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AN ECONOMIC ANALYSIS OF CONTOUR FURROWS AND  
GULLY CHECKS ON THE FRAIL LANDS  
OF SOUTHEASTERN UTAH

by

Karl A. Simonson

A thesis submitted in partial fulfillment  
of the requirements for the degree

of

MASTER OF SCIENCE

in

Range Science

Approved:

UTAH STATE UNIVERSITY  
Logan, Utah

1970

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Karl A. Simonson

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## TABLE OF CONTENTS

	Page
INTRODUCTION . . . . .	1
BENEFIT-COST ANALYSIS . . . . .	2
History of Benefit-cost Analysis . . . . .	2
Project Evaluation . . . . .	3
Definition of Terms . . . . .	4
LITERATURE REVIEW . . . . .	11
STUDY AREA . . . . .	15
Climate . . . . .	15
Soils . . . . .	15
Vegetation . . . . .	18
Grazing . . . . .	18
Physical Characteristics . . . . .	18
Treatments . . . . .	19
METHODS OF PROCEDURE . . . . .	21
Field Measurements . . . . .	21
Economic Measures . . . . .	24
RESULTS AND DISCUSSION . . . . .	28
Control Measurements . . . . .	28
Silt Retention . . . . .	29
Vegetation Response . . . . .	39
Economic Measures . . . . .	45
SUMMARY AND CONCLUSION . . . . .	61
SUGGESTIONS FOR FURTHER RESEARCH . . . . .	64
Erosion Measurements . . . . .	64
Vegetation Measurements . . . . .	64
Miscellaneous . . . . .	65
LITERATURE CITED . . . . .	66
VITA . . . . .	70



## LIST OF TABLES

Table	Page
1. Potential soil loss of the Cisco project . . . .	28
2. Amount of silt caught by contour furrows and gully checks in the four study areas . . . .	38
3. The number of transects needed to estimate the species composition mean within 10 percent of the true mean ( $P > .05$ ) and the number available for study . . . . .	40
4. Net gain in Animal Unit Months on treated and untreated areas . . . . .	43
5. Net gain in Animal Unit Months in the "zone of influence" of each treatment . . . . .	46
6. Estimated annual benefits from Lake Powell . . . .	48
7. The annual cost of silt deposition in Lake Powell . .	48
8. Total annual benefits of silt retention . . . .	49
9. The cost to down-stream industries to remove the silt from the Colorado River water . . . . .	50
10. Estimated income stream to project . . . . .	52
11. Total benefits of the Cisco project . . . . .	53

## LIST OF FIGURES

Figure	Page
1. Benefit--cost relationships for various scales of development . . . . .	9
2. Location of the Cisco project . . . . .	16
3. The study areas . . . . .	17
4. Furrow failure due to "overtopping" . . . . .	30
5. Furrow failure due to having been put across a well-established gully . . . . .	30
6. Amount of silt retained in Areas 1 and 4 at different intensities of treatment . . . . .	32
7. Amount of silt caught per acre in Areas 2 and 3 at different intensities of treatment . . . . .	34
8. Estimated amount of silt caught in Area 2 by gully checks alone . . . . .	36
9. Silt deposition in a furrow that escaped measurement . . . . .	39
10. Characteristic growth of vegetation around a gully check . . . . .	41
11. Characteristic vegetation growth around the contour furrow . . . . .	41
12. Characteristic vegetation growth pattern as the gully check fills in with sediment . . . . .	44
13. Total product (benefit) and price relationships on Area 4 . . . . .	56
14. The optimum intensity of treatment for contour furrows . . . . .	57
15. The optimum intensity of treatment for contour furrows and gully checks . . . . .	58

## ABSTRACT

An Economic Analysis of Contour Furrows and  
Gully Checks on the Frail Lands  
of Southeastern Utah

by

Karl A. Simonson, Master of Science  
Utah State University, 1970

Major Professor: Dr. Jack F. Hooper

Department: Range Science

The upper Colorado River drainage system yields approximately 104,000 acre-feet of silt annually to the Colorado River. In an attempt to reduce the silt load, federal land management agencies have installed numerous land surface treatments. A study was conducted to measure the economic benefits of the land treatments near Cisco, Utah, and to compare them to the treatment costs and to develop predictive criteria for estimating the optimum intensity of treatment.

The economic evaluation was done in a benefit-cost framework and the criteria for estimating optimum intensity of treatment was done in a production-function framework.

The land treatments were found to be effective in retaining silt, but treatment apparently resulted in decreased livestock carrying capacity. Over-all, the land treatments were found to be uneconomical.

(76 pages)

## INTRODUCTION

The upper Colorado River drainage system yields approximately 104 thousand acre-feet of silt annually to the Colorado River (Gessel, 1963). This silt is reducing the storage capacity of downstream reservoirs and causing additional operating expense to the industries using the Colorado River water. In an attempt to reduce the silt load, federal land management agencies have installed numerous land surface treatments.

The objective of the present study is to measure the silt retention and other benefits of the land treatments and to compare them with the treatment costs. The study will also attempt to develop predictive criteria for estimating the optimum intensity of treatment for maximum benefits.

## BENEFIT-COST ANALYSIS

With the initiation of the Program Planning and Budgeting System (PPBS) in 1965, resource managers have become more aware of the need to make economic decisions. To do this, a systematic approach is needed for the evaluation of individual projects, for the selection of the best project to accomplish a given purpose, and for ranking the various alternatives in an order of priority, given the available budget.

### History of Benefit-cost Analysis

Benefit-cost analysis in its most simple form has been long used, either knowingly or unknowingly, in investment decisions. When faced with an investment decision, one usually examines the investment costs and returns. He then invests only if the investment returns (benefits) exceed or at least equal the investment costs. However, the approach in estimating benefits and costs is very different and involves differing degrees of complexity among various investigators. Senate Document 97, which is an attempt at the uniformity of analysis, has been suggested as a guide for investments on public lands (U.S. Senate, 1962).

Senate Document 97 was prepared to bring agreement on allocating costs and benefits. It had its beginning in 1961 when President John F. Kennedy proposed the Water Resource Planning Act. This Act provided for a Water Resource Council to be composed of the

Secretaries of the Departments of the Interior, Agriculture, Army, and Health, Education and Welfare. In this way, the resources would be considered from four viewpoints to arrive at their best possible use. Later, the President requested that the Council develop standards and evaluation procedures that could be adopted for uniform application by all agencies. The requested information was approved by the President on May 15, 1962, and was published as Senate Document 97.

#### Project Evaluation

Benefit-cost analysis can be used for three broad purposes: (1) to evaluate the economic characteristics of a given project, (2) to determine which of several ways to achieve a particular objective produces the largest benefit-cost ratio, and (3) to determine which of a number of objectives returns the greatest net benefit to the economy as a whole (Sewell et al., 1962). At present, only the first and, to a limited extent, the second purposes have been used. The third purpose should be of most concern to the resource or land manager, for he usually has numerous investment possibilities with several means to attain those objectives. It is his obligation to choose that investment or objective that will return the greatest net benefit to the economy as a whole. An individual ranching or farming operation can be substituted for the economy in the above statement to emphasize benefit-cost analysis in the private sector of the economy.

The first step in a benefit-cost analysis involves the

elimination of objectives or alternative methods to achieve those objectives that fail to meet certain requirements. In other words, one asks (1) which of the alternative methods of attaining the objective(s) are technically feasible, (2) which of these alternatives are economically sound (i.e., do the benefits exceed the costs involved?), and (3) which of the numerous objectives chosen are most economical (i.e., which objective has the largest benefit-cost ratio)?

To answer these questions, much data must be gathered and analyzed. The amount of time and effort used in answering them should be fit to the manpower, time, and budget available. To expedite research, however, the technical feasibility of the objectives should be considered first, and those that are technically unfeasible eliminated from further analysis. Then economic and financial considerations of the remaining projects can be considered. For the data to be meaningful, all facets of benefits and cost must be considered. Therefore, a working knowledge of the terms used in benefit-cost analysis is useful.

#### Definition of Terms

##### Benefits

Benefits are the dollar value of goods or services realized from a given project. They may be either primary or secondary, tangible or intangible, or any combination thereof.

Primary or direct benefits are those that result directly from a given project. M. E. Marts (1956) considered all of the net

income to farmers as the primary benefits of an irrigation project in Payette, Idaho. Agriculture here, as well as the entire economy, was wholly dependent on this particular irrigation project; therefore, the net value of agricultural products (net income to farmers) was the primary benefit. Primary benefits of a large dam such as Glen Canyon Dam in Arizona were identified as the dollar value of recreation on Lake Powell, irrigation, electricity, and the value of fish and wildlife (Bureau of Reclamation, Region 4, 1968). Primary benefits are most easily identified, for they are usually the reason for which the project was conceived.

Secondary benefits, on the other hand, are more difficult to identify. Secondary benefits are those benefits realized indirectly or as a result of the project. Marts (1956) was able to identify secondary benefits of the irrigation project mentioned above. He considered all the net income from non-farm sources as secondary benefits. Kimball and Castle (1963) stated that secondary benefits could be thought of as those that occur from the processing of goods produced on or by the project. If, for example, an irrigation project resulted in enough grain production to warrant a flour mill or a feed lot being built, then the net income from these industries would be considered as secondary benefits. Caution should be used, however, in showing that the flour mill or feed lot was a result of the irrigation project and not merely a relocation of an existing flour mill or feed lot.

The above examples have all been tangible benefits. Tangible benefits are those which can be assigned an exact dollar value, as



determined from past or present market prices. Intangible benefits, on the other hand, are much more difficult to measure. At best, they are estimates backed by sound reasoning and research. Intangible benefits may be such things as the value to society of a roadway that was put into a once primitive area where people can now gain pleasure from viewing scenic country that they once couldn't, or the value of a nature trail into scenic country. Intangible benefits are important considerations in the profitability of a project, but judgment, free from personal bias, must be used so as to not over or under estimate the value of these benefits. Sewell and coworkers (1962) list several guides for estimating intangible benefits.

#### Costs

Like benefits, project costs fall into primary and secondary and tangible and intangible categories. Primary costs are the actual costs incurred in constructing the project. These costs include not only the monetary expenditures, but also interest during construction, promotional expenses, engineering and supervision, acquisitions of land and the relocation of existing facilities.

In addition to the primary costs, there may be associated costs. These costs are those incurred by the primary beneficiaries of a given project. In the case of the irrigation project described before, the associated costs may be such things as the cost to the farmer for installing irrigation ditches, head gates, or equipment needed to construct irrigation ditches for his land.

Secondary costs are those that are incurred in the production of the secondary benefits. In the example of the flour mill or the

feed lot, the secondary costs would be the building and operating costs (labor, materials, etc.) of each industry.

Intangible costs, like intangible benefits, are hard to place a value on because they are not usually priced in the market. If, for example, the flour mill or feed lot were built on drained marshland, then the loss of the waterfowl hunting or sport fisheries would be viewed as intangible costs. Whenever intangible costs are identified, one should attempt to attach a monetary value. Guides to value intangible costs are presented by Sewell and coworkers (1962).

A cost that should be excluded from benefit-cost analysis is a "sunk cost." This is a cost that was incurred in the past and has no bearing on a future investment. For example, if a farmer were considering cement-lining his irrigation ditches, the original cost of constructing those ditches would not enter into the analysis. Only the total cost of cementing them would be compared with the total benefits from such an investment.

When the benefit-cost ratios have been calculated for the projects under consideration and for the alternative ways to accomplish those objectives, one is ready for the last step of benefit-cost analysis. This is the choosing of the largest benefit-cost ratio.

Suppose, for example, a rancher wants to invest in one of three investments for a particular year. His investment possibilities are (1) invest in some purebred bulls to improve his cow herd, (2) invest in a new tractor for use on the cultivated land, or (3) build a farm pond for irrigation and recreation. The benefit-cost analysis he undertakes shows ratios of 1:1, 2:1, and 3:1 respectively.

Clearly, the rancher chooses investment number three. This investment will return \$3 for every dollar invested to his ranching operation as a whole. However, the rancher may increase the scale or size of that project (whether it be a larger pond or several ponds) until the benefit cost ratio is decreased to that of the next best alternative (Figure 1).

As seen in Figure 1, three points are significant in the selection of the most economic scale of development of a project (Sewell et al., 1962). The first (point X) is where the benefit-cost ratio is a maximum. The second (point Y) is where the benefits exceed the cost by the maximum amount. Point Z is where the benefits of the project just equal the cost of the project.

It will be noted that any scale beyond point Y returns smaller increment to benefits than to costs. In other words, for every unit increase in cost one realizes less than a unit increase in benefits (marginal benefits are negative). Therefore, any increase in scale beyond point Y is economically unsound. Any scale less than point X is also economically unsound because with a unit change in cost, benefits go up by more than one unit. The optimum benefit cost ratio is between X and Y. However, the extent to which one increases the scale from point X toward point Y is limited by the benefit-cost ratio of the next best alternative. Optimization in this case rarely leads to a maximization of benefits.

In summary, benefit-cost analysis involves several steps:

1. The derivation of a total cost figure, including primary and secondary and tangible and intangible costs, calculated for all

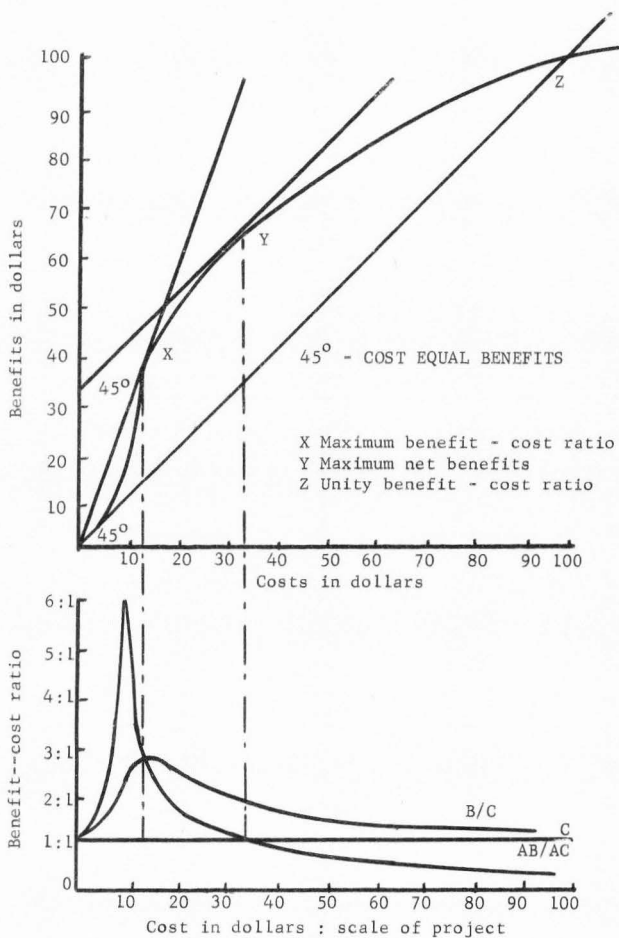


Figure 1. Benefit-cost relationships for various scales of development.

the projects under consideration.

2. The derivation of the total benefits (present value of all the income "streams"), including primary and secondary, tangible and intangible benefits, calculated for all of the projects under consideration.

3. The project with the largest benefit-cost ratio is chosen as the desired investment.

4. This investment is increased in scale (size) until the benefit-cost ratio approaches, but does not equal, that of the next best alternative.

When investment decisions are preceded by benefit-cost analyses, it is easier to identify the investment that will give the largest net returns.

## LITERATURE REVIEW

Land managers have for many years attempted to conserve moisture, prevent erosion, and increase forage production on range lands. Frequently, mechanical land treatments have been used as management tools. Barnes (1952) reported that very little mechanical range treatment had been done prior to the 1930's. Several early workers who evaluated surface land treatments (Dahl, 1937; Newport, 1937; Whitfield and Fly, 1939; Barnes and Nelson, 1945; Anderson and Swanson, 1949) found that treatments reduced erosion, conserved moisture, and increased forage production on range lands.

The type and intensity of treatment play an important role in over-all effectiveness. Ripped furrows in southern Arizona spaced at 5-foot intervals increased forage production 2.5 times over that of untreated areas (Brown and Everson, 1952). Contour furrows at 5-foot intervals or pitting spaced at 2- to 8-foot intervals resulted in the most significant forage increase in southwestern Wyoming (Barnes and Nelson, 1945). Caird and McCorkle (1946) found that listed furrows near Amarillo, Texas, produced a significant increase in forage at 7-foot intervals. Other workers (Whitfield and Fly, 1939; McCorkle and Dale, 1941; Branson et al., 1966) found that furrows spaced at 4-8 feet, 3-15 feet apart, and closely spaced furrows produced the most significant increase in forage production, respectively.

Pits or gully checks have also been found effective in retaining

silt and increasing forage production. In addition, the pits and gully checks require less care in constructing. Barnes and Nelson (1945) found that pits placed at 2-foot intervals produced the most significant forage increases. They also observed that pits required less preliminary planning. The pits were not connected and thus it was not necessary to get them on the exact contour, as was the case with contour furrows. If furrows are not on the exact contour, accelerated erosion can result. Anderson and Swanson (1949) found this to be true. They noted that water ran to the lowest portion of the furrow, which resulted in spotty vegetation and accelerated erosion.

Soil characteristics have been found to have a direct influence on the effectiveness of mechanical land treatments. Brown and Everson (1952) found that furrows on sandy loam soils increased forage production 2.5 times. Houston (1965) found that treatments in eastern Montana increased soil moisture (hence forage production) on clay loam soils but were ineffective on silty clay loam soils, clayey soils, or fine sandy loam soils. "Slick" soils (soils with considerable sodium near the surface which prevents rapid infiltration), even though furrowed, seeded, and ungrazed, remained barren (Branson, Miller, and McQueen, 1962). Valentine (1947) found that land treatments failed to improve vegetal cover on sandy soils.

Very little information is available on treatment costs and returns. Pitting spaced at 2-foot intervals was found to be between \$0.50 and \$1.00 per acre (Barnes, 1952). Hubbard and Smoliak (1953) reported a cost of \$1.60 per mile for constructing contour furrows.

in southeastern Alberta. Ripped furrows at 5-foot intervals cost \$6 to \$15 per acre on Arizona range land (Brown and Everson, 1952). Branson, Miller, and McQueen (1966) report furrows made by the model B contour furrower (makes a furrow 8-20 inches deep, 20-30 inches wide, with small cross dams, at intervals of 4-20 feet) cost \$3.50 to \$15.30 per acre. Treatment costs, Hubbard and Smoliak (1953) stated, could be paid back in a few years if one assumed a 50 percent increase in vegetation and if leased grass was valued at \$0.60 per acre.

An important factor in recovering the cost of the treatment is its expected life (i.e., how long will the benefits from that treatment last?). The size and intensity of the treatment play an important role here. Brown and Everson (1952) estimated the life of furrows, spaced 5 feet apart, at 15 years. These furrows were about 18 inches deep and 2 feet wide. Furrows near Amarillo, Texas, had an estimated life of 5-7 years. These furrows were 18 inches deep, about 2 feet wide, and were 4-44 feet apart (Caird and McCorkle, 1946). Coltharp (1967) estimated the life of contour furrows and gully checks at 10-12 and 7 years respectively on the frail lands of southeastern Utah. The furrows were 6-7 inches deep, about 2 feet wide and were an average of 25 feet apart. The gully checks averaged 1.9 feet deep, 28.1 feet long, and 22.4 feet wide.

The literature contains many tools for the economic evaluation of mechanical range treatments. As previously stated, one such tool --benefit-cost analysis--has been proposed as a tool for evaluating investments on public lands (U.S. Senate, 1962). This analysis



compares the estimated total cost and estimated benefits of a given project(s). A benefit-cost ratio greater than one indicates a profitable investment, that is, the returns are greater than the costs (Sewell et al., 1962). Other workers who have used benefit-cost analysis in investment decisions include Gertel (1949), Timmons (1954), Ciriacy-Wantrup (1955), and Williams (1962).

Benefit-cost analyses are a powerful tool for determining the profitability of a project or projects, but determining least cost combinations of inputs and optimum levels of output is basic to deriving the largest benefit-cost ratios. Valuable in this endeavor is the production or response function as described by Heady and Dillon (1961). A production or response function, as it will be called in this paper, is an expression of the dependent or functional relationship that exists between the inputs (factors) of a production process and the output (product) that results (Spencer, 1968). As both Spencer and Heady and Dillon point out, the response functions are used to estimate the optimum intensity of input factors for maximum output. The optimum intensity of treatment is the point on the response curve or surface where its slope and the slope of the inverse price ratio of the input factor(s) and output factor are equal.

## STUDY AREA

This study was conducted in the southeastern desert region of Utah known as the Grand River Valley. The area is bounded on the north by the Book Cliffs, on the west by Crescent Junction, Utah, and Highway 160, on the south by the Colorado River, and on the east by the Utah-Colorado border (Figure 2). Within the specific study area, four 40-acre areas were used to collect data (Figure 3). Area 1 was located in a shadscale-galleta grass community, Area 2 in a Nuttall saltsage community, Area 3 in a mat saltbush community, and Area 4 was located in a Nuttall saltsage community.

### Climate

The climate at Cisco is characterized by hot, dry summers and cold winters. Precipitation occurs mainly as rain during August, September, and October. Snow during the winter is quite insignificant. The annual precipitation averages 7.18 inches (Coltharp and West, 1966).

### Soils

Soils in the study area are derived from Mancos shale and sandstone (West and Ibrahim, 1968). They vary from sandy loams on the upper pediment remnants (Area 1) to silty-clay loam on the pediment slopes (Areas 2 and 4), to silty clay in the lower flats (Area 3). These soils generally exhibit a poor structure due to the

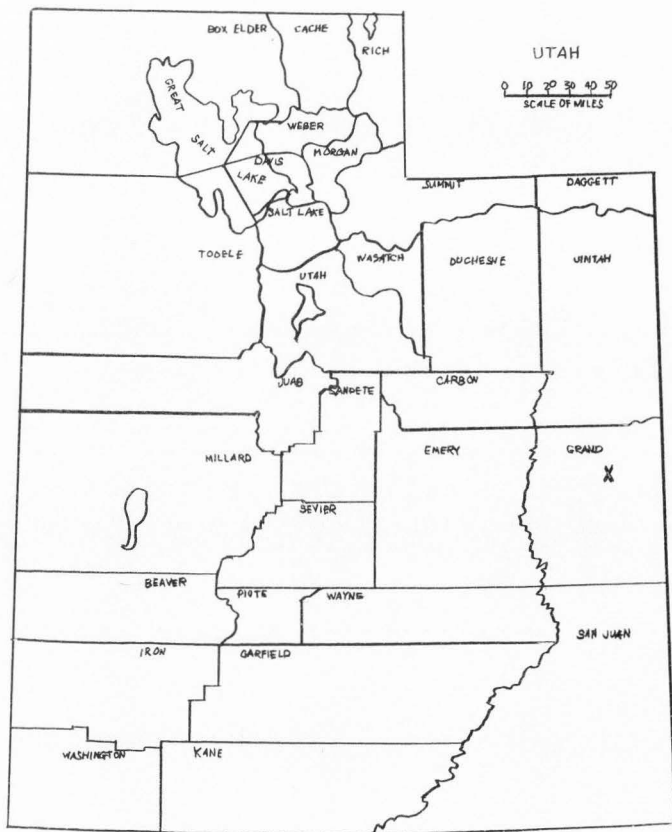


Figure 2. Location of the Cisco project.

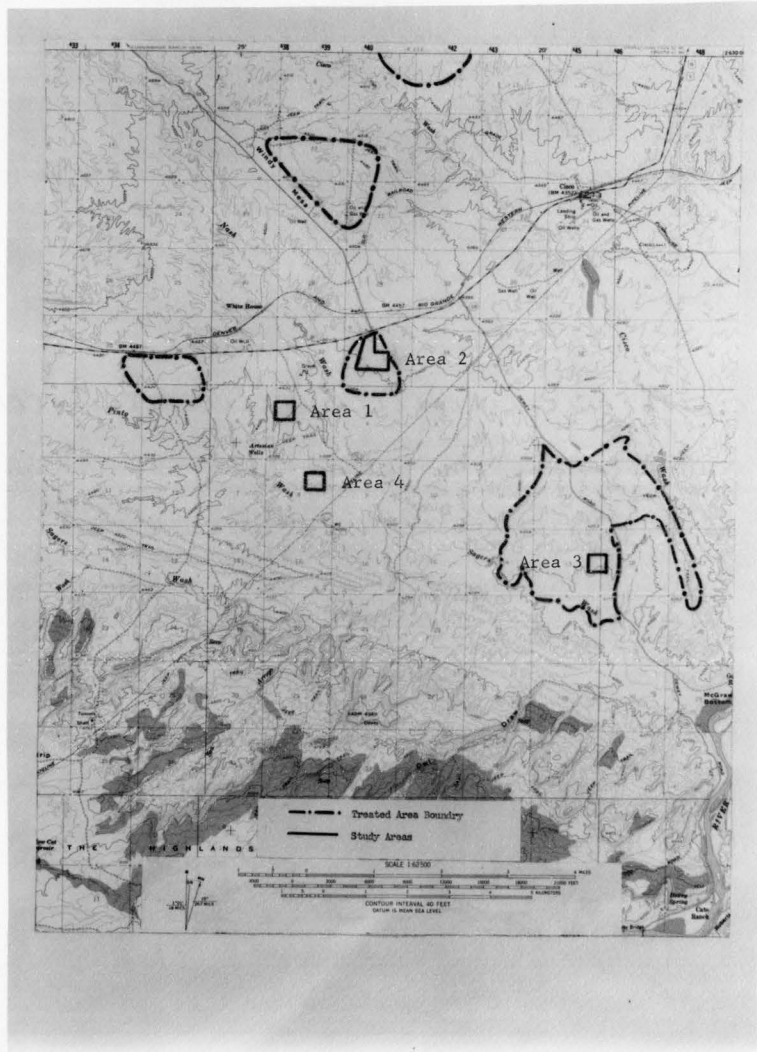


Figure 3. The study areas.

deflocculation effects of sodium. Poor structure of the soil makes the infiltration and percolation rates minimal (Coltharp and West, 1966).

#### Vegetation

The native vegetation is very sparse, averaging 4-5 percent total cover, and is of the salt desert shrub type (West and Ibrahim, 1968). Shadscale (Atriplex confertifolia), Nuttall saltsage (Atriplex nuttallii), mat saltbush (Atriplex corrigata), Indian ricegrass (Oryzopsis hymenoides), and Galleta grass (Hilaria jamesii) are the principal species. Crested wheatgrass (Agropyron cristatum) was seeded in the treatment areas and now makes up a considerable portion of the vegetation.

#### Grazing

The study area was originally grazed by sheep owned by Colorado operators during the late 1800's and the early 1900's. During this period, the area was grazed in a nomadic fashion with many herds coming and going as they pleased. Today it is winter range for sheep and cattle. Sheep graze this area November 11 to May 10, and cattle graze November 1 to May 15. The carrying capacity averages 14 acres per Animal Unit Month (AUM) (Bureau of Land Management, 1968).

#### Physical Characteristics

The study area is characterized by large flats cut with numerous

gullies and rills, steep slopes, highly erodible soils, and sparse vegetation. These characteristics combined with the high intensity summer storms make this area a high contributor of silt to the Colorado River. Similar lands of the upper Colorado River drainage yield only about 5 percent of the water to the Colorado River but contribute 44 percent of the silt load as measured at Lee's Ferry, Arizona (Coltharp, 1967).

#### Treatments

During the 1950's, the Bureau of Reclamation requested that the Bureau of Land Management (BLM) initiate various land treatments near Cisco, Utah. The Bureau of Reclamation provided the funds for construction of the gully checks and contour furrows and the BLM carried out the field work and supervision. Five to six thousand acres were contour furrowed and over 25,000 gully checks were constructed. Construction was begun in 1958 and concluded in 1964. Utah State University, in cooperation with the Utah Agricultural Experiment Station, was then asked to evaluate the treatments with regard to their ecology, watershed values, and economics.

#### Contour furrows

The contour furrows were constructed by a crawler type tractor with an attached Holt Model A Trencher. The Holt Trencher has two discs, one slightly to the side and behind the other. This implement, when pulled through the soil, left a furrow with an average 2-foot wide bottom and a spoil bank about 1.5 to 2.5 feet wide. The furrows averaged 35 feet long and were an average of 25 feet apart.

Gully checks

The gully checks were constructed with a D-7 size crawler tractor with an attached front end blade. They were built in most of the gullies and in other areas at the junction or confluence of numerous rills. The tractor built the checks with the earth dam on the down-hill end. The gully checks were either oval or rectangular. The rectangular ones were made with one or two pushes of the blade. They averaged 20 inches deep, 21 feet long and 15 feet wide. The oval checks were made by several pushes in a circular motion. They averaged 3 feet deep and 30 feet in diameter.

## METHODS OF PROCEDURE

Field Measurements

Siltation data which had been gathered over a two-year period (July 1966 to July 1968) were used in this study. Measurements had been made about three times each year.

Contour furrows

The erosion transects for contour furrows were composed of 6-foot lines that crossed the furrows at right angles. The transect ends were permanently marked by iron stakes. There were 10 such transects in each of the four study areas. Measurements were taken by placing a 6-foot reference rod across the stakes and measuring, at 4-inch intervals, the distance to the soil surface in the furrow bottom. For these data to be used in an economic analysis, an additional measurement was needed. A measurement of siltation at different intensities of treatment necessitated knowing the distance between furrows. Therefore, the distance from the center of the furrow on which the transect was located to the center of the next up-hill furrow was recorded.

To estimate the livestock carrying capacity increase or decrease due to treatment, vegetation cover was indexed by the line intercept method (Canfield, 1941). Vegetation data which had been collected in August, 1966, were used for this study. This was the only year that reliable data were available because the study areas had not been



fenced prior to that time. The transects were originally 25 meters long, but only the portion in the immediate vicinity of the furrow was used in this analysis. Measurements were taken between two points, each point 2 meters on either side of the furrow's edge. Although soil moisture was found to extend only 4 feet beyond the edge of the treatment (Hancock, 1968), 2 meters were used because West (1966) noted an increase in vegetal cover at that distance. Plant roots could logically extend this distance and "tap" the additional moisture. The acreage occupied by this "zone of influence" was calculated by assuming a furrow measured 208.7 feet x 16.5 feet (a furrow was considered as extending the width of an acre plot (208.7 feet) and the "zone of influence" extended 2 meters on either edge of the furrow (5 m = 16.5 feet), which is 0.087 acre). However, in comparing treated areas as a whole with untreated areas, the entire 25 meters were used.

#### Gully checks

Siltation data for the gully checks that had been gathered over the same 2-year period (1966-1968) was used. Each gully check measured had three 6-foot transects. "A" transect was on the right looking down-hill into the pit, "B" transect was in a 90-degree clockwise direction from "A," and "C" transect was 90 degrees clockwise from "B." The three transects formed a "T" in the pit. Areas 2 and 3 each had ten such transect groups. An average of the three transects yielded the estimated silt deposition for the pit. Measurements were taken in the same manner as the furrow transects. Aerial photographs were used to locate the gully check under study

and to determine the number of gully checks in an acre plot upslope from it. In this manner, the amount of siltation at different intensities of treatment could be estimated.

Carrying capacity increase or decrease due to the gully checks in Areas 2 and 3 was also estimated by using line intercept transect data. Measurements were taken along four transects, two extending lengthwise through the pit and two across the width. Each transect extended 25 meters outward from the center of the pit. Only the distance from the center of the pit to 6 meters beyond was examined. Again, this was considered to be the zone of influence of the treatment. The "zone of influence" for gully checks occupied 0.123 acre.

The two year average of the silt data was computed for each gully check and furrow to represent the average silt retention per year per treatment. These figures were then multiplied by the number of furrows or gully checks per acre at the particular study site to arrive at an estimate of the silt retention per acre at different intensities of treatment. The vegetation transects were examined to determine the percent composition for each species and the average density for each treatment. With the aid of the proper use factors for the area (Bureau of Land Management, 1968), this information was then used to compute the carrying capacity (Acres/Animal Unit Month) as described by Stoddart (1952).

#### Control measurements

An estimate of the potential soil loss from the Cisco area was made by examining erosion transect data on control (untreated) plots in Areas 1, 2, 3, and 4. Each erosion transect was 6 feet long with

the ends permanently marked with iron stakes. Measurements were made in the same manner as described above for siltation measurements. These data were averaged over the same two year period (1966-1968) for each area to give the average soil loss per acre per year. These figures were then multiplied by the number of acres similar to each study area to arrive at an estimate of the potential soil loss in the vicinity of Cisco. The control (untreated) estimate was later used to estimate the silt retention benefit if the treatments caught all the silt produced by the project.

#### Statistical measures

The only statistical "tool" employed was in determining the number of line intercept transects needed in order to estimate the species composition mean within 10 percent of the true mean at the .95 confidence interval. It was also initially intended to subject all the vegetation and silt data to regression analysis to estimate and graph the response equations. However, due to the limited data and high variability, freehand regression lines were fitted to the scatter diagrams. For the gully checks, the plotted line was the mean of the observation at each intensity of treatment.

#### Economic Measures

The economic evaluation was done in a benefit-cost framework (Sewell et al., 1962). Criteria for determining optimum intensity of treatment for maximum benefits was done in a production or response function framework (Heady and Dillon, 1961).

The total benefits per year for the project were estimated by

placing a value per acre-foot on the amount of silt held on the treated area and adding that figure to the estimated value of the increase or decrease in carrying capacity. The value of an acre-foot of silt was estimated by determining the value per acre-foot of storage capacity of Lake Powell. The value of an acre-foot of storage capacity was the estimated value of an acre-foot of silt. In addition, industries using the Colorado River water were contacted to obtain an estimate of the damage to pumping equipment due to the silty water and the cost of settling out the silt so clear water could be used in their processes. Any percent reduction in the silt load of the Colorado River would be a benefit to them. Also, the reduced silt load would improve water quality because it would reduce total dissolved solids. By summing these benefits, a total benefit per year figure was obtained. This figure was then considered as a uniform income stream. To determine the value of that income stream over the life of the project, the income (benefits) per year was multiplied by the present worth factor (i.e., the value of \$1 received for n years at 4.5 percent interest). This interest rate (the present rate is 4 5/8 percent, but 4 1/2 percent is used for convenience here) is the present rate "based on the average rate of interest payable by the Treasury on interest-bearing marketable securities of the United States . . ." (U.S. Senate, 1962, p. 12)

The total cost estimate was obtained by compiling the project completion reports supplied by the Bureau of Land Management, Moab and Monticello, Utah.

The benefit-cost ratio was computed by dividing the total

benefits (present value) by the total cost.

In estimating the optimum treatment intensity, graphs were constructed that related the silt deposition in the particular land treatment to different intensities of treatment. Graphs were constructed for contour furrows alone in Areas 1 and 4 and for a combination of contour furrows and gully checks in Areas 2 and 3. No studies had been put in areas where there were gully checks alone. However, one corner of Area 2 has four gully checks that have no furrows above them and therefore they were used to obtain an estimate of the benefits of gully checks as the only treatment.

From the graphs, total benefit schedules were constructed. This was done by using the following equation:

$$TB = Px_1(X_1) + Px_2(X_2)$$

where TB = Total benefits

$Px_1$  = The price (value) of an acre-foot of silt

$X_1$  = The cubic feet of silt caught at a particular intensity of treatment

$Px_2$  = The price (value) of an Animal Unit Month of grazing capacity

$X_2$  = The number of Animal Unit Months of grazing at a particular intensity of treatment

This formula is actually a total value product (TVP) function, but can be converted to a total product function by considering the benefits (which in this case are dollars) as physical units valued at one dollar per unit.

On these schedules, the inverse price ratio schedules were

drawn. These two schedules (TB and price ratio) were then used to estimate the optimum intensity of treatment for maximum returns or benefits.

## RESULTS AND DISCUSSION

Since the "original Cisco project" treatments were not designed to yield information suitable for economic analysis, and since later data collections by ecologists and watershed science people were also not designed to yield data suitable for economic analysis, the available information and consequent findings of this study are less than ideal.

Control Measurements

Measurements on untreated plots in each study area showed an average yearly soil loss during the period July 1966 to July 1968 of 696.9 cubic feet per acre (Table 1).

Table 1. Potential soil loss of the Cisco project

Area	Acres of land similar to the study plots	Av. depth of soil lost (ft.)	Cu. ft. of silt lost/acre	Total silt lost (cu. ft.)
1	40	0.0176	766.7	30,668
2	3,540	0.0141	614.2	2,174,268
3	3,264	0.0127	553.2	1,805,645
4	40	0.0212	923.5	36,940
Totals	6,884			4,047,521
Average			696.9	

A further analysis of the entire project with stratification by similar topography, soil, and vegetation types revealed a total of 4,047,521 cubic feet or 93 acre feet per year of soil lost on control areas (Table 1). The "project" was considered as the total acres treated. Therefore, if the treatments were 100 percent effective, 93 acre feet would be retained.

### Silt Retention

#### Contour furrows

Area 3 was the only area where the furrows had failed (i.e., negative silt retention values were recorded). The method of measuring the erosion may partially account for this, for as the National Academy of Sciences-National Research Council (1962) reports:

Such methods (measuring the distance to the ground surface from a fixed frame), however, give only relatively crude measures of a change in surface elevation . . . Furthermore, changes in elevation may be obscured by factors other than erosion such as frost heaving, colloidal swelling of the soil . . . (National Research Council, 1962, p. 181)

Also, many furrows, other than those studied, failed because: (1) the furrows were not on the exact contour (the Holt Model A Trencher had a tendency to pull down-hill), (2) the furrow was not large enough to retain all of the run-off, and (3) the furrows were put across well-established gullies (Figures 4 and 5). Of these explanations, the first is possibly the most important. As Anderson and Swanson (1949) found, furrows not on the exact contour allow water to run to the lowest portion and overflow the dam, which accelerates the erosion process.





Figure 4. Furrow failure due to "overtopping."



Figure 5. Furrow failure due to having been put across a well-established gully.

When contour furrows were the only treatment, soil type was found to influence silt retention characteristics. No relationship was found between the number of furrows per acre and the cubic feet of silt retained per acre on Area 1 (Figure 6).<sup>1</sup> Because of the sandy loam soil, overland flow was minimal. However, the silt that was caught can most likely be traced to three sources. First, the soil bank no doubt acts as a windbreak and allows wind-borne sediment to settle out into the furrow. Secondly, soil can be easily washed from the soil bank into the furrow. Lastly, the furrows provided a low spot into which water could flow that would have otherwise spread over the ground and infiltrated; without the furrow the water would have spread the sediment over a large area. Contour furrows on sandy soils do not seem effective in retaining silt and thus future treatments on similar sites should be evaluated very carefully.

Area 4, however, revealed a strong relationship between the silt retained per acre and the number of furrows per acre (Figure 6). The nature of this soil prevented rapid infiltration and thus allowed overland flow. The furrows intercepted this flow and thus trapped the soil. Because the intensity of treatment (spacing) was not great (close) enough, the intensity at which the maximum silt retention occurred was not observed.

Contour furrows in Area 2, when aided by gully checks, were

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<sup>1</sup>The lack of a relationship is probably due to a lack of data over a wide enough range of treatments in the original project. The lack of a relationship, in this instance, should not be extrapolated beyond this area under the existing treatment.

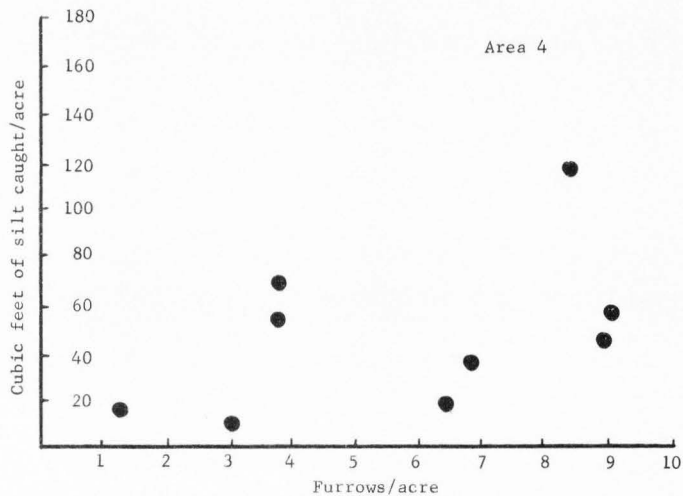
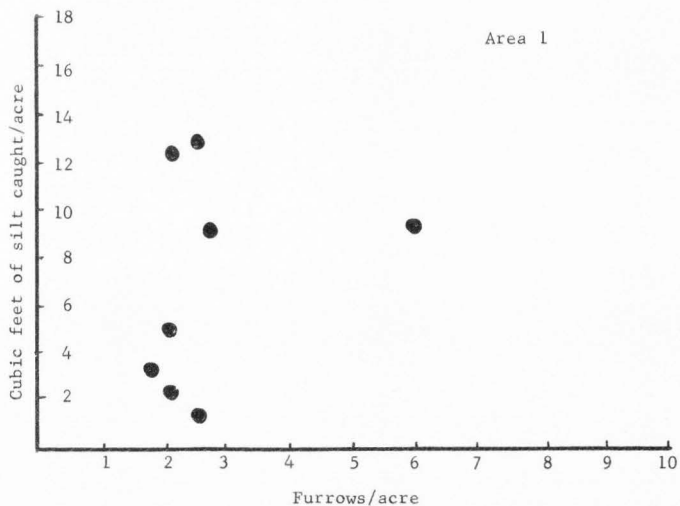


Figure 6. Amount of silt retained in Areas 1 and 4 at different intensities of treatment.

also found to show a definite relationship between the silt caught per acre and the number of furrows per acre. However, the furrows in Area 3 did not show such a relationship (Figure 7). This is most likely explained by the lack of a complete range of treatment intensities which did not allow observation of the relationship. Area 3 had only 3 to 8 furrows per acre whereas Area 2 had 7 to 16 furrows per acre. The number of furrows per acre might have shown a relationship to the cubic feet of silt caught per acre at some unexamined intensity.

#### Gully checks

Areas treated with both gully checks and furrows revealed a definite relationship between the cubic feet of silt caught per acre and the number of gully checks per acre (Figure 7). Because of the limited data, only a segment of the response function in Area 2 was evident. Area 3, however, had a wide enough range to include the entire response function (Figure 7). The estimated maximum silt retention (18 cubic feet per acre) occurred at an estimated intensity of 4 gully checks per acre. Area 2 had more silt retained than Area 3, perhaps because Area 2 is located at the foot of steep slopes that break from the upper pediment layer.

When gully checks were the only treatment, there was also a direct relationship between the cubic feet of silt caught per acre and the intensity of treatment. However, the limited data revealed only a segment of the response function (Figure 8). This graph is only a generalized estimate of silt retention characteristics because: (1) the sample was very small, and (2) the plot locations were not

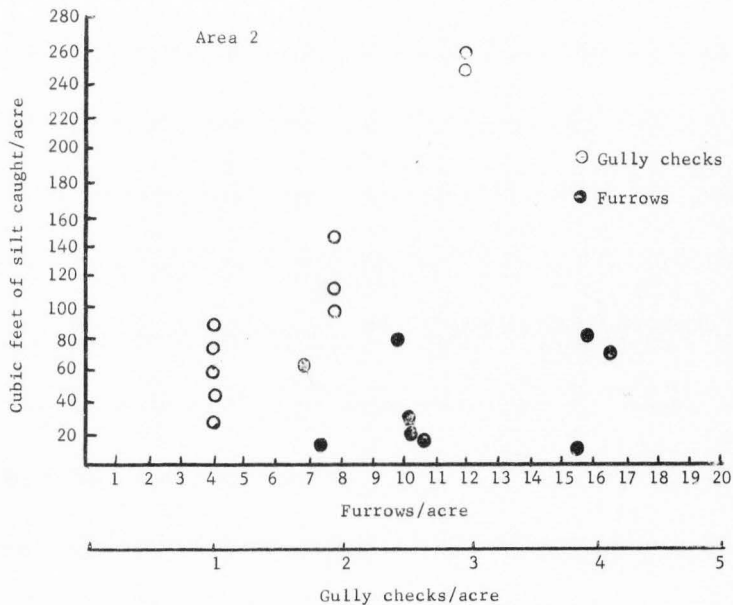


Figure 7. Amount of silt caught per acre in Areas 2 and 3 at different intensities of treatment.

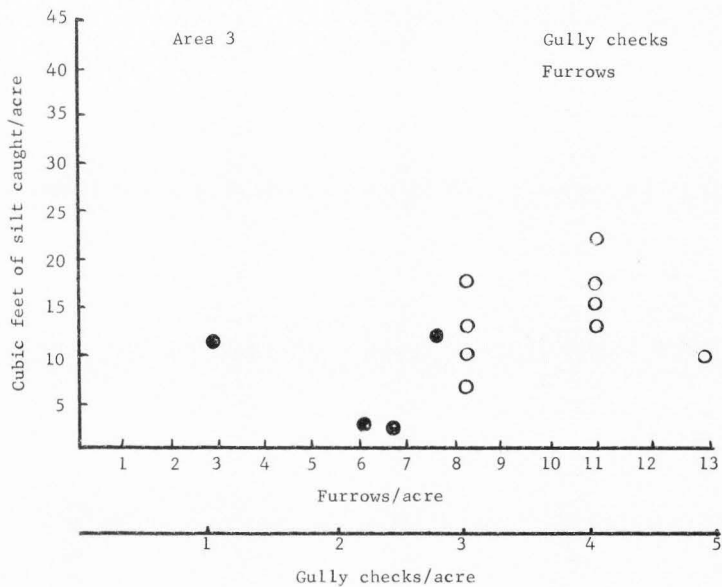


Figure 7. Continued.

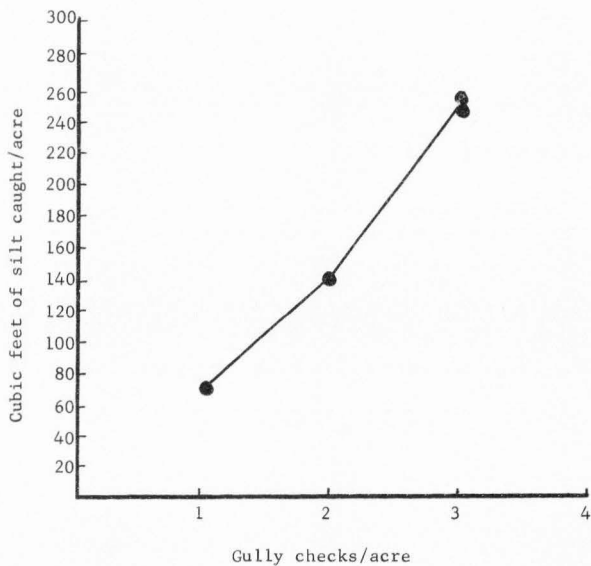


Figure 8. Estimated amount of silt caught in Area 2 by gully checks alone.

characteristic of the other areas where gully checks were the only treatment.

#### Treatments versus controls

Table 2 summarizes the type(s) of treatment, the acres of each treatment, and the average silt retention per acre. The total silt retention of the project was estimated at 462,907 cubic feet or 11 acre-feet. This is approximately 11 percent of the amount (93 acre-feet) the area may produce without treatment. One might expect the treatments to be more effective. However, errors due to measurement method and location of the transects, especially those across the furrows, could in part account for the low figure. Because there was only one transect per furrow and it was located near the center, deposition could occur at a different place (Figure 9). Also, since many of the study furrows were not on the exact contour, the silt could be carried to the lower end, thus escaping measurement.

In addition, the comparison of control measures directly with silt caught in treatments may be misleading. Since the control measurements were unaffected by treatment, overland flow was unchecked. Consequently, the moving water had a great distance to build up its erosive force and move considerable soil. However, when the treatments were installed, this distance was reduced, hence reducing the erosive force of the overland flow. Thus, after treatment, the amount of soil moving on the treated areas is probably much less than the control measures show. That is, the treatments not only catch what soil is moving, but also reduce the amount which does move. Because of possible errors in measuring retention and the reduction in soil



Table 2. Amount of silt caught by contour furrows and gully checks in the four study areas

Area	Type of treatment	Acres treated similar to study area	Average treatment size (ft <sup>2</sup> )	Depth of silt per treatment (in.)	Av. silt caught/treatment (ft <sup>3</sup> )	Av. no. treatments per acre	Total silt caught (ft <sup>3</sup> )
1	Furrows	40	417.4	.07	2.6	2.8	291.2
2	Gully checks	3,540 <sup>a</sup>	273.9 <sup>b</sup>	2.58	65.3	1.7	392,975.4
	Furrows	220	417.4	.12	3.8	10.5	8,778.0
3	Gully checks	2,553	147.4 <sup>b</sup>	.25	4.3	3.5	38,422.7
	Furrows	2,313	417.4	.04	1.2	7.4	20,539.4
4	Furrows	40	417.4	.26	8.8	5.4	1,900.3
TOTAL		8,706					462,907.0

<sup>a</sup>For this study equal acreage was given to each treatment when both appeared together in the same area. For example, 200 acres treated with gully checks and furrows are equal to 200 acres of furrows and 200 acres of gully checks.

<sup>b</sup>In areas similar to Areas 2 and 3 where gully checks are the only treatment, the average silt caught per gully check is the sum of the average silt retention for both furrows and gully checks. It is assumed that the silt caught by the furrows is eventually deposited in the gully checks.



Figure 9. Silt deposition in a furrow that escaped measurement.

movement, the actual amount of silt retained on the area due to treatment may be as great as the amount of soil loss shown by the control measurements (93 acre feet).

#### Vegetation Response

##### Statistical measurements

The number of transects required to estimate the mean species composition within 10 percent of the true mean at the 0.95 confidence interval was much greater than the available data (Table 3). Data were lacking for this type of analysis because the transects were originally used to estimate the total vegetation cover. Fewer transects were required, at the same level of significance, to

Table 3. The number of transects needed to estimate the species composition mean within 10 percent of the true mean ( $P > .05$ ) and the number available for study

Area	Treatment	Transects needed	Transects available for analysis
1	Treated, ungrazed	---	---
	Ungrazed, untreated	---	---
	Furrows	414	53
2	Treated, ungrazed	161	140
	Ungrazed, ungrazed	307	140
	Furrows	725	140
	Gully checks	205	140
3	Treated, ungrazed	749	140
	Ungrazed, ungrazed	112	140
	Furrows	534	140
	Gully checks	310	140
4	Treated, ungrazed	631	140
	Ungrazed, ungrazed	185	140
	Furrows	75	54

estimate total cover than to make the same estimate by species. The dominant species of plant in each area was used to estimate the number of transects to examine.

#### Furrows and gully checks

Crested wheatgrass, which was planted in the treatments, was observed to grow only in the immediate vicinity of the treatments. Because the gully checks accumulated much water, plants were not found in the bottom but only around the rim of the pit (Figure 10). The furrows had most vegetation growing in the furrow bottom or within 2 meters of either edge (Figure 11). There was no noticeable increase in native vegetation around the treatments, but as Wein (1969)



Figure 10. Characteristic growth of vegetation around a gully check.



Figure 11. Characteristic vegetation growth around the contour furrow.

has pointed out, the native vegetation in the immediate vicinity of the treatments is more vigorous. This is most noticeable in the increased seed production and increased foliage.

#### Carrying capacity

The Bureau of Land Management, Moab, Utah, reported the estimated carrying capacity for the Mancos shale soils (Areas 2, 3, and 4) as being between 15 and 25 acres per Animal Unit Month (AUM) and for the sandy loam soils (Area 1) as being between 7 and 10 acres per AUM. Compilation of the transect data for both treated and untreated areas revealed comparable figures (Table 4):

The average carrying capacity of the treated areas decreased 13.8 AUM's under common use as compared to the untreated areas (Table 4). No data were available for Area 1. Area 3, however, was the only area that showed an actual decrease in carrying capacity, but its influence was great enough to show an over-all decrease for the project area. Branson et al. (1966), working in winterfat (Eurotia lanata) areas, also found decreased forage production when land treatments were installed. The soils of the study area may be one factor that accounts for the decreased production. Houston (1965) found that treatments failed to increase soil moisture on clay soils. With no additional soil moisture, there could be little vegetation increase due to treatment. Bennett (1939) stated that on soil types of low moisture holding capacity, contour furrowing appears to have doubtful value. On stiff clays of high salt content, the practice has given poor results; the surface tends to seal over and prevent infiltration. Another factor that may have contributed



Table 4. Net gain in Animal Unit Months on treated and untreated areas

Area	Acres/AUM treated			Acres/AUM untreated			Acres	Net gain in AUMs/area		
	Cattle	Sheep	Common	Cattle	Sheep	Common		Cattle	Sheep	Common
1	--	--	--	--	--	--	40	--	--	--
2	16.2	12.4	11.7	17.1	14.2	13.9	3,460	+11.3	+35.3	+46.8
3	26.6	16.8	16.5	17.1	12.6	12.6	3,264	-68.2	-64.7	-61.2
4	16.3	12.9	12.7	17.4	14.2	14.0	40	- 0.3	+ 0.6	+ 0.6
TOTAL								-56.6	-28.8	-13.8

to the reduced number of AUMs was the physical destruction of the vegetation during the treatment construction. It was difficult not to tear out existing vegetation when constructing the treatments, especially the gully checks. Once the vegetation is destroyed, new vegetation has an extremely hard time becoming established because of the harsh micro-environment (Wein, 1969). There is evidence that the carrying capacity may increase as the treatments fill in. Several of the older gully checks have filled in and become ineffective in holding large amounts of surface water. Consequently, there is a noticeable increase in vegetation (Figure 12).



Figure 12. Characteristic vegetation growth pattern as the gully check fills in with sediment.

The average carrying capacity in the immediate vicinity of the treatments was found to have decreased .0022 AUM per furrow or gully check under common use (Table 5). Area 4 was the only area to show an increase in carrying capacity around the treatments. However, its influence was too small to change the over-all average. No data were available for Area 1. Explanations for the average decrease in carrying capacity around the treatments are no doubt due to the same factors listed before: (1) little increase in soil moisture, (2) the physical destruction of the vegetation during the treatment construction, and (3) the harsh micro-environment.

The carrying capacities are only relative and could easily change from year to year. These figures should be used with caution because of the variability inherent in the analysis. Variation exists because: reliable data from only one year were available for analysis; the vegetation data were gathered following an unusually wet year (1965, which had 13.70 inches of precipitation); and lastly, the carrying capacities would tend toward the maximum figures as reported by the BLM because the Forage Acre Requirement (FAR) used to calculate the carrying capacity was estimated by the BLM in a "wet" year (1965). Also, the estimate of the FAR differs among investigators.

#### Economic Measures

In constructing the benefit-cost ratio for the Cisco project, the benefits were considered first.



Table 5. Net gain in Animal Unit Months in the "zone of influence" of each treatment

Area	Treatment	Acres/AUM treated			Acres/AUM untreated			Acres occ. by 1 treat.	Net gain of AUMs/treat.		
		Cattle	Sheep	Common	Cattle	Sheep	Common		Cattle	Sheep	Common
1	Furrow	7.4	8.9	7.1	--	--	--	--	--	--	--
2	Furrow	18.9	21.9	17.1	17.1	14.2	13.9	.087	-.0005	-.0026	-.0038
	Gully check	21.4	22.6	21.2				.123	-.0015	-.0031	-.0030
3	Furrow	28.0	20.6	20.4				.087	-.0020	-.0027	-.0026
	Gully check	29.0	18.6	17.9	17.1	12.6	12.6	.123	-.0030	-.0032	-.0029
4	Furrow	14.8	11.6	11.5	17.4	14.2	14.0	.087	+.0009	+.0014	+.0014
	Average								-.0012	-.0020	-.0022

### Benefits

The primary benefits were identified as (1) the value of the sediment remaining on the treated area rather than adding to the silt load of the Colorado River, and (2) the increased carrying capacity due to treatment. The greatest benefit was found to be silt retention. The reduced silt load would have its greatest impact in prolonging the life of Lake Powell. A dollar value was placed on the benefit of reduced siltation by expressing it as the cost of sediment being deposited in the lake.

In determining the feasibility of the Glen Canyon Dam, the Bureau of Reclamation used a benefit-cost approach (Bureau of Reclamation, Region 4, 1968). Since a benefit-cost ratio greater than 1:1 indicates a profitable investment, it is logical to use the derived benefits as a figure to express the value of Lake Powell's storage capacity. This approach has been used by Pavelis and Timmons (1960).

The annual benefits from the Glen Canyon project were estimated at \$36,900,000 (USDI Bureau of Reclamation, Region 4, 1968 [Table 6]). The cost of siltation of Lake Powell or the benefits of holding the sediment on the treated area was calculated at \$1.32 per acre foot per year. The annual cost of silt deposition for the entire upper Colorado River drainage was \$112,200 (Table 7).

The total silt retention of the Cisco project was estimated at 462,907 cubic feet or 11 acre feet per year and valued at \$14.01 (Table 8).

In addition, down-stream industries realized an estimated \$5.52 in benefits. This was due to the reduced silt load of the Colorado

Table 6. Estimated annual benefits from Lake Powell

Source of benefit	Value
Irrigation	\$ 4,000,000
Electric power	28,100,000
Fish and wildlife	400,000
Recreation	4,400,000
TOTAL	\$36,900,000

Table 7. The annual cost of silt deposition in Lake Powell

1. Lake Powell total capacity to 3,700 feet	28,040,000 acre feet
2. Annual benefits	\$36,900,000
3. Value/acre foot/year ( $2 \div 1$ )	\$1.32
4. Estimated yearly accumulation of sediment	85,000 acre feet <sup>a</sup>
5. Annual loss of storage capacity (cost of silt deposition/year)	\$112,200

<sup>a</sup>Due to the compaction of the sediment in the lake, the 104,000 acre feet annual inflow is estimated to occupy 85,000 acre feet annually in Lake Powell (Bureau of Reclamation, 1968). Therefore, 85,000 acre feet is used as the "actual" silt load of the Colorado River in this paper.

Table 8. Total annual benefits of silt retention

Area	Treatment	Acres of land similar to study area	Av. silt caught/acre (ft <sup>3</sup> )	Total silt caught (acre-ft.)	Value/A.F sediment (\$)	Total value
1	Furrows	40	7.3	.01	1.32	.01
2	Gully checks	3,540 <sup>a</sup>	111.0 <sup>a</sup>	9.02	1.32	11.91
	Furrows	220	39.9	.20	1.32	.26
3	Gully checks	2,553 <sup>a</sup>	15.1 <sup>a</sup>	.88	1.32	1.16
	Furrows	2,313 <sup>a</sup>	8.9	.47	1.32	.62
4	Furrows	40	47.5	.04	1.32	.05
TOTALS		8,706				14.01

<sup>a</sup>Equal acreage was given to each treatment when both appeared together in the same area. For example, 200 acres treated with gully checks and furrows is equal to 200 acres of furrows and 200 acres of gully checks.

River.

Each year, Atlas Minerals Inc. and Texas Gulf Sulphur Company of Moab, Utah, spend an estimated \$42,430 for water treatment (Table 9). This cost includes pumping expense, chemicals used to settle out the silt, labor and repairs to pumping equipment. Equipment repairs are those in excess of normal (assuming one always pumps clear water). The abrasive action of the silty water damages the equipment more rapidly than if only clear water was being pumped. Since the Cisco project retains approximately 11 acre-feet of silt annually, the silt load of the Colorado River is reduced .013 percent (11 acre-feet/85,000 acre-feet = .013 percent). Therefore, .013 percent of the \$42,431 per year water treatment cost (\$5.52) is saved, thus another primary benefit.

Table 9. The cost to down-stream industries to remove the silt from the Colorado River water

<u>Texas Gulf Sulphur</u>		
1. Annual water treatment cost	\$10,000	
2. Repairs to equipment (additional cost incurred because of excessive wear to pumping equipment)	<u>4,000</u>	
TOTAL		\$14,000
<u>Atlas Minerals</u>		
1. Chemicals	\$10,904.24	
2. Maintenance and repairs (labor)	12,235.71	
3. Maintenance supplies	<u>5,290.22</u>	
TOTAL		<u>\$28,430.17</u>
TOTAL EXPENSE		\$42,430.17

Another benefit of the reduced silt load of the Colorado River or of the silt remaining on the treated area is the reduced total dissolved solid (TDS) content of the river water. Excessive TDS impairs the water quality.

Water quality is a very important component in over-all water value. If the TDS content reaches 1,000/ppm, only the most salt tolerant crops can grow and, hence, agriculture would suffer a considerable loss (Richards et al., 1954). Pincock (1967) studied water quality of the Colorado River in Yuma County, Arizona, and concluded that TDS content would reach approximately 1,233 ppm by the year 2010, but that crop yields attributable to increased salinity will be more than offset by increases in yields due to improved agrotechnical practices. In this study, the benefit of reduced TDS content will therefore be considered negligible.

The second primary benefit of the Cisco project was identified as the value of additional grazing capacity due to treatment. The carrying capacity on the treated areas under common (cattle and sheep) use decreased 13.8 AUMs, 56.6 AUMs under cattle use, and 28.8 AUMs under sheep use (Table 4). The value of this decrease at \$3.50/AUM amounts to \$48.30, \$198.10, and \$100.80, respectively. An Animal Unit Month was valued at \$3.50, the value of an AUM on private land, rather than \$0.33, the value charged in 1968 by the BLM because benefits are those to society as a whole, not to the U. S. Treasury only (Hooper, 1969). Benefits are the dollar value of goods and services as determined from the current market. The total benefits per year for the Cisco project are thus decreased by this amount. By

summing the benefits, the income stream per year for the project was calculated at -\$28.77 for common use, -\$178.57 for cattle, and -\$81.27 for sheep (Table 10).

Table 10. Estimated income stream to project

Source of income	Income (dollars per year)		
	Class of livestock		
	Cattle	Sheep	Common
Silt retention	14.01	14.01	14.01
Benefits to downstream industry	5.52	5.52	5.52
Income from grazing	<u>-198.10</u>	<u>-100.80</u>	<u>-48.30</u>
TOTAL	-178.57	- 81.27	-28.77

The total value of the Cisco project for the life of the project is calculated by multiplying the income per year by the present worth factor of \$1 received for N years (the expected treatment life). Senate Document 97 (U.S. Senate, 1962) outlines the procedure for determining the proper discount rate. The current rate is 4 5/8 percent, but 4 1/2 percent is used here for convenience. The total benefits were calculated at -\$204.20 for common use, -\$507.85 for sheep and -\$1,071.71 for cattle (Table 11). These figures should be viewed as very conservative, however, because as the treatments silt in, flooding damage decreases and vegetation can become established (Figure 12). No data are available to show when or at what rate this occurs. The income stream for the silt benefit was assumed to

Table 11. Total benefits of the Cisco project

Area	Treatment	Av. years since treat. (years)	Est. remain- ing life (years)	Silt retention	Benefits (\$) (income/year)			Total value <sup>b</sup> at 4 1/2 percent		
					Forage <sup>a</sup>			Cattle	Sheep	Common
					Cattle	Sheep	Common			
1	Furrows	4	9	.01	--	--	--	--	--	--
2	Gully checks	8	2	11.91	39.55	123.55	163.80	270.60	758.82	992.76
	Furrows		5	0.26						
3	Gully checks	6	4	1.16	-238.70	-226.45	-214.20	-1,348.63	-1,278.88	-1,209.14
	Furrows		7	0.62						
4	Furrows	4	9	0.05	1.05	2.10	2.10	<u>6.32</u>	<u>12.18</u>	<u>12.18</u>
TOTAL								-1,017.71	- 507.88	- 204.20

<sup>a</sup>Net gain in AUM's (Table 4) times the value of an AUM of grazing capacity (\$3.50).

<sup>b</sup>Total value = benefits (silt retention plus forage) times the proper interest factor for estimating the present value of a uniform income stream received for n years.



remain constant over the life of the treatment, for each year the same average amount of silt will be caught. When less silt is caught because the treatment cannot hold all the runoff, its effective life is lost.

#### Costs

Compilation of data from the Bureau of Land Management project completion reports indicated a total cost of the Cisco project as \$49,107.67. The cost per acre for furrows alone, gully checks alone, and the combination of both was found to average \$5.45, \$7.86, and \$13.31 respectively. These costs are primary costs and include labor, machinery rental, seed, and supervision costs. No secondary, associated, or intangible costs were identified.

#### Benefit-cost ratio

The benefits derived from the Cisco project were negative. Therefore, the benefit-cost ratio is negative. By attempting to reduce the silt load of the Colorado River and increase forage production, the economy as a whole suffered a loss. However, as previously mentioned, the silt retention figure may approximate the control figure (93 acre-feet). If this is correct, the benefits are \$165.19 per year or a total value over the life of the project of \$1,203.16 for cattle use, \$1,438.25 for sheep, and \$1,492.03 for common use with benefit-cost ratios of .02, .03, and .03 respectively. These ratios are considerably less than 1:1, the cutoff point for a profitable investment.

Optimum intensity of treatment

Only Area 4 was used to estimate the optimum intensity. The returns from the other areas were negative; therefore, it would have been better to have left these areas untreated. Every dollar invested in Areas 2 and 3 returned less than a dollar. Area 1 had insufficient data to draw any conclusions.

No optimum intensity could be estimated on Area 4 because there was not a wide enough range of treatment intensity. Figure 13 shows that the total product (TP) never reaches a peak and the slope of the price line (inverse price ratio) is such that it will be tangent to the TP at some point beyond the available data. The TP did not reach a maximum because the intensity of treatment was not great enough for diminishing marginal returns to set in. In other words, each additional unit of input resulted in a greater than one unit increase in output. When this condition occurs, one should add more input factors (more furrows per acre) until the marginal product is equal to the inverse price ratio.

Because all areas were inadequate to estimate the optimum intensity of treatment, two examples are given to illustrate the principle (Figures 14 and 15). Figure 14 has one input such as gully checks or contour furrows and is two dimensional. Figure 15, however, has two inputs--gully checks and contour furrows. As a result, the total product function is a three dimensional surface of response function and the price function is a plane rather than a line. In both cases, the optimum intensity occurs where the inverse price line (plane) is tangent to the total product curve (surface).

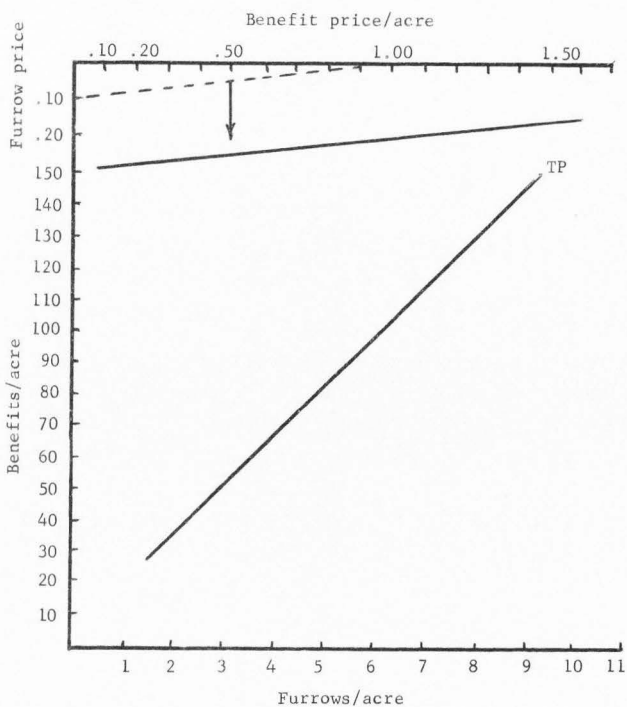


Figure 13. Total product (benefit) and price relationships on Area 4.

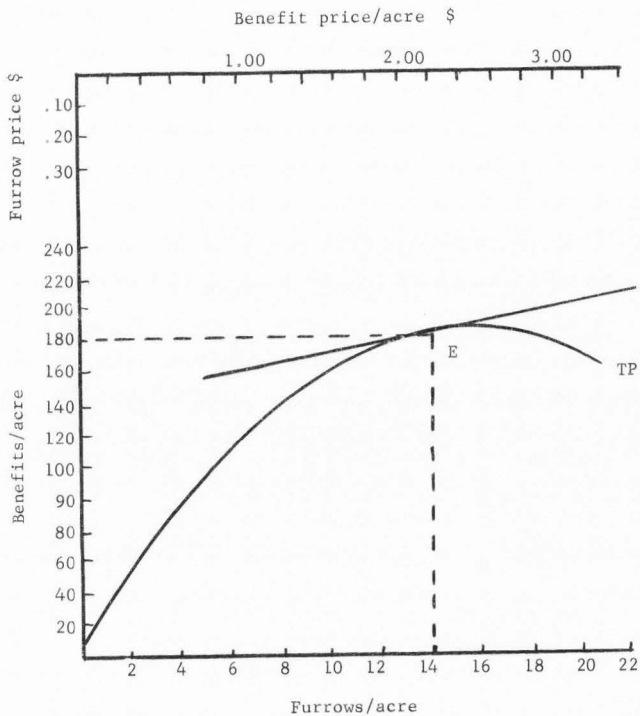


Figure 14. The optimum intensity of treatment for contour furrows.

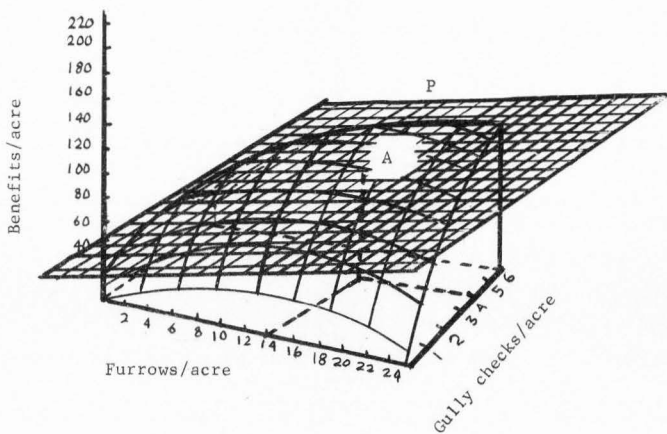


Figure 15. The optimum intensity of treatment for contour furrows and gully checks.

Suppose Area 4 had a total product curve and price ratio, as pictured in Figure 14. Point E represents the point at which the slope of the total product (TP) is equal to the inverse price ratio. This is the point where the last unit of benefits (marginal revenue) is equal to the cost of producing that unit (marginal cost). When marginal revenue equals marginal cost ( $MR = MC$ ), the treatment level is optimum maximum profits.

An example of estimating the optimum intensity of treatment for both gully checks and contour furrows is shown in Figure 15. Figure 15 shows the total product or response surface and the price ratio plane. The price ratio plane P represents the linear cost function of both furrows and gully checks. This plane is tangent to the response surface at point A. Here, the marginal return is equal to the marginal cost, the condition for maximum profit. Therefore, in this example, the optimum intensity of treatment would be 14 furrows/acre and 4 gully checks/acre.

This type of analysis would also lead to obtaining the largest benefit-cost ratio for this particular area. When this is done for all areas, the combined benefit figures will be the maximum amount for the given cost and thus produce the maximum benefit-cost ratio.

A graphical approach is possible when no more than two inputs are used. If, for example, the treated areas had three input factors, say contour furrows, gully checks, and pits, one would have to subject the data to regression analysis to estimate the response or total product function. Then the total product and price function could be equated at the margin.

If more data were available for this study, regression equations could have been derived. With these equations, a more accurate estimate of the optimum intensity could have been made. For example, with only one input factor, the regression equation might have taken the form  $Y = b_1X - b_2X^2$  where Y equals the output or added benefits and X equals the number of furrows per acre. Benefits increase but at a decreasing rate, and the rate may become negative ( $-X^2$ ). To find the optimum intensity of treatment, one would simply take the derivative of the function, set it equal to the inverse price ratio of the input and output factor, and solve for X. With two inputs the equation might have taken the form  $Y = b_1X_1 - b_2X_2 - b_3X_1^2 - b_5X_1X_2$  where Y equals the added benefits,  $X_1$  equals the number of furrows per acre, and  $X_2$  equals the number of gully checks per acre. The interaction, if any, would be measured by  $b_5$ . The partial derivatives would be taken, equated to the price ratio and solved for  $X_1$  and  $X_2$  (Heady and Dillon, 1961).

## SUMMARY AND CONCLUSION

The upper Colorado River drainage system yields approximately 85 thousand acre-feet of silt annually to the Colorado River (Bureau of Reclamation, Region 4, 1968). This silt is reducing the storage capacity of down-stream reservoirs and causing additional operating expense to the industries using the Colorado River water. In an attempt to reduce the silt load, federal land management agencies have installed numerous surface land treatments.

A study was undertaken to measure the silt retention and other benefits of the land treatments and to develop predictive criteria for estimating the optimum intensity of treatment.

The treatments, contour furrows and gully checks, were found to be only about 11 percent effective in retaining all the sediment the area is estimated to be producing. The low effectiveness of treatments was attributed to several factors. Perhaps the most important factor was the difficulty of comparing control measurements with measurements on treated areas. When the treatments were installed, the control measurements no longer represented the potential soil loss. Other factors were: (1) the method of measuring the silt loss or deposition on the control and treated areas contained much variability; (2) many of the contour furrows were not on the exact contour and therefore excessive erosion from overtopping occurred; and (3) the furrows were sometimes put across well established gullies and thus washed out and caused further erosion.



The carrying capacity on the 6,884 acre treated area was found to decrease 13.8 AUMs for common use, 56.6 AUMs for cattle, and 28.8 AUMs for sheep. Only one area had an actual decrease in carrying capacity, but when added with the other areas, there was an over-all decrease. The decrease was attributed to (1) too little soil moisture increase due to treatment, (2) the physical destruction of plants during treatment construction, and (3) the difficulty of vegetation becoming established in the extreme micro-environments of the Cisco area.

The benefit-cost analysis of the Cisco project yielded negative ratios. Possibly, because of the difficulty of measuring silt retention on treated and "control" areas, most of the silt that is capable of moving from the Cisco area is retained by the treatments. If one assumed this to be correct, the benefit cost ratio was still only 0.03, considerably less than 1:1. Therefore, the project, as a whole, was an unprofitable investment. This is most likely due to the low silt retention qualities of the treatments, the low value of an acre foot of sediment, and the lack of increased forage production due to treatment. Because down-stream reservoirs are built large enough to accommodate the silt load of the Colorado River, an acre foot of storage is very inexpensive (\$1.32/acre-foot for the Glen Canyon Dam).

The optimum intensity of treatment (i.e., optimum number of gully checks per acre) could not be estimated because of insufficient data. The treatments were put in at essentially only one intensity. However, the procedure that could be used to determine optimum

intensity is illustrated.

From this pilot study, it is concluded that land treatments on the frail lands in the upper Colorado River drainage are presently unprofitable and that, unless additional benefits can be ascribed to such treatments, no future treatment should be undertaken.

#### SUGGESTIONS FOR FURTHER RESEARCH

One of the major problems throughout this study was the lack of data. If one wanted to make a more accurate study, the experimental design for each phase of research should be planned before the treatments are installed. If such a study was started and the funds were available, the suggestions below would be beneficial.

##### Erosion Measurements

1. Place treatments at several intensities (gully checks/acre or foot of furrows/acre) on each different site.
2. Have several observations at each intensity of treatment so the response function can be estimated by statistical methods and an optimum intensity determined.
3. Install several erosion transects on each furrow so a more accurate picture of the sediment accumulation can be obtained.
4. Install "control" transects between the furrows or gully checks so a more accurate measure of the erosion potential is possible.
5. A catch basin on the main drainage from the study area should be constructed to measure any sediment that the treatments fail to catch.

##### Vegetation Measurements

In this study, only ocular estimates of forage production data

were available for a comparison of treated and untreated areas. No data were available to show forage production at each different intensity of treatment. A more accurate method to estimate benefits due to forage increase would have been a clipping study. This would have required many plots and much time, but a more accurate measure could be made. Also, several observations or plots should be established at each intensity of treatment, and a complete range of intensities should be examined. However, all these suggestions must be viewed in the light of whether the additional information gained will justify the added expense of new studies.

#### Miscellaneous

It would be interesting to search for other ways to handle the siltation problem of major reservoirs. Perhaps large earth-fill dams on major and minor drainages into the Colorado River would cost less and catch more silt than land treatments on the headwater areas of these drainages. Possibly pumping the silt from these reservoirs as they fill and spreading it over the land to be cultivated might be more economical. Pumping of silt may be a possibility at major reservoirs such as Glen Canyon. It may be more economical to pump silt out of the reservoirs than to treat the headwater areas.

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## VITA

Karl A. Simonson

Candidate for the Degree of

Master of Science

Thesis: An Economic Analysis of Contour Furrows and Gully Checks on the Frail Lands of Southeastern Utah

Major Field: Range Science--Resource Economics

## Biographical Information:

Personal Data: Born at Las Vegas, Nevada, March 8, 1945, son of Eric E. and Naomi M. Simonson; reared in Salt Lake County, Utah.

Education: Attended Lincoln Elementary School, Salt Lake County; graduated from Granite High School in 1963; received the Bachelor of Science degree from Utah State University, specializing in range science, in 1968; completed requirements for the Master of Science degree, specializing in range science, at Utah State University in 1970.

Professional Experience: Range aid for the Bureau of Land Management at Price, Utah, and range aid for the U. S. Forest Service at Paris, Idaho, in the summers of 1966 and 1967, respectively.

Professional Organizations: Member of the American Society of Range Management, Soil Conservation Society of America, and Xi Sigma Pi.