil. With the furrows in this area filling at the rate of 0.49 cm/yr, (based on 4 years' data) the life expectancy of the furrows is 11 years (Table 2).

The average size of pits in Area III is 3.44 m wide by 4.0 m long by 0.49 m in depth. This gives a storage capacity of 6.7 m³ of sediment. This pit storage volume is equal to 9.3 MT of sediment per pit. At the rate of 8.6 pits per ha, the gross pit storage capacity is 80.6 MT/ha of sediment. The effective storage at three-fourths capacity is 60.5 MT/ha of sediment (Table 6).

With the pits in Area III filling at the rate of 1.12 cm/yr, as determined by measurements of the pit stakes, it will take 33 years to reach the three-fourths capacity mark which is considered the effective life of the treatment as discussed for Area II.

During the study period the pits filled at the average rate of 0.2 MT/pit/yr, or 1.8 MT/ha of sediment per year (Table 6).
slower rate of filling is probably due to the fact that there are more pits per unit area than in Area II. There is another reason, however, which is felt to be significant on this area. As mentioned previously, this soil is subject to extensive shrinking and swelling and when the soil is dry, numerous cracks of 2 to 2.5 cm in width occur over the surface. Some of these cracks have been probed and found to be one meter and greater in depth. The runoff producing storms usually occur when the soils are very dry during July, August, and September. It has been observed that storm runoff water will follow a small rill until it is intercepted by a crack, at which time the runoff water will enter the crack and disappear. It is concluded, therefore, that erosion may take place from any given spot but sedimentation may be difficult to measure as it may not be deposited in a constructed pit, furrow or crack. As in Area II, the pits in this area are catching and holding virtually all of the sediment that moves because of intense storms. The control erosion transects in Area III show an average soil loss of 0.31 cm/yr which is equivalent to 35.8 MT/ha/yr (Table 3). The total sediment caught by both furrows and pits is 6.9 MT/ha/yr with the furrows catching nearly six times as much sediment as the pits are collecting at the present time. Area III treated showed a net yearly soil loss of 0.10 cm as measured by erosion stakes. Compared to this, the control portion showed a net yearly soil loss of 0.20 cm. This shows a reduction in sediment loss of 50 percent as a result of the land treatment.

The results of the regression analysis for Area III control are shown in Table 5. The total of all factors combined resulted in an
R² of 0.42. Per cent slope was shown to be the single most important factor.

Table 5 also shows the results of regression analysis for Area III treated. All factors together gave an R² of 0.29. As in Area II, location in relation to treatment, was found to be the single most important factor. The analysis of variance on Area III shows a significant difference in the amount of soil lost between the treated and control portions (Table 7).

Discussion of Area IV

Area IV is in the saltsage-woody aster community. The soil texture in this area is silty clay. The drainage pattern is well defined, but the area is not as deeply dissected by gullies as in Area II. This area was contour furrowed with a Holt trencher in the spring of 1966 along with Area I. As there were no deep gullies in the area, it was concluded that contour furrowing was all that would be needed to control surface runoff on the area.

It soon became evident, however, that contour furrows would not hold all of the water moving across the area, as they were soon overtopped and broken along the main drainage pattern that crosses both the treated and untreated portion of Area IV. The furrows which are located across the smaller secondary drainages on the area did hold, however, and are apparently sufficient to hold the water originating from within the area.

Area IV is located on the pediment level below the shadscale plant community and runoff from this steep, barren area is concen-
treated and crosses both treated and untreated portions of Area IV by way of rather shallow gullies. The contour furrows which were constructed across these gullies were the ones that were overtopped and broken.

The average soil loss from Area IV as measured by the control erosion transects was 0.50 cm/yr, which is equivalent to 64.3 MT/ha/yr (Table 3). The contour furrows in Area IV were installed at the rate of 850 m/ha. The average size of furrows on this area is 9.30 m long by 0.62 m wide by 0.10 m in depth. The total holding capacity of these furrows is 56.3 m$^3$/ha or 82.8 MT/ha. The life expectancy of these furrows will be reached when they have filled to 50 percent of their constructed capacity. When filled to this capacity they will hold 41.4 MT/ha of sediment. At this present time these structures are filling at the rate of 0.85 cm per year. This is the fastest rate of filling of any of the furrows on the four treated areas. At this rate of filling, the furrows will reach their life expectancy in just 6 years as shown in Table 2. Area IV treated shows a net yearly soil loss of 0.30 cm as measured by erosion stakes. The factors affecting erosion on Area IV treated as determined by the stepwise multiple regression analysis are shown in Table 5. The total of all factors combined gave an $R^2$ of 0.26. The single most important factor was percent slope.

The analysis of variance comparing soil loss between the treated and control portions showed no significant difference (Table 7).
SUMMARY AND CONCLUSIONS

Rapid erosion of "frail lands" in the Upper Colorado River Drainage, of which the eastern Utah desert is typical, results in rapid sedimentation of Lake Powell and other man-made structures on the Colorado River. The sedimentation of these reservoirs will materially reduce their storage capacity and useful life. To reduce the rapid rate of sedimentation, the BLM constructed contour furrows and gully plugs on some of the more seriously eroding lands in the Cisco Basin area to hold the sediment on site.

Contour furrows and gully plugs were found to be effective in catching and holding sediment; however, difficulties in constructing the furrows on the contour resulted in a shortened useful life of the structures. The constructed pits provide adequate storage for both water and sediment to keep overland flow from leaving a treated site. Areas II and III treated with both contour furrows and gully plugs held all runoff and sediment on site, while Areas I and IV treated with contour furrows alone, held only a portion of the runoff and sediment. It was apparent from the study that the greater the density of furrows and gully plugs, the longer the life expectancy of the treatments. It was also apparent that the amount of sediment moving in an area has a substantial effect on the life expectancy of the treatments. The rate of sediment accumulation in gully plugs and furrows combined varied from 1.9 MT/ha/yr on Area I to 14.3 MT/ha/yr on Area II.

Interpretation of the data from the measurement of changes in
stake height and also changes in soil profile was made difficult due to the shrinking and swelling of the soils resulting from changes in soil moisture. The soils were found to expand over the winter months when they became wet and frozen. As they would dry out in the summer, they would shrink and settle again. As the soils became wet with individual summer storms, they were found to expand, then shrink after approximately two weeks drying time.

The change in the soil profile caused by swelling and shrinking was found to be more pronounced than the change resulting from soil erosion. The study of micro-watersheds showed that the collection and measurement of sediment in plastic-lined pits gave a more reliable measure of soil loss from an area than did the measurement of erosion stakes or control erosion transects.
LITERATURE CITED


VITA

Dee Browning Thomas

Candidate for the Degree of

Master of Science

Thesis: The Effects of Gully Plugs and Contour Furrows on Erosion and Sedimentation in Cisco Basin, Utah

Major Field: Watershed Science

Biographical Information:


Education: Attended elementary school in Lorenzo, Sugar City, and Rexburg, Idaho; graduated from Madison High School in 1952; attended Ricks College for 2 years, receiving A.S. degree in Zoology; attended Utah State University and received the Bachelor of Science degree in Forest-Range Management, in 1960; returned to Utah State University in 1968 to do graduate work. Will receive Master of Science degree in Watershed Science in 1975.

Professional Experience: 1960 to 1963 worked on the Targhee National Forest as Forester, then as Range Conservationist; 1963 to 1968 worked on Caribou National Forest as Assistant Ranger; 1970 to 1972 worked on Manti LaSal National Forest as Hydrologist; 1972 to present, assigned to Fishlake National Forest as Forest Hydrologist.