EVALUATION OF TRAIL EROSION IN GUADALUPE

MOUNTAINS NATIONAL PARK, TEXAS

by

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CHAPTER 1

INTRODUCTION

Iverson et al. (1981) noted that "Arid lands in the southwestern United States are being used increasingly for recreation...." A prime example of this is one of our Nation's newest National Parks: Guadalupe Mountains National Park located in southwest Texas. The park was created in 1966 by Public Law 89-667 and was formally dedicated in 1972. This 77,500 acre (31,364 hectare) scenic park consists of the tallest peaks in Texas arising out of the vast Chihuahuan Desert. Elevations in the park range from 3650 feet (1112.5 meters) above mean sea level on the salt flats in the southwest, to 8749 feet (2666.6 meters) above mean sea level at the top of Guadalupe Peak.

Situated in the Trans-Pecos region of Texas, the park lies between El Paso, Texas which is 110 miles (177 kilometers) to the west and Carlsbad, New Mexico located 55 miles (88.5 kilometers) to the northeast. Excellent access is provided by Highway 62-180 which runs through the southeastern portion of the park (Figure 1).

Study Area

The mountains are made up of an extensive Permian marine limestone reef which resembles a huge V pointing southward into Texas. Fish and Dvoracek (1980) describe the semi-arid climate of the park as "...extreme and variable." Normally most of the rainfall occurs from May through October, with only about 30% of the annual precipitation occurring during the rest of the year. Precipitation amounts

Fig. 1. Location Map.

range from 13.4 inches (34 centimeters) on the Chihuahuan Desert to 29.9 inches (75.9 centimeters) in the coniferous forest (Fish and Dvoracek, 1980). Another important climatic factor is the wind. Due to the variable terrain of the area, moderate winds of 13-25 miles per hour (5.9-11.4 meters per second) are frequent and strong winds of 26 miles per hour (11.8 meters per second) or greater are not uncommon, especially in winter and spring.

In this park one can find not only vegetation common to the southwestern deserts but also those species normally associated with northern forests. Creosote bush (Larrea tridentata), lechuguilla (Agave lechuguilla), New Mexico agave (Agave neomexicana), yucca (Yucca spp.) and smooth sotol (Dasyllirion leiophyllum) are common in the desert; and ponderosa pine (Pinus ponderosa), Douglas fir (Pseudotsuga menziesii), limber pine (Pinus flexilis) and a few aspens (Populus tremuloides) can be found at the higher elevations. Of special importance are the few species such as big-tooth maple (Acer grandidentatum), choke cherry (Prunus virginiana) and Texas madrone (Arbutus xalapensis) that coexist with species of both lower and higher elevations in the many sheltered canyons found within the park.

Various wildlife species are found within the park including elk (Cervus elaphus), mule deer (Odocoileus hemionus), wild turkey, (Meleagris gallopavo), ringtail (Bassariscus astutus), raccoon (Procyon loter), porcupine (Erethizon dorsatum), kit (Vulpes macrotis) and gray foxes (Urocyon cinereoargenteus), coyote (Canis latrans), bobcat (Felis rufus), black bear (Ursus americanus), cougar (Felis

concolor) and numerous amphibian, reptile and bird species.

Some of the significant features of the park that tend to draw visitors are the 1000 foot cliff, El Capitan; Guadalupe Peak, the highest point in Texas; the relict forest of the bowl region in the high country; McKittrick Canyon with its rare biotic associations; and the extraordinary cross-sectional exposures of the reef.

Trails and Trail Use

Guadalupe Mountains National Park is primarily a hiker's and backpacker's park. Most of the scenic features and attractions can only be reached via the park's more than 63 miles of primitive trails. In a survey conducted during the summer of 1977 it was found that 63% of the park visitors participated in hiking and backpacking related activities (Marlett and Mertes, 1978). Trail use data initiated in 1976 by the National Park Service reflect the fact that Guadalupe Mountains National Park is becoming increasingly known as a haven for trail users. Trail use has increased from 15,986 in 1976 to 23,754 in 1982 (see Figures 2, 3 and 4). This represents a 48% increase in trail use over a period of 7 years. A peak trail use of 36,418 was recorded in 1981, representing a 128% increase over that recorded in 1976. A problem associated with the increasing use of trails is the fact that many of the trails "...were constructed to minimal standards and do not fulfill current recreational trail design criteria" (Fish and Dvoracek, 1980). Since 1980 several new trails have been constructed, and several more miles of trail are presently under construction.

Fig. 2. Backpacker user days in Guadalupe Mountains National Park (National Park Service Monthly Use Reports; submitted to Park Superintendent, from Park Ranger Supervisor, Guadalupe Mountains National Park, 1976-1982).

Fig. 3. Number of dayhikers per year using trails in Guadalupe Mountains National Park (National Park Service Monthly Use Reports; submitted to Park Superintendent, from Park Ranger Supervisor, Guadalupe Mountains National Park, 1976-1982).

Fig. 4. Total trail user days in Guadalupe Mountains National Park (National Park Service Monthly Use Reports; submitted to Park Superintendent, from Park Ranger Supervisor, Guadalupe Mountains National Park, 1976-1982).

National Park Service Policy

The National Park Service has had a preservation mandate since its beginning. However, the organic statute (National Parks Act of 1916) that created the service has created a "double jeopardy" situation for National Park Managers:

The service thus established shall promote and regulate the use of federal areas known as national parks...hereinafter specified by such means and measures as conform to the fundamental purpose of said parks...which purpose is to conserve the scenery and the natural and historic objects and the wild-life therein, and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.

Thus, the National Park Service is charged not only with preserving the natural ecosystem, but also with providing access to visitors including hikers and backpackers. White and Bratton (1980) noted that,

The human influence, whether direct or indirect, is the greatest threat to preservation goals. Direct impacts on ecosystems and species include visitor use of reserves and the roads, trails, and developments that are constructed for them.

The act that established Guadalupe Mountains National Park charges the park service with the responsibility of preserving "...in public ownership an area...possessing outstanding geologic values together with scenic and other natural values of great significance..." (80 Stat. 920). And at the same time, the service is responsible for providing access (namely trails) so that visitors can view some of the outstanding features of the park. That this double responsibility in a unique, fragile environment is a problem is evidenced by the following:

Any development of any degree, including trail reconstruction; will alter the ecosystem to some extent. In addition, any visitor use of the park, including hiker use, will also alter

the ecosystem... Compaction of soil and erosion caused by foot and horse traffic is expected to contribute the largest element of environmental damage, though other factors associated with increasing visitor use, such as littering, and some limited vandalism will also pose some management problems. (National Park Service, 1975).

Trails in Guadalupe Mountains National Park are important as routes of access. At the same time these trails may be contributing a significant negative environmental impact. It is essential that the park service understand the factors which are influencing trail erosion in order to minimize this impact.

CHAPTER 2

REVIEW OF LITERATURE

Erosion has been defined as: "The wearing away and removal of material on the earth's surface" (Foster, 1979). Geologic or normal erosion is a natural process that has been slowly but constantly changing the face of our landscape for millions of years (Hudson, 1971). Foster (1979) estimated that if it weren't for internal uplifting all the mountains and other topography would be removed in a matter of 12 million years or so.

When discussing erosional and depositional processes related to man made trails, the main emphasis in this thesis will be on what has been termed "accelerated erosion": erosion speeded up by man's influence (Hudson, 1971). In order to study the factors influencing trail erosion, familiarization with the agents of erosion will be required.

Erosion Agents

For erosion to occur, there must first be a detachment of the soil particles, and secondly these soil particles must be transported (Satterlund, 1972). Hudson (1971) mentioned that water, wind and biological activity are the three main erosion agents functioning to detach and transport soil particles.

Water because of its great "...dispersive action and transporting power..." is by far the most prevalent erosion agent (Baver, Gardner and Gardner, 1972). These authors also mention that the four main factors which influence water erosion are climate, topography, vegetation and soil.

In arid areas, wind as well as water can be an effective erosion agent (Baver et al., 1972; Hudson, 1971). The three main factors that affect wind erosion are soil, climate and vegetation characteristics. The fact that the Guadalupe Mountains as a whole is classified as a semi-arid environment implies that both water and wind will function as effective erosion agents.

Finally, one other agent that needs to be considered is of a biological nature. Although some living organisms may actually cause erosion, their main effect "...is the disturbance which speeds up the effect of other agents" (Hudson, 1971). This is especially true on trails where man, horses or vehicles can create a disturbance. Ketchledge and Leonard (1970) believed that the greatest disturbances on trails were due to pounding from hiker's boots. They noted that, "The constant cutting-in of boots roughens the surface, thereby creating an easily eroded topography." Bates (1950) noted that the human foot in motion tended to impart a grinding action on the soil surface. Whittaker (1978) noticed that soil loosening as a result of horse travel on trails was evident. These observations imply that the human foot or a horse hoof can detach the soil and make it more susceptible to being transported by wind or water. Trampling on trails can also compact the soil, which in turn leads to increased runoff and therefore also causes accelerated erosion (Burden and Randerson, 1972; Chappell et al., 1971; Kruss and Morgan, 1980).

Previous Research

The first scientific investigations concerning erosion were

carried out between 1877 and 1895 (Hudson, 1971). Patric (1976) mentioned that "Studies of soil erosion and how it is affected by human activity number far into the thousands." A large amount of this past research has been dedicated to the study of the mechanics of erosion and also to the erosional process as it relates to agriculture. This research ultimately resulted in the Universal Soil Loss Equation: an equation which is used to predict soil erosion losses on cropland and also helps the farmer to choose appropriate agricultural practices (Hudson, 1971). Kruss and Morgan (1980) have even used the Universal Soil Loss Equation to estimate the physical carrying capacity of recreation areas. They note, "However, the USLE cannot be used for predicting soil loss on trails and other recreation areas subject to gully (channel) erosion...."

Several erosion studies have been conducted in the national forests. Patric (1976) gives an account of what is known about erosion in the eastern forests. Kidd and Kochenderfer (1973); Kochenderfer (1970); Bethlahmy (1967); Megahan and Kidd (1972) have studied some of the erosion processes and problems related to logging practices in forested areas.

Trail erosion and deterioration have long been recognized as being major problems in many recreation areas. For example Snyder (1966) said, "I place the trail situation as the most critical problem in the John Muir Wilderness." Much of the information regarding trail erosion and deterioration has resulted from studies dealing with vegetation. These studies include the effects of physical disturbance (Babb and Bliss, 1974), paths (Boorman and Fuller, 1977), and trampling (Burden

and Randerson, 1972; Chappell et al., 1971; Dale and Weaver, 1974; Liddle, 1975; Weaver and Dale, 1978) on vegetation. Some important results of the above studies related to trail erosion and deterioration are as follows:

1. Heavy use results in bare ground and soil erosion (Liddle, 1975).
2. Trampling increases soil bulk density (Chappell et al., 1971).
3. Paths running vertically up and down slopes tend to exhibit the greatest amount of soil erosion (Burden and Randerson, 1972).
4. Soil compaction, erosion and path width are positively related to the amount of trampling (Burden and Randerson, 1972; Boorman and Fuller, 1977; Weaver and Dale, 1978).
5. Trails in meadows are wider than those in forests (Dale and Weaver, 1974).
6. Trail erosion depends upon various factors such as climate, vegetation type, soil type, slope and type of user (Weaver and Dale, 1978).

Compared to the extensive literature available concerning erosion mechanics, agriculture and forest erosion, studies dealing directly with the erosion processes on recreational trails have been somewhat limited. Helgath (1974) mentioned that Meinecke in 1929 was one of the first to actually study trail deterioration in some manner. However, only recently (since approximately 1970) have several studies been conducted that have actually described methods to study and quantify trail erosion. In some of these studies the causes of trail erosion and deterioration have also been discussed.

Ketchledge and Leonard (1970) noted that, "Trails, wherever they may be, are sure to become eroded with use...." These authors had encountered severe trail erosion in the Adirondack High Country and decided to set up a trail transect system to quantify erosional losses.

Their transects consisted of a taut tape stretched between two permanent reference points (trees in this case) on either side of the trail. They then measured a series of verticals from the taut tape to the trail surface with a flexible tape and plumb-bob. After periodically measuring the transects for 4 years it was found that:

1. The trails were losing an average of 1 inch (2.54 centimeters) of soil a year,
2. Most of the erosion losses occurred during the summer months, and
3. Trail erosion isn't just a problem of downward cutting, but also one of lateral erosion at the same rate.

In a later report, Leonard and Whitney (1977) discussed and described in detail the method established by Ketchledge and Leonard (1970). They also mentioned that information from a trail transect system "...could be used directly in the design and location of new trails, and the reconstruction of existing trails."

As part of their evaluation of impacts of backcountry use near Lake Louise in Banff National Park, Canada, Trottier and Scotter (1973) studied trail conditions using a weighted rating system, measured trail erosion at various sites and then gave reasons for a given trail condition. Sixteen transects were established on both damaged and undamaged portions of the various trails. From these transects (a meter tape stretched between two reference points on either side of the trail) depth measurements were made at the beginning and end of the hiking season to determine the rate of erosion. At each transect location vegetation, slope, aspect of the trail, parent material, soil characteristics and moisture regime were noted. The authors reported that, "The primary value of the transect study is that it provides a base measure-

ment whereby rates of future trail erosion can be monitored and appropriate measures applied where erosion becomes a problem." Next most of the trails were evaluated as to their condition. Each trail was categorized as to trail width, trail depth, moisture regime, stones and roots, and walkability. A rating scale was established and the degrees of impairment for each category for a given trail were totaled to obtain a single trail condition number which could be compared with other trails. Finally they discussed for each particular trail, "Causes of trail damage and the effects of trail use on unique features...." They found that "Erosion by runoff water, groundwater seepage or a high water table during the spring is the most influential factor affecting trail condition in the Lake Louise area." Their recommendation was for increased maintenance to alleviate the problems of severely deteriorating trails.

In another study Trottier and Scotter (1975) used basically the same techniques mentioned in the above study, as part of their evaluation of backcountry impacts in the Egypt Block of Banff National Park. In an attempt to measure trail erosion or wear, trail transects were again used; however, in order to achieve greater accuracy some changes were made. Metal rods were placed in sunken pipe receptacles on either side of the trail. A string from which depth measurements could be made was strung between the two rods. The transects were established on fairly uniform sites in order to determine if use intensity influenced the amount of tread wear. The transects were set up not only to determine the amount of trail wear after one season of use, but also to determine long term changes in trail conditions. As in the

earlier study, all trails were evaluated as to their condition, and this condition was expressed as a single number representing different degrees of impairment within several different categories. The authors also noted the most chronic trail problems and discussed not only maintenance procedures to rectify the problems but also possible reroutes where maintenance was not the answer. After one season of use, the authors found no measureable changes in the trail treads at the various transect sites. They concluded that on well-drained sites visitor use was not causing excessive erosion. Finally the authors "...assumed then that poor trail conditions observed throughout the study area are the direct result of inadequate trail design, location and lack of maintenance" and "...not an indication of overuse of trails."

Helgath (1975) used a cross sectional area loss index to quantify erosional losses from trails in the Selway-Bitterroot Wilderness Area. In order to obtain the area loss index, a taut tape was first stretched across the trail at the original soil level height. Then vertical measurements were taken from this tape to the trail tread at 3.94 inch (10 centimeter) intervals. The transects were measured once and various physical characteristics of the environment were noted at each site.

The study indicated that vegetative habitat, landform, and trail slope are factors importantly related to trail erosion. Aspect, elevation, use, and parent material have variable relations and should be further examined. (Helgath, 1975).

The end result of this study was the mapping of biophysical units, each depicting trail deterioration, soils, vegetation and landform.

These units were to be used in choosing future trail locations.

In a study conducted in the mountains of Sweden, Bryan (1977) examined the effects of different soil properties on the degradation of hiking trails. In this study two soil pits were dug at each sample site: one pit was dug on the trail and the other was dug as close as possible outside the trail corridor [generally 6.5 feet (2.0 meters) from the trail]. The author found that the amount of use was an important factor influencing the widespread degradation of trails in the study area. He noted that heavy use led to profile truncation by horizon removal; therefore, with sufficient use, damage could occur at any location. It was found that at lower levels of use soil characteristics, vegetation and topography were closely related to the amount of degradation. The author finally noted,

In physical terms damage is insignificant and presents neither direct or indirect hazard. It is however, aesthetically significant for degraded, eroding trails are a clear indication of human impact on the natural landscape. (Bryan, 1977).

Coleman (1977) discussed three methods for measuring footpath deterioration: first by using aerial photographs to determine path width, secondly by measuring "...a series of verticals from a taut cord or wire, stretched between two fixed points, to the surface of the path." and thirdly by using a rigid steel bar with holes drilled in it, placed across the trail to obtain the verticals mentioned above.

Rinehart, Hardy and Rosenau (1978) felt that studies using direct, on-the-ground measurements weren't the most reliable way to document trail conditions. In their study they used "...close-range, oblique stereo photographs taken with the aid of a pivoting parallel-plane camera mount ... to monitor trail conditions." The authors noted that

some problems with their technique were vegetation obscuring the view, and "...the availability of photogrammetric expertise and equipment...."

Bratton, Hickler and Graves (1979) surveyed all the maintained trails in Great Smoky Mountains National Park in order to locate problem erosion areas and to study the relationship between environmental factors and trail erosion in different areas of the park. Width, depth and a variety of types of erosion were measured on each sample section of the different trails. A somewhat subjective erosion classification for each sample site was obtained from this information. Due to individual variations in the estimates of the various types of erosion, they also developed an "objective" computer erosion classification. "The...computer erosion classification sorts the reported width, depth, and percentage erosion for a trail sample and assigns a value of 1 through 5, where 5 is the poorest value...." They then correlated these erosion classes with various factors such as slope, forest type, geology, and etc. It was found that erosion was not due to just one factor, but that in Great Smoky Mountains National Park erosion was highly related to vegetation, elevation, slope of the trail, and section of the park. Trail slope was determined to be the most important factor related to trail erosion.

In a study of the effects of horse traffic on trails in Rocky Mountains National Park, Summer (1980) used a variety of morphometric techniques and a qualitative survey of biophysical characteristics to evaluate geomorphic changes on trails that cross different landforms. She found that horse traffic was not the only factor influencing trail erosion and that, "Impacts are a function of biophysical characteris-

tics of the terrain interacting with traffic in varying degrees." ¹⁹ She found that parent material, trail slope and side slope, soil texture and organic content, rockiness, stoniness, vegetation, and drainage were the most important factors determining the amount of trail erosion at any given site.

Fish, Brothers and Lewis (1981) in a preliminary study conducted in Guadalupe Mountains National Park used a cable stretched between two permanent steel stakes both on and off trails to quantify trail erosion. A ground profile was established by measuring the vertical ground to cable distance at 34 positions along the cable. The authors found that not only were erosion losses greater at certain sites on major trails and roads, but depositional gains were also greater on some on-trail sites when compared to control (off-trail) transects.

Cole (1983) described techniques for assessing and monitoring trail conditions. In reviewing techniques that had been used in the past, the author noted that the techniques for assessing trail conditions could be grouped into three categories: "...replicable measurements of a small sample of trail segments, rapid surveys of a large sample of trail segments, and complete censuses of trail problems or conditions." Replicable measurements are made on permanently located sample points; therefore, changes at these points over time can be determined with subsequent measurements. Rapid survey techniques allow the observer to study more trail segments; however, the author noted that only those observations easily and rapidly made could be used. This technique usually involves systematically sampling portions of the trail and collecting "...data on both trail

conditions and characteristics of environment, trail design, and use."

The author noted that this technique is especially valuable when evaluating the gross condition of a given trail. The final technique discussed by the author was the census technique. This involves studying an entire trail system. The trail system is divided into individual segments and the condition of each segment is described. This technique is useful in assessing overall trail condition, and the end result is often complete maps of the condition of individual trails within the system, which may aid managers in planning and budgeting. Cole also noted a variation of the census technique which is to only census trail problems.

Elsewhere in the same paper, Cole (1983) describes a study conducted on two trails in the Selway-Bitterroot Wilderness in Montana. In this study all three of the techniques discussed above were applied: twelve trail transects (ten systematically located every mile along Big Creek trail, and two purposively located on deeply incised portions of the trail) were established, a rapid survey [from which data concerning the trail were obtained every 0.2 mile (0.32 kilometer)] was conducted, and problem segments [those that were incised more than 10 inches (25.4 centimeters) or were excessively muddy] were censused. The trail transects consisted of a tape stretched between two permanent stakes from which the cross sectional area below the tape could be calculated. The transects were then remeasured and a cross-sectional area change over time was obtained. Of the ten systematically placed transects, six indicated a net gain of soil over a two year period. Both of the purposively located transects exhibited a

net soil loss over a period of one year illustrating the severity of trail deterioration in some locations. From the rapid survey it was found that width and depth values were similar to those found elsewhere in the Northern Rocky Mountains, and on 65 percent of the trail segments none of the defined trail problems were noted. However, some of the trail segments exhibited severe problems. From the rapid survey data it was also found that trails in certain habitat types were in worse shape than others. Trails on steeper slopes had greater maximum depths; and, heavier use resulted in greater trail widths. The results of the census technique showed that only one percent of the trails were considered to be problem areas.

The author concluded that the Big Creek trail system was generally in good condition; however, there were some segments with severe problems.

The probability that a given segment will deteriorate is a function of the trail's immediate environment, its design and maintenance, and the amount and type of use the trail receives.

Cole noted that most problems could be avoided with proper location, and if a given location couldn't be avoided, engineering (proper design, water bars, and bridges) would help to alleviate the problems.

Cole (1981) and Kidd and Kochenderfer (1973) as well as some other authors (Helgath, 1975; Summer, 1980; Bratton et al., 1979; and Weaver and Dale, 1978) have found that trail erosion is not due to just a single factor (use, for example) but is a complex interaction between various factors such as slope, elevation, aspect, vegetation and use. Burden and Randerson (1972) sum up this interaction between use and the environmental factors by stating that, "The effect of a given

intensity of recreation pressure is dependent upon the nature of the physical and biotic environment...." A knowledge of the various factors influencing trail erosion and deterioration will provide the recreation manager with facts "...on locating, maintaining, and rehabilitating trails and for predicting possible implications of increasing...use" (Summer, 1980).

CHAPTER 3

JUSTIFICATION AND OBJECTIVES

This study is a continuation of research that was part of a comprehensive analysis to examine the impacts of recreational developments in Guadalupe Mountains National Park. It is hoped that by expanding the erosion aspects of the study the following objectives can be met:

1. To determine if on-trail erosion is significantly greater than that occurring off of the trail.
2. To determine what factors are contributing to the erosional/depositional process. This will be done by comparing the following factors (environmental and human impact) with erosion losses and depositional gains both on and off the trail:
 - a. vegetative community
 - b. soil and parent material
 - c. landform
 - d. site aspect
 - e. trail grade and side slope steepness
 - f. environmental angle
 - g. elevation
 - h. trail width
 - i. visitor use
3. To identify management strategies that will be helpful in reducing future negative impacts on or of existing trails and will also be helpful in locating new trails that will have the least negative impact on the surrounding environment.

The study area is unique due to the fact that it has a semi-arid climate. Although trail erosion studies have been conducted, they have all been in more mesic environments.

In previous studies, erosion on a particular section of trail has generally only been compared with other sections of the trail. In this study, trail erosion will also be compared with erosion occurring off the trail.

Several authors at the conclusion of their studies have indicated the need for additional research:

1. Burden and Randerson (1972) note that the need for investigations relating trampling pressure to environmental effects "...cannot be overemphasized as a preliminary to the formulation of management policies for any...area that is to be used for recreation."
2. Trottier and Scotter (1973) indicate that, "It is of great value to know exactly how fast trails are deteriorating."
3. Helgath (1975) called for trail erosion studies in areas other than the highly erosive Idaho Batholith.
4. Iverson et al. (1981) mentioned that it is desirable to document, and analyze environmental impacts resulting from recreational use.

CHAPTER 4

METHODOLOGY

Trail Erosion Measurements

In 1979, 29 erosion transects were located throughout Guadalupe Mountains National Park, both on and off trails, to include a variety of different environmental conditions (Fish and Dvoracek, 1980). In order to document change over time, measurements on these transects were obtained twice yearly from May 1979 to December 1982. At the onset of the present study (May, 1981), 13 additional transects were established. Some were established to monitor newly constructed trails and some were to be used as controls for already established on-trail transects (Note that two transects established in 1979 and one in 1981 were destroyed by construction activities or vandalism.).

A transect consisted of two steel stakes driven into the ground approximately 20 feet (6 meters) apart. The stakes were then notched to provide a permanent reference point for attachment of a cable (profile line). Since these stakes were to be permanent they were hidden with rock cairns to prevent disturbance by park visitors. A cable 0.12 inches (3 millimeters) in diameter with a hook on one end and a turnbuckle on the other was subsequently stretched between the two stakes. From this cable a ground profile (from which over a period of time erosional gains and losses can be determined) was obtained. This profile was established by measuring the vertical cable to ground distance to the nearest 1/8 inch (3 millimeters) at 34 permanently marked stations along the cable (13 on a smaller cable that was used on narrow sites). The vertical distances mentioned above were measured

either with a tri-square or a meter stick depending upon the height of the profile line from the ground surface. The distance recorded was that distance from the station on the profile line to the first surface encountered by the measuring instrument. These surfaces included soil, rocks, sticks, grass clumps, etc. Unique hits, those other than the soil surface, were recorded as such. The positions (stations) along the cable were 6 inches (15.2 centimeters) apart (Plates 1 and 2).

Two dependent variables (net and absolute area change) obtained from the transect measurements were used to study the erosion process in the park. The following discussion presents the source of the variables and their interpretation.

Each time a transect was measured, the vertical cable to soil surface distance was recorded from the 34 integrally spaced stations along the cable. From these measurements a ground profile as well as the area under the profile line from station 1 to station 34 was obtained (Figure 5). Area was calculated with the following formula:

$$A = \left[\frac{V_1 + V_2}{2} + \frac{V_2 + V_3}{2} + \dots + \frac{V_n + V_{n+1}}{2} \right] \times D$$

where: A = area under the profile line in square centimeters,

V_n = vertical cable to ground distance measurements in centimeters,

D = interval between stations on the horizontal cable (15.24 centimeters).

Area under the profile line could not be used to compare erosion between the various transects initially because factors such as original trail design and initial elevation of the cable above the

Plate 1. Typical trail corridor erosion transect.

Plate 2. Erosion transect measurement technique.

Area under the cable equals 10,375.392 sq cm

<u>STATION</u>	<u>VERTICAL CABLE TO GROUND DISTANCE (cm)</u>
1	22.2
2	27.3
3	27.9
4	27.3
5	23.5
6	18.7
7	23.8
8	27.3
9	27.9
10	24.1
11	27.9
12	32.4
13	34.9
14	31.8
15	28.9
16	23.5
17	21.6
18	19.0
19	18.7
20	16.2
21	18.4
22	17.5
23	17.1
24	18.1
25	18.7
26	16.5
27	13.6
28	14.9
29	14.6
30	13.3
31	10.8
32	8.6
33	3.5
34	2.8

Fig. 5. Example transect profile - initial measurements.

ground surface would be influencing the recorded area. However, changes in the area under the profile line over time could be used to compare erosion/deposition between the various transect sites. Additionally the amount of erosion/deposition that occurred at a transect site over a given time interval, could be compared with another similar interval of time. For example, after six months the transect in Figure 5 was remeasured and the area under the profile line from station 1 to station 34 was again determined (Figure 6).

The fact that $10,946.892 \text{ cm}^2$ (2nd measurement) was greater than $10,375.392 \text{ cm}^2$ (1st measurement) indicates that for the six month time interval a net change of 571.5 cm^2 of soil material was lost from underneath the profile line. However, more soil movement than just the loss of 571.5 cm^2 had occurred at the transect site. Some points on the transect line lost soil while other points gained soil material (Figure 7). In essence for the six month time interval in question, both erosion and deposition occurred at this transect site. The net area change (-571.5 cm^2) was the difference between the erosion area and the deposition area. The negative sign indicates that more erosion than deposition occurred at this transect for the six month time interval. The absolute area change (1879.9 cm^2) was the sum of the erosion area loss and the deposition area gain and is an indication of how much actual soil movement (both erosion and deposition) occurred at the transect site after six months.

Any time a transect was measured (initial or later measurements), the net and absolute area changes of soil material from that point in time to any later measuring date could be determined. For example, if

Area under the cable equals 10,946.892 sq cm

STATION

VERTICAL CABLE TO
GROUND DISTANCE (cm)

1	31.8
2	27.6
3	28.2
4	27.6
5	21.3
6	10.5
7	13.6
8	17.5
9	24.4
10	30.5
11	31.1
12	31.4
13	30.5
14	30.8
15	29.5
16	28.6
17	27.6
18	27.0
19	24.8
20	24.4
21	23.5
22	21.3
23	22.5
24	22.2
25	21.9
26	20.3
27	19.7
28	15.2
29	10.2
30	13.0
31	11.4
32	8.6
33	4.1
34	3.2

Fig. 6. Example transect profile - subsequent measurements.

Fig. 7. Example transect - summary of soil movement after six months.

a transect was measured on the following dates: May 3, 1981; November 3, 1981; May 3, 1982, net and absolute area changes of soil material that occurred underneath the profile line could be determined for 3 different time intervals:

1. May 3, 1981 to November 3, 1981 (six month interval)
2. November 3, 1981 to May 3, 1982 (six month interval)
3. May 3, 1981 to May 3, 1982 (twelve month interval)

Photographs were taken at the transects during each monitoring date to further document the changes occurring over time.

Environmental Factors Measurements

Vegetative Community

Vegetative communities for various areas within the park have been described by Bunting (1978), and Fish and Dvoracek (1980). This information was used on a macro-scale to place each transect within a major community type. Field observations were utilized to describe the specific vegetation growing in the immediate vicinity of each transect.

Soil

The soil units of various areas within the park have been mapped (Fish and Dvoracek, 1980). This information along with field observations was used to characterize the soils at each transect location.

Parent Materials

Various areas within the park have been characterized as to their geologic parent materials, and these areas have been mapped (Fish and Dvoracek, 1980). Another geologic map (Goolsby, 1974) shows the major geologic parent material boundaries within the park. Information from

the above sources and field observations were used to determine the specific parent materials at each transect location.

Landform

The landform that each transect was situated on was recorded utilizing field observations and aerial photographs. Each site was also classified as to its position on the landform. For example a particular transect might have been on the upper slope of a bajada as opposed to the lower slope.

Site Aspect

The general aspect of the landform at each transect site was determined using a compass. Two other compass readings for the on-trail transects included the up-trail grade direction and the side slope aspect if present.

Trail Grade and Side Slope Steepness

Up-trail slope gradients were obtained with an Abney Level mounted on a tripod. The slope at each transect was measured from a point 25 feet (7.62 meters) down trail from the transect to a point 25 feet (7.62 meters) up-trail from the transect. Side slope gradients were obtained for the on-trail transects with an Abney Level. For the off-trail transects slope of the landform was also obtained with the Abney Level.

Environmental Angle

Environmental angle was calculated as the difference between the trail aspect and the aspect of the side slope. Environmental angles

could range from 0 to 90 degrees (Bratton et al., 1979).

Elevation

Each transect was located on a U.S. Geological Survey 7.5 minute series (topographic) map. Elevation in feet above mean sea level was recorded for each transect site from the map.

Human Impact Factors Measurements

Trail Width

Trail widths were obtained from the erosion transect. When measuring the trail profile the stations that intersected the trail edges were noted. The distance between these stations indicated the width of the trail.

Visitor Use

Information regarding the number of users passing through each trail erosion transect were obtained from National Park Service, Monthly Use Reports. These reports indicated the number of people using various portions of all trails for each month of the year.

Data Analysis

Trail Erosion Measurements

The data obtained from the transects were converted to metric units (cm) and punched onto computer cards for easy storage and analysis. A program was written to calculate ground elevation at each position (station) along the cable, for each monitoring date, and to calculate differences in elevation between different monitoring dates.

The program also calculated net and absolute area changes underneath the profile line between the different monitoring dates.

To achieve the objectives of this study, net and absolute area changes from 9 different time intervals were analyzed (Table 1). The specific analyses used will be discussed below. Henceforth, the time intervals will be referred to by a number from 1 to 9.

On-trail Versus Off-trail Erosion

Paired t-tests (Wright, 1979) and split plot in time analysis of variance (Steel and Torrie, 1980) were the statistical techniques utilized to compare on-trail erosion/deposition with that occurring off the trail. Hypotheses tested were whether the on-trail net and absolute area changes were significantly different from those changes occurring off the trail.

Environmental Factors

The qualitative factors were vegetative community, soil, parent material, landform, and site aspect. Because the factors were not easily quantified, split plot in time analysis of variance was used to test for any differences in the treatment (the different vegetative communities, soils, parent materials, landforms, or site aspects) net and absolute area changes for each factor. This testing allowed for decisions to be made as to whether different vegetative communities, soil types, parent materials, landforms, and site aspects were significantly affecting the erosion process on or off the trail.

In order to determine what quantitative environmental factors were influencing the erosion process on the trail, correlation analysis

TABLE 1
Time Intervals

Monitoring Dates	Time Interval	n
May, June, July of 1979 to February of 1980	1	25
February of 1980 to July, August of 1980	2	25
July, August of 1980 to November of 1980	3	25
November of 1980 to May of 1981	4	28
May of 1981 to Oct., Nov. of 1981	5	22
Oct., Nov. of 1981 to May, June of 1982	6	35
May, June of 1982 to Nov., Dec. of 1982	7	39
May, June, July of 1979 to Nov., Dec. of 1982	8	25
Oct., Nov. of 1981 to Nov., Dec. of 1982	9	34

of these factors (slope, side slope, environmental angle and elevation) with the measured erosional losses and depositional gains (net and absolute area changes) was performed (Johnson, 1976). The slope of the landform and elevation at the off-trail transect sites were also correlated with net and absolute area changes to determine if either of the two factors significantly affected the natural erosion process.

Human Impact Factors

Correlation analysis was also utilized to determine if trail width or visitor use were significantly influencing the on-trail erosion process. Both trail width and visitor use were correlated with net and absolute area changes. This was an attempt to discern if wider trails were subject to more erosion, and if visitor use intensities were significantly affecting the erosion process.

CHAPTER 5

RESULTS AND DISCUSSION

On-trail Versus Off-trail Erosion

As mentioned previously most studies have dealt only with the on-trail erosion process. The first question to be answered in this research was whether the changes occurring on the trail were significantly different from those occurring off the trail. In other words did the presence of man made trails necessarily result in "accelerated erosion" or were the changes simply analogous to the geologic or normal erosion process occurring off the trail.

Although some paired transects were established in 1979 it was not until 1981 that enough were established to allow for statistical comparison of the two transect categories. A pair consisted of one transect located within the trail corridor (on-trail transect) and another transect in the immediate vicinity but outside the trail corridor (off-trail transect). The net and absolute area changes from the last two six month time intervals (time intervals 6 and 7) were analyzed using a split plot in time randomized block design analysis of variance (Steel and Torrie, 1980). Blocks were used to account for the heterogeneity of the environment. The paired transects were assumed to be homogenous subgroups (same location, vegetation, soils, etc.) and the two treatments (trail corridor vs. off-trail) were applied to each block split over time. The null hypotheses tested were as follows:

H_{0_1} : On-trail net area means = off-trail net area means.

H_{0_2} : On-trail absolute area means = off-trail absolute area means.

The results of the analyses are presented in Table 2. From these results, both the above hypotheses were accepted. Also net area changes were significantly different for the two time intervals, while the absolute area changes for the two time intervals were not significantly different.

Again utilizing the paired transects a paired t-test was used to test the above hypotheses for time interval 9, which was the one year interval that included both time intervals 6 and 7. For net area changes, $t=0.3279$ which lead to acceptance of H_{01} , and for absolute area changes, $t=3.351$ which lead to rejection of H_{02} at the 0.05 level of significance.

In order to gain more information and to utilize all the available data, an assumption was made that the different areas in the park were "fairly homogeneous." It was felt that this was an acceptable assumption because in the randomized block split plot analyses the blocks were not a significant source of variation in the data. Accepting the above assumption allows for including in the analyses the data from all the transects (both on and off the trail) established in and since 1979. It was felt that the possible benefits gained from the extra information more than offset any efficiency that was lost going from a randomized block design to a completely randomized design. One benefit was that the on and off-trail erosion process could be better characterized from 3.5 years of data as opposed to one year. Based upon the above assumption a split plot in time completely randomized design was used to test time intervals 1-7 for the null hypotheses previously mentioned. The results of these analyses are presented in Table 3. H_{01} was accepted and H_{02} was rejected. The on and off-trail

TABLE 2

F Values from Split Plot in Time Randomized Block Analysis of Variance
for On-trail vs. Off-trail Paired Transects -- Time Intervals 6 and 7*

Source of Variation	F Value	Prob. > F
<u>Net Area Means</u>		
blocks	0.940	0.5382
treatment	0.060	0.8101
time interval	10.990	0.0090
time interval x treatment	0.020	0.8979
<hr/>		
<u>Absolute Area Means</u>		
blocks	1.090	0.4504
treatment	2.360	0.1591
time interval	0.001	0.9785
time interval x treatment	0.050	0.8262

* See Appendix A for complete analysis of variance.

TABLE 3

F Values from Split Plot in Time Completely Randomized Analysis of Variance for On-trail vs. Off-trail Transects -- Time Intervals 1 through 7*

Source of Variation	F Value	Prob. > F
<u>Net Area Means</u>		
treatment	0.06	0.8034
time interval	7.61	0.0001
time interval x treatment	0.76	0.5995
<u>Absolute Area Means</u>		
treatment	4.38	0.0433
time interval	1.61	0.1486
time interval x treatment	0.60	0.7282

* See Appendix B for complete analysis of variance.

transects were experiencing similar net area changes. The trail corridor transects (on-trail transects) were experiencing significantly greater absolute area changes than the off-trail transects. For both the on and off-trail transects the net area changes experienced were also significantly different for the various time intervals (Table 4).

Table 4

Duncan's Multiple Range Test of Time Interval Net Area Changes

Time Interval	Mean Net Area Change (cm ²)*	
3	114.63	a
6	49.55	ab
1	47.92	ab
4	-70.79	bc
5	-101.32	c
2	-143.53	c
7	-249.55	d

* Means within a column followed by the same letter are not significantly (P<.05) different.

Both the on and off-trail transects exhibited similar absolute area changes for the various time intervals.

Figures 8 and 9 graphically present the net and absolute area means by time intervals for on-trail versus off-trail transects used in the statistical analyses from which the following may be concluded:

1. There are no significant differences between the amounts of erosion or deposition (net area changes) experienced by the on and off-trail transects.
2. The various six month time intervals experienced significantly different net area changes.

Fig. 8. A comparison of off-trail and on-trail net area changes.

Fig. 9. A comparison of off-trail and on-trail absolute area changes.

3. The on-trail transects experienced significantly greater amounts of soil movement (absolute area changes) than the off-trail transects.
4. There were no significant differences in absolute area changes for the various time intervals.

During four of the seven time intervals both the on and off-trail transects experienced similar amounts of erosion or deposition (Figure 8). For five of the seven time intervals the difference in net area change between the on and off-trail transects was less than 88 cm^2 (13.6 in^2). Even though for time intervals 4 and 5 the off-trail transects experienced depositional gains, and the on-trail transects experienced erosion losses a parallel trend was noted. During time interval 5 the off-trail transects showed a lessened amount of deposition than was experienced during time interval 4. Likewise the on-trail transects exhibited a similar trend during time interval 5 as they experienced more erosion than was seen in time interval 4. Some factor was favoring greater amounts of erosion and lessened amounts of deposition during time interval 5. Similar trends in the data were not noted for absolute area changes experienced by the two transect categories. This along with the fact that the mean absolute area changes were always greater on the trail suggests that the presence of a trail corridor does substantially alter the soil movement process.

Factors Influencing the Erosion/Deposition Process

Environmental Factors

Qualitative Environmental Factors

Those environmental factors not easily quantified were vegetation, soil, parent material, landform and site aspect. For each factor,

three or more categories were established and transects were classified into the category which "best fit" the transect location. In the statistical analysis the individual categories were characterized as treatments. In order to determine if differences between these categories were resulting in significantly different net or absolute area changes the following null hypotheses were tested:

Ho_1 : Mean net area changes between categories of a qualitative environmental factor are equal.

Ho_2 : Mean absolute area changes between categories of a qualitative environmental factor are equal.

For example, Ho_1 for the environmental factor soil would be as follows: mean net area changes for all soil types are equal. A split plot in time randomized block design was used to test for any differences in the treatment (the different vegetation communities, soils, parent materials, landforms, and site aspects) net and absolute area changes for each factor. Blocks were used to account for the variation in the data that was due to whether a transect was located on or off the trail.

Transects were located in 16 different vegetation communities (Appendix C). Although past studies have found that vegetation types are one of the most important factors influencing erosion both on and off the trail, it would appear that although the vegetation in Guadalupe Mountains National Park is very heterogeneous it is not causing significant differences in the amount of erosion and deposition that is occurring (Table 5).

Transects were located on 11 different soil types (Appendix D).

TABLE 5

F Values from Split Plot in Time Randomized Block Analysis of Variance for the Qualitative

Environmental Factors

Source of Variation	F Values/Prob. > F				
	Vegetative Community	Soil	Parent Material	Landform	Site Aspect
<u>Net Area Means</u>					
blocks	1.40 0.2705	2.20 0.1819	0.02 0.9022	2.19 0.1990	1.07 0.4089
treatment	0.91 0.5788	0.72 0.6936	0.78 0.6060	0.49 0.8448	3.08 0.2453
time interval	12.55 0.0036	4.67 0.0414	6.52 0.0191	4.44 0.0463	7.64 0.0130
time interval x treatment	1.13 0.2846	0.86 0.7085	1.69 0.0358	0.80 0.8152	1.09 0.3700
<hr/>					
<u>Absolute Area Means</u>					
blocks	2.30 0.1678	3.52 0.1026	1.51 0.2735	7.23 0.0434	1.60 0.3333
treatment	0.98 0.5318	1.22 0.4068	1.30 0.3896	1.27 0.4199	0.38 0.7250

Table 5 cont.

Source of Variation	F Values/Prob. > F				
	Vegetative Community	Soil	Parent Material	Landform	Site Aspect
<u>Absolute Area Means</u>					
time interval	0.37	0.50	1.87	0.11	1.18
	0.8724	0.7931	0.2324	0.9924	0.4224
time interval x treatment	0.94	0.56	1.00	0.54	0.58
	0.6000	0.9843	0.4651	0.9937	0.8591

The results indicate acceptance of both null hypotheses (Table 5).

Although the soil categories were not significantly different for net area change, it is interesting to note that soil associations with similar series members experienced similar amounts of net area change (Table 6). This suggests that soil may be useful in predicting the relative amount of erosion or deposition a site is likely to experience.

Six different parent materials were noted at the transect locations (Appendix E). The results indicate acceptance of both null hypotheses (Table 5). However, there was a significant time interval x treatment interaction for the mean net area changes. This indicates that for one or more of the study time intervals, different parent materials did result in significantly different amounts of erosion or deposition: this short term effect was negated in the long run.

Transects in this study were located on 11 different landforms (Appendix F). The results again indicate the acceptability of both null hypotheses (Table 5). Apparently different landscape positions were not causing significantly different net or absolute area changes. Also within the various landform categories the on-trail and off-trail transects were experiencing significantly different amounts of absolute area change.

It was felt that the aspect of the site was the most important aspect measurement recorded, because it gave a good indication of the overall exposure of a given transect position. Site exposures are often good indicators of moisture conditions in semi-arid environments. Three exposure categories included all of the transects (Appendix G). Again the results indicate acceptance of the null hypotheses, and there-

TABLE 6

Duncan's Multiple Range Test of Soil Net Area Changes

Soil	Mean Net Area Change*
Nickel-Canutio Complex (NCB)	14.46 a
Canutio-Nickel Complex (CND)	-5.32 a
Sombordoro-Rock Outcrop Complex (ORD)	-34.04 a
Remunda-Ruidoso-Pena Complex (RRB)	-34.72 a
Holloman-Canutio-Nickel Complex (HCD)	-44.43 a
Deama-Rock Outcrop-Flume Complex (DRD)	-50.85 a
Penasco Soils (PAB)	-57.56 a
Pena-Penasco-Haplustolls Association (PPB)	-66.67 a
Pena-Penasco Complex (PND)	-68.34 a
Flume-Rock Outcrop Complex (FRF)	-99.57 a
Flume-Rock Outcrop Complex (FRD)	-114.09 a

* Means within a column followed by the same letter are not significantly ($P < .05$) different.

fore different exposures within the park were not causing significantly different net and absolute area changes.

For net area means, significant F values were found for the time interval main effect in all the qualitative environmental factors (Table 5). This finding further supports the earlier finding, that the various six month time intervals experienced significantly different net area changes.

Quantitative Environmental Factors

Tables 7 and 8 present the results from the correlation analysis of the four quantifiable environmental factors with the trail corridor transect net and absolute area changes. The results suggest that these factors have no appreciable effects on the net and absolute area changes trail corridor transects experience. These findings were mostly contrary to what previous researchers have reported.

Transects were located on landscape positions with immediately up trail grades ranging from 1.74% to 17.63%. Previous studies (Helgath, 1975; Bratton et al., 1979) have found that trails with steeper slopes tend to experience greater soil losses. Although in Guadalupe Mountains National Park, trail slopes up to 17.63% are not resulting in linearly differing amounts of erosion or deposition, it is suspected that trail grades steeper than 17.63% might cause greater amounts of erosion within the trail corridor.

In this study, side slopes ranged from 0.00% (those sites with no attributable side slope influence) to 55.43%. Those sites having an attributable side slope may receive water flow from more than one

TABLE 7

Correlation Analysis Between the Quantifiable Environmental Factors
and On-Trail Net Area Changes*

Time Interval	Factor			
	Trail Slope	Side Slope	Environmental Angle	Elevation
1	-0.06075	0.25438	0.45047	-0.23134
	0.8169	0.3245	0.2627	0.3716
2	0.06283	-0.21625	-0.83663	0.03757
	0.8107	0.4045	0.0096	0.8862
3	-0.36559	-0.10352	0.01637	-0.05973
	0.1490	0.6926	0.9693	0.8199
4	0.21980	0.16979	-0.24266	0.08185
	0.3518	0.4742	0.5293	0.7315
5	-0.00170	0.22435	0.56313	0.18869
	0.9950	0.4035	0.2446	0.4840
6	-0.20114	-0.20136	-0.42141	-0.21059
	0.3820	0.3814	0.2252	0.3595
7	-0.14960	0.05687	0.50348	0.01053
	0.4957	0.7966	0.1144	0.9620
8	-0.08373	0.17781	-0.19197	0.06334
	0.7493	0.4948	0.6488	0.8092

* Correlation Coefficients/Prob>r Under Ho: $\rho=0$

TABLE 8

Correlation Analysis Between the Quantifiable Environmental Factors
and On-trail Absolute Area Changes*

Time Interval	Factor			
	Trail Slope	Side Slope	Environmental Angle	Elevation
1	-0.01200 0.9635	0.01725 0.9476	0.26279 0.5295	-0.16363 0.5303
2	-0.05463 0.8350	0.20846 0.4220	0.67247 0.0677	-0.16306 0.5318
3	-0.29730 0.2465	-0.13161 0.6146	0.28164 0.4992	-0.15766 0.5456
4	0.00891 0.9703	0.02363 0.9212	0.09354 0.8108	-0.13507 0.5702
5	0.00161 0.9953	-0.31826 0.2296	0.47765 0.3380	-0.40991 0.1148
6	0.14171 0.5400	0.04916 0.8324	0.02145 0.9531	-0.00254 0.9913
7	0.10781 0.6244	-0.11466 0.6024	-0.57587 0.0637	-0.12912 0.5571
8	-0.13955 0.5932	-0.36427 0.1506	0.35797 0.3839	-0.22203 0.3917

* Correlation Coefficients/Prob>r Under Ho: $\rho=0$

direction. This author initially believed like Fish et al. (1981) that the presence of trail corridors might act to interrupt normal water flow and act as soil catchment areas. If this is indeed true, it would be expected that trails with steep side slopes could receive greater amounts of deposited soil. Helgath (1975) found that steep side slopes in certain landforms were more important than trail grade in causing trail deterioration and erosion. She found that in these landforms, the presence of the trail interrupted subsurface drainage on the side slope, and subsequently water flowed perpendicularly over the trail carrying the soil making up the trail surface with it. It would seem in Guadalupe Mountains National Park both erosion and deposition are occurring on trails, depending more on microsite topographic factors rather than side slope steepness.

Environmental angle is a factor that is closely related to trail slope and side slope steepness (it is the angular relationship between the side slope aspect and the trail aspect). Environmental angles in this study ranged from 23 to 73 degrees. Bratton et al. (1979) found the environmental angle of the trail to be significantly negatively correlated with erosion. In other words, trails that cross steep slopes at a 90 degree angle experience smaller amounts of erosion than those trails that traverse straight up a steep slope. The fact that environmental angle was not found to be significantly correlated with net or absolute area changes in the present study may be due to the fact that those trails with similar trail and side slope aspects were on less steep grades. Time interval 2 appears to be an exception to the overall findings and indicates a significant negative correlation

between net area change and environmental angle did exist during a short time period.

Topographic relief within the park is quite pronounced. Trail corridor transects were located on sites ranging in elevation from 3830 feet (1167.3 meters) to 7950 feet (2423.2 meters). In mountainous areas such as the Guadalupe, topographic discontinuity tends to result in increased precipitation due to orographic uplift with the higher elevations usually receiving more moisture from both rainfall and snowfall. Bratton et al. (1979), and Ketchledge and Leonard (1970) found that trails in higher elevation ecosystems are often more susceptible to erosion. The results of the present study suggest that the higher elevations of the park are not experiencing significantly greater amounts of erosion than the lower elevation areas.

For the off-trail transects two quantifiable environmental factors (slope of the landform and elevation) were correlated with net and absolute area changes (Table 9). This analysis was done to determine if different elevations and/or landform slopes were affecting the erosion process outside the trail corridor.

Off-trail transects were located on sites with slopes ranging from 2.27% to 55.43% and at elevations ranging from 3825 feet (1165.9 meters) to 7847 feet (2391.8 meters). Neither the landform slope or the elevation were found to be significantly correlated with net area changes.

Although not correlated for any of the six month time intervals, both landform slope and elevation were significantly positively correlated with the 3.5 year (time interval 8) absolute area changes.

TABLE 9

Correlation Analysis Between Quantifiable Environmental Factors and
Off-trail Net and Absolute Area Changes*

Time Interval	Net Area Changes		Absolute Area Changes	
	Factor		Factor	
	Landform Slope	Elevation	Landform Slope	Elevation
1	-0.35226 0.3921	-0.17176 0.6842	-0.07972 0.8511	0.44665 0.2672
2	-0.30581 0.4613	0.05930 0.8891	-0.04623 0.9134	0.26846 0.5203
3	0.42611 0.2925	0.24108 0.5652	0.16651 0.6935	0.58614 0.1268
4	-0.36750 0.3705	-0.11647 0.7836	-0.10738 0.8002	0.44754 0.2662
5	-0.76556 0.0760	-0.56893 0.2387	-0.26611 0.6103	0.10701 0.8401
6	-0.27446 0.3423	-0.21754 0.4550	-0.28464 0.3240	-0.16239 0.5791
7	0.16694 0.5366	-0.08417 0.7566	-0.18557 0.4914	0.00707 0.9793
8	-0.68077 0.0631	-0.26433 0.5270	0.76221 0.0279	0.76008 0.0286

* Correlation Coefficients/Prob>r Under Ho: $\rho=0$

Apparently steeper undisturbed slopes experienced greater amounts of soil movement over time; however, this increased movement did not result in greater net erosion losses or depositional gains. The fact that elevation and absolute area changes were positively correlated was not unexpected. One would expect the higher elevation sites to receive more moisture in the form of rainfall or snowfall and thus more soil movement could be expected. The greater absolute area changes on the steeper slopes and at the higher elevations were a result of the natural erosion process and not accelerated erosion.

Human Impact Factors

Trail width and visitor use (quantifiable human impact factors) were correlated with net and absolute area changes. Table 10 presents the results of the correlation analyses.

Routes of access for day use visitors and backpackers include old jeep roads and narrower newly constructed trails. The widths of these "trails" ranged from a minimum of 1.3 feet (0.4 meters) to a maximum of 11.9 feet (3.6 meters). These varying trail widths are more a function of original trail design rather than different visitor use intensities.

Since most of the trails in Guadalupe Mountains National Park are completely devoid of vegetation it might be expected that the wider the trail the greater the erosion losses would be; however, no significant correlations between trail width and net area changes were noted. Although trail width and absolute area changes were significantly positively correlated for only one of the six month intervals, they were positively correlated for the 3.5 year interval.

TABLE 10

Correlation Analysis of the Quantifiable Human Impact Factors with
On-trail Net and Absolute Area Changes*

Time Interval	Net Area Changes		Absolute Area Changes	
	Factor		Factor	
	Trail Width	Visitor Use	Trail Width	Visitor Use
1	0.13740	0.07262	0.50060	0.25112
	0.5990	0.7818	0.0407	0.3309
2	0.07389	-0.28588	0.26797	0.17143
	0.7781	0.2660	0.2984	0.5106
3	-0.23378	-0.09779	0.11646	0.16513
	0.3665	0.7089	0.6562	0.5265
4	0.24013	0.30835	-0.21380	-0.19631
	0.3078	0.1859	0.4949	0.4068
5	-0.32173	-0.53823	0.46202	0.20430
	0.2243	0.0315	0.0716	0.4479
6	0.08541	-0.03774	0.13238	-0.03754
	0.7128	0.8710	0.5673	0.8717
7	-0.06170	-0.53169	0.10239	0.61727
	0.7797	0.0090	0.6420	0.0017
8	-0.21119	-0.44918	0.50619	0.54329
	0.4158	0.0705	0.0381	0.0242

* Correlation Coefficients/Prob>r Under Ho: $\rho=0$

This indicates that wider trails did exhibit greater amounts of soil movement over longer periods of time.

Previous studies (Cole, 1983; Weaver and Dale, 1978) have found that different trail widths within a trail system are due to varying amounts of visitor use. In order to test this relationship for trails in Guadalupe Mountains National Park the changes in trail width over time were compared with the visitor use for that same period of time. For all trail sites tested no significant correlations were found between visitor use and changes in trail width.

As noted earlier the number of visitors using individual trails was obtained from National Park Service records of unmanned trail registers. One problem with this type of trail register is its accuracy in depicting the actual number of people who use a trail. Does everyone who uses a trail, register his or her presence? Specific studies of compliance rates for unmanned trail registers have yielded different answers. In 1961 and 1962 Wenger and Gregerson (1964) reported a compliance rate of 74 percent for the Three Sisters and Mountain Lakes Wilderness areas in Oregon. Lucas (1975) reported a compliance rate of only 28 percent in the Selway-Bitterroot Wilderness in Idaho. The main problem then is the fact that the visitor use information probably under-estimates the true visitor use in the park.

Visitor use in the park was extremely variable ranging from a high of 11,930 people per year for the entry station of the McKittrick Canyon Trail to less than 25 people a year using the old jeep road trail in the northwest corner of the park. As mentioned earlier, researchers initially believed visitor use was the main factor influ-

encing trail erosion (Ketchledge and Leonard, 1970). Later studies reported visitor use to be less important as a factor influencing erosion on trails (Helgath, 1975). The results of the present study indicate that visitor use may be having some effect on net area changes on the trail during particular time intervals. Visitor use was significantly negatively correlated with net area changes for two of the six month time intervals. The correlation between visitor use and net area changes for the 3.5 year interval (time interval 8) was approaching significance at the 0.05 level. No positive conclusion can be drawn but it is expected that the result of increasing visitor use over time will be greater amounts of erosion on the trail. Although only significantly positively correlated for one of the six month time intervals, visitor use was significantly positively correlated with absolute area changes for the 3.5 year interval (time interval 8).

The results from both the net and absolute area correlations indicate that amount of visitor use on a trail plays a role in the erosion/deposition process. In Guadalupe Mountains National Park, visitors are a major factor of disturbance on the trails. The movement of their feet while walking constantly rearranges soil and rocks and creates a dynamic situation of soil movement that usually but not always results in erosion.

One trail site in McKittrick Canyon consistently lost soil material over time. In fact, at this particular location a net loss of 3223 cm (499.6 in²) was recorded from underneath the transect profile line after 3.5 years (time interval 8). This author felt that the

excessive erosion on this portion of the trail was due to a combination of several factors. The site in question received the highest numbers of visitor use for any transect site within the park. It was also on a relatively steep slope for a site located on the Pena-Penasco-Haplustolls Soil Association (PPB soils). Pena-Penasco-Haplustolls soils are usually found on relatively level slopes (Fish and Dvoracek, 1980). At this highly erosive site the trail cuts up the bank of McKittrick Canyon stream creating a steep slope situation in a PPB soil. Fish and Dvoracek (1980) mentioned that this soil isn't readily erodible; however, they also noted that with increased use, increased erosion could occur on the more sloping areas (Plate 3, see page 71).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The soil erosion/deposition process in Guadalupe Mountains National Park is dependent upon complex biotic-abiotic relationships which are not easily explained. The presence of man made corridors (trails) does not appear to be resulting in accelerated erosion (net soil losses) in Guadalupe Mountains National Park. In fact, the net erosion losses or deposition gains over time on the trails closely approximated the natural net erosion and deposition occurring off the trail. This finding was not anticipated, because most previous studies have stressed the problems of rutting, entrenchment, and overall deterioration associated with trails. With one exception, no other study compared, within a specific location, those processes occurring both on and off the trail. Bryan (1977) noted few differences between on-trail and off-trail soil profiles. Anyone observing differences between a trail corridor and the surrounding terrain might initially assume that more net erosion losses were occurring on the trail because its surface is often lower than the surrounding ground surface. It is my belief that, at least in Guadalupe Mountains National Park, the trail surface which is indeed often times lower is a result of initial trail construction and not accelerated erosion. Any subsequent erosion losses or deposition gains occurring after construction are similar to those that occur naturally off the trail. Most of the studies that have reported severe trail erosion, were conducted in considerably more mesic environments. In these areas the presence of the man made

corridors are possibly resulting in greater amounts of accelerated erosion.

The transect sites experienced both erosion and deposition of soil material. There were seven sequential six month time intervals: for some of these intervals deposition of soil at the transect site was predominant, and for others erosion of soil was the net change. The fact that net depositional gains of soil were prevalent during certain time intervals was not too unusual. Indeed some deposition was not unexpected, because it is essentially an integral component of the long term erosion process. The transects in this study acted as "gates" through which soil passed. Not only was soil eroding from the transect sites, it was also eroding from other sites. The soil eroding from the surrounding up-slope terrain passed through the transect profile ("gate"): if this transect was measured as this soil was passing through, deposition would have been recorded as the net change for that time interval. For one time interval (2 years), Cole (1983) noted an increase in soil material at some on-trail transect sites in the Selway-Bitterroot Wilderness of Idaho. After one summer season, Trottier and Scotter (1973) noted soil deposition at some on-trail transects in Banff National Park, Canada. The erosive forces of nature are working to remove the Guadalupe Mountains from the skyline; however, this extremely slow, long term process at any given site is made up of both erosion losses and deposition gains. In the long run, the erosion losses are greater than the deposition gains, which ultimately results in a net loss of soil material at any given site.

Since net area changes were significantly different for the

various time intervals, some factor that also changes over time must be responsible for the differences. Visitor use although changing with time probably is not the answer, because both the on and off-trail transects experienced statistically similar amounts of erosion and deposition for the various time intervals. Although sufficient data were not available for testing, I believe that precipitation type, pattern, duration, frequency and intensity were having effects on the amounts of erosion/deposition occurring in the park.

Barring a major disturbance, a given transect in the park tended to experience similar amounts of relative soil movement (absolute area changes) for all the different six month time intervals. Though not experiencing greater net soil losses, most of the trails within the park experienced greater absolute area changes than the off-trail sites. The trails due to their lack of vegetative cover combined with increased disturbance were relatively more unstable. Here, the movement of rocks and soil material was less impeded than on the off-trail sites.

What are the ramifications of the increased amount of soil movement (absolute area change) on the trail? To answer this question, another question must be answered first. Why was the rate of soil erosion (net area change) on the trail similar to that off the trail? Both Bryan (1977) and Eckert et al. (1979) indicate that rocky, gravelly, or cobbly soils tend to be resistant to soil erosion. The rockiness of the soil helps to negate the effects of compaction and also lends the trails resistance to entrainment (Bryan, 1977). The on-trail soils in Guadalupe Mountains National Park are very rocky:

this coupled with a semi-arid climate probably accounts for the similar erosion rates on and off the trail. Bryan (1977) also noted that at some point in time with sufficiently intense visitor use pressures, soil coherence is destroyed. Then the role of rocks in the soil changes and their presence on the trail may lead to increased erosion-al losses. It is not likely that increased soil movement on the trails in Guadalupe Mountains National Park will ever result in the rock component of the soil being removed. The rock component is not confined to the top layer, but is present throughout the soil profile. Bryan (1977) notes that in the Grovelsjon District of Sweden, it may take 25 years of sufficient use pressure, after initial trail construction, for severe trail degradation to occur. In Guadalupe Mountains National Park due to the semi-arid environment and the extreme rockiness of the soil, one can only postulate that this process will take a very long time if indeed it ever occurs.

The qualitative environmental factors (vegetative community, soil, parent material, landform, and site aspect) were not found to be significantly affecting the amounts of erosion (net or absolute area changes) occurring on or off the trail.

The quantitative environmental factors (trail slope, side slope, environmental angle, and elevation) were not found to significantly affect the on-trail erosion process. For the off-trail sites, steeper landform slopes and higher elevations did experience greater absolute area changes. This does not necessarily mean that trails should not be constructed on these sites. Because as was noted, trails on steeper slopes and at higher elevations did not consistently experience

greater amounts of soil movement. Evidently the presence of the trail corridor disrupted the natural erosion process and caused slope steepness and elevation to become less important as factors influencing soil movement.

Most of the results suggest that the erosion rate is fairly uniform for the whole park. Although the park possesses tremendous ecological heterogeneity and a wide range of environmental gradients, the park as a whole is acting as a homogeneous unit with respect to the amounts of erosion/deposition that are occurring. Although factors such as topography, vegetation, and soils have been shown in other studies to influence the amounts of erosion an area experiences, it was difficult to detect any differences in the amounts of erosion occurring that were a result of any of the environmental factors studied at this location.

Of all the site factors, the human impact factors (trail width and visitor use) were found to have the greatest effects on the soil erosion/deposition process. Wider trails experienced greater amounts of soil movement, indicating their greater instability. They were not experiencing greater amounts of net erosion; however, much more soil was moving (absolute area change) and in the future this may result in increased net erosion losses.

Visitor use was found to have some variable effect on the amounts of erosion or deposition (net area changes) a trail experienced. The trail user is one of the major soil and rock movers in the park. Generally an increase in the human disturbance factor tended to result in increased erosion. However, at some sites the opposite was true and

increased use was accompanied by increased deposition. Visitor use was significantly positively correlated with absolute area changes. The visitation data indicate that the visitor is a significant contributor to biological erosion. These results differ from those reported on more mesic environments. Both Helgath (1975) and Bratton et al. (1979) note that poorly located (i.e., on steep slopes), poorly designed, low use trails experienced greater amounts of erosion than well designed heavily used trails. The results of these studies were probably due to water as an erosive force playing a more important role in a mesic environment. The findings of this study reveal that in a semi-arid environment, visitor use impacts have a greater effect on the erosion/deposition process. There seems to be a precipitation threshold below which this biological disturbance takes its place along with and possibly becoming more important than climate, vegetation and topography in influencing the erosion/deposition process. Call, Barker and McKell (1981) note,

...that constant, repetitious use of an area constitutes an environmental impact supplementary to such other effects as climate and topography. This environmental impact may be amplified in relatively dry regions of the West.

Although most of the correlations noted in the results were not statistically significant, an examination of the variation in the correlation coefficients provides additional insight into the complexity of the erosion/deposition process. As mentioned previously, measurements from the transects collected every six months (short term interval) led to the conclusion that the net area changes were significantly different from time interval to time interval with both

erosion and deposition occurring. While this information is important for complete understanding of the dynamics of the erosion process, studying the shorter term six month intervals alone may lead to confusion concerning the true long term effects of a given factor on the erosion/deposition process. The long term effects of a given factor on the erosion/deposition process may only be ascertained after an extended period of time. In this study, the 3.5 year interval correlations may be more valuable than those from the shorter six month time intervals for determining the true effects of the site factors on the erosion/deposition process. In essence, long term studies including both short term and long term measurements may be the only means of accurately identifying and explaining both the on and off trail erosion process. Short term studies (one time measurements, ending after 6 months, etc.) alone probably do not give a true picture of what is happening, and in fact may be extremely misleading.

In summary, achieving the first two objectives of this study led to the following conclusions:

1. Both erosion losses and deposition gains are occurring at the transect sites over time. The net erosion/deposition changes on the trail closely approximate those changes occurring naturally off the trail. However, trail sites are relatively more unstable and do experience greater amounts of soil movement (absolute area change) than do the off-trail sites.

2. In general, differences in the environmental site factors (vegetative community, soil, parent material, landform, site aspect, trail grade, side slope steepness, environmental angle, and elevation)

are not significantly affecting the on-trail erosion process. However, heavily used trails located on sloping areas of Pena-Penasco-Fluventic Haplustolls Association soils (PPB soils) are likely to be highly erosive sites. For the off-trail sites, steeper landform slopes and higher elevations tend to result in increased amounts of soil movement (absolute area change). The human impact factors (trail width, and visitor use) are contributing to the erosion/deposition process. Although not necessarily resulting in greater amounts of net erosion, wider trails are resulting in increased amounts of soil movement (absolute area change). Increased visitor use on trails also results in increased soil movement (absolute area change). The more heavily used trails will usually, but not always, experience greater amounts of erosion than trails receiving less use.

In light of the above conclusions, management considerations (Objective 3) are presented in the following section.

Recommendations

The fact that on-trail erosion losses are not significantly different from those occurring naturally off the trail might provide the impetus for a policy of building modern well designed trails to provide access to previously inaccessible areas of the park, to provide new routes of access to already accessible areas, and to replace old trails and jeep roads. Before new trails are constructed, three factors should be given additional consideration: (1) visual impact of trail scars, (2) visitor perceptions concerning trails, and (3) trail corridor recovery rates.

Due to underlying geological material, and the lack of sufficient screening vegetation, trail scars are a readily visible feature of the Guadalupe Mountains landscape (Plate 4). Many visitors come to wilderness areas to leave the urban setting with its undesirable aesthetic conditions behind; and, for these visitors, multiple trail scars may detract from the aesthetic qualities they are seeking (Bainbridge, 1974). To what extent is the wilderness experience degraded for the backpacker who climbs to the high country only to find that along the way and at his destination, many panoramic views are disrupted to some extent by trail scars and other developments? What are the feelings of the people who travel through the park on Highway 62/180 and have their dramatic vistas marred to some degree by numerous trail scars?

A study by Lucas (1980) on wilderness areas in Montana, Idaho and California as well as another study by Marlett and Mertes (1978) at Guadalupe Mountains National Park suggest that from the visitor viewpoint it might be best to maintain the status quo of the present trail system in Guadalupe Mountains National Park. Lucas (1980) found that most visitors favored low standard trails rather than modern high standard well designed trails. "About 70 percent of the visitors to each area (80 percent in the Desolation) feel it would be desirable to leave some areas without trails" (Lucas, 1980). Lucas basically found that visitors want wilderness areas to be minimally developed. Marlett and Mertes (1978) found that only 5% of the visitors to Guadalupe Mountains National Park wanted improved trails while 56% stated "...a liking for the primitive aspect of the park and a dislike for

Plate 3. Highly erosive trail site in McKittrick Canyon.

Plate 4. View of Smith Springs trail scar.

possible development of the park." It seems visitors favor conditions less remindful of their everyday environment which they are attempting to escape.

When a trail corridor is closed and removed from the system, how long will it take to completely return to its natural predisturbance condition? Willard and Marr (1971) note that it might take some Rocky Mountain tundra sites as long as 200 to even 1000 years to completely recover from visitor disturbance. In a study of off-road vehicle impacts on arid landscapes, Iverson et al. (1981) suggested that it might require tens to hundreds of years for impacted sites to recover.

Due to lack of quantitative data, one can only speculate how long it will take for closed trail corridors in Guadalupe Mountains National Park to completely recover. Some observations over the past few years indicate that it may be a substantial period of time. One site located on relatively deep soils, although somewhat revegetated, still had not completely recovered after 3.5 years (Plate 5). The trail sides are still evident and the ground surface is still mostly devoid of cover. Another "closed trail" showed an increase of 1.5 feet (0.46 meters) in width over two years (Plate 6). For trail closure and subsequent recovery to be successful, visitors have to be kept off the closed trail. This can be a major task as substantiated by Bayfield and Bathe (1982) who found most trail barriers to be an ineffective means of keeping visitors off of "closed trails."

Park managers have to decide when the balance between adequate means of access and the preservation of the environment is achieved. Routes of access in any National Park are necessary. Since the present-

(May 20, 1979)

(November 7, 1982)

Plate 5. Closed section of Dog Canyon road corridor.

(October 19, 1980)

(November 5, 1982)

Plate 6. Closed section of Pine Canyon trail.

ly existing trails and old jeep roads in the park are not experiencing greater amounts of erosion than areas off the trail and in light of the above discussion on aesthetic considerations it might be desirable to delegate all impacts present and future to the existing corridors. The cost of maintaining the present corridors will be substantially less than the threefold expenditure of new trail construction, maintenance and rehabilitation of closed trails.

Even though the National Park Service is now experiencing a development trend with emphasis on improvements, I would suggest that in Guadalupe Mountains National Park a moratorium be placed on any future trail construction until the visual impacts of trail scars, visitor perceptions of the adequacy of existing trail corridors, and trail recovery rates are fully studied.

In the event of new trail construction, the following recommendations are presented:

1. Pena-Penasco-Fluventic Haplustolls Association soils are found mainly on the floor and terraces of McKittrick Canyon. Any new trails should traverse this soil only on level sites. Artificial creation of a substantial slope gradient in this soil by constructing a trail up the bank of McKittrick Stream should be avoided.
2. Only minimal width trails should be constructed to insure minimal vegetation removal. Once in use, narrower trails will also experience lesser amounts of soil movement.
3. New trails should be routed to effectively screen them from the visitor's eye and not to interrupt the harmony of scenic vistas.
4. New trails should be located to avoid directly impacting any threatened and endangered plant species in the park.

A trail transect system such as the one used in this study is very useful for quantitative evaluation of erosion losses and deposi-

tion gains on trails. Due to time and fiscal constraints it was not⁷⁵ feasible to use this transect system to sample all sections of the trails in an area the size of Guadalupe Mountains National Park. The trails in the park are in relatively good shape and are not experiencing significant amounts of erosion; however, certain sections of the trail system have and will exhibit severe deterioration due to certain unique microenvironmental conditions. A census of the entire trail system similar to that described by Cole (1983) should be conducted. The census should be repeated as necessary after major rainfall events, and after a substantial snow cover starts to melt, to completely identify problem areas or severely damaged sections of the trail. Once identified these sections could be checked periodically and needed maintenance could be performed. For example, field observations suggest that more water bars are needed on the seemingly level sections of trail near the mouth of McKittrick Canyon. In this area, melt water from a heavy snow cover (April, 1983) flowed two inches deep down certain sections of this wide trail (Plate 7).

Monitoring of the erosion transects used in this study should continue on an annual or biannual basis, so the long term erosion/deposition process both on and off the trail in Guadalupe Mountains National Park can be better understood. This author would also like to suggest similar studies comparing on- versus off-trail net and absolute area changes in more mesic environments. In these areas where rainfall is more abundant, it would be interesting to note how closely the erosion process occurring on the trail approximates the erosion process occurring off the trail.

Plate 7. Water flow on McKitttrick Canyon trail.

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APPENDICES

APPENDIX A: TABLE 11. ANALYSIS OF VARIANCE, ON VERSUS OFF-TRAIL, TIME INTERVALS 6 & 7

Source	DF	SS	MS	F
(Dependent Variable = Net Area Change)				
Blocks	9	483418.53	53713.17	0.94
Treatment	1	3513.72	3513.72	0.06
Error a	9	516230.84	57358.98	
Time Interval	1	1302740.70	1302740.70	10.99**
Time Interval x Treatment	1	1955.11	1955.11	0.02
Error b	9	1067159.70	118573.30	
Error c	8	890833.23	111354.15	
(Dependent Variable = Absolute Area Change)				
Blocks	9	1200912.63	133434.73	1.09
Treatment	1	288662.63	288662.63	2.36
Error a	9	1102560.46	122506.73	
Time Interval	1	57.56	57.56	0.0001
Time Interval x Treatment	1	3296.67	3296.67	0.05
Error b	9	675638.00	75070.89	
Error c	8	512492.63	64061.58	

** Significant at the 99 percent level of confidence.

APPENDIX B: TABLE 12. ANALYSIS OF VARIANCE, ON VERSUS OFF-TRAIL, TIME INTERVALS 1-7

Source	DF	SS	MS	F
(Dependent Variable = Net Area Change)				
Treatment	1	3782.84	3782.84	0.06
Rep. (TRT)-Error a	37	2225375.24	60145.28	
Time Interval	6	2772661.92	462110.32	7.61**
Time Interval x Treatment	6	278412.81	46402.14	0.76
Error b	148	8990476.74	60746.46	
(Dependent Variable = Absolute Area Change)				
Treatment	1	492111.78	492111.78	4.38*
Rep. (TRT)-Error a	37	4158178.95	112383.21	
Time Interval	6	458459.92	76410.00	1.61
Time Interval x Treatment	6	171672.96	28612.16	0.60
Error b	148	7030696.30	47504.70	

* Significant at the 95 percent level of confidence.

** Significant at the 99 percent level of confidence.

APPENDIX C: VEGETATION FACTOR CLASSES

The following is a list of the vegetation community names that were used to identify the particular vegetation community found at each transect site.

Map Unit	Community Name
4B ¹	Pinyon pine-mountain mahogany-desert ceanothus-New Mexico muhly
10A ¹	Alligator juniper-gray oak-sideoats grama
13C ¹	Douglas fir-gambel oak-New Mexico muhly-littleawn needlegrass
13D ¹	Douglas fir-gamble oak-south-western white pine
14A ¹	Alligator juniper-wavyleaf oak-New Mexico muhly-piny muhly
23A ¹	Range ratany-creosotebush- <u>Dyssodia</u> -wooly Indian wheat complex
26A ¹	Sandpaper oak-redberry juniper-curlyleaf muhly-Warnock grama complex
29A ¹	Blue grama-black grama
35A ¹	Gray oak-sideoats grama-plains lovegrass
35B ¹	<u>Quercus</u> -redberry juniper-plains lovegrass
36A ¹	Redberry juniper-hairy grama-blue grama
37A ¹	Ponderosa pine-Arizona fescue-pringle needlegrass
40A ¹	Redberry juniper-smooth sotol-hairy grama
40B ¹	Chinkapin oak-big-tooth maple-wavyleaf oak
2	Smallseed sacahuista-mariola-sideoats grama
2	Gray oak-sideoats grama-pine muhly

¹ Fish and Dvoracek (1980).

² Bunting (1978).

APPENDIX D: SOIL FACTOR CLASSES*

CND: Canutio - Nickel Complex

DRD: Deama - Rock Outcrop - Flume Complex

FRD: Flume - Rock Outcrop Complex (5-30% slope)

FRF: Flume - Rock Outcrop Complex (20-50% slope)

HCD: Holloman - Canutio - Nickel Complex

NCB: Nickel - Canutio Complex

ORD: Sombordoro - Rock Outcrop Complex

PAB: Penasco Soils

PND: Pena - Penasco Complex

PPB: Pena - Penasco-Haplustolls Association

RRB: Remunda - Ruidoso - Pena Complex

* Fish and Dvoracek (1980).

APPENDIX E: PARENT MATERIAL FACTOR CLASSES*

MI - Massive or thick bedded limestone and/or dolomite

Qc - Generally coarse, often partially consolidated

Qc-fl - Coarse to fine material, non-consolidated

SL - Narrow outcrops of alternating sandstone and limestone

SS - Sandstone

TI - Thin bedded limestone and/or dolomite

* Goolsby (1974).

APPENDIX F: LANDFORM FACTOR CLASSES

The following is the hierarchical landform classification system upon which the specific landscape position of each transect was based.

I. Mountains (Reef Complex)

A. Canyon

1. channel site
2. terrace site
 - a. terrace bench
 - b. terrace slope
3. canyon wall
 - a. toe slope
 - b. upper slope

B. Upland

1. ridge
 - a. ridgetop
 - b. upper half of the ridge
 - c. lower half of the ridge
2. parks (swales)

II. Bajada

A. Upper Bajada

1. ridgetop
2. slopes
 - a. upper third of the slope
 - b. middle third of the slope
 - c. lower third of the slope
3. bottom sites

B. Middle Bajada

1. ridgetop
2. slopes
 - a. upper third of the slope
 - b. middle third of the slope
 - c. lower third of the slope

APPENDIX F (Continued)

- 3. bottom sites
- C. Lower Bajada
 - 1. ridgetop
 - 2. slopes
 - a. upper third of the slope
 - b. middle third of the slope
 - c. lower third of the slope
 - 3. bottom sites

The following is a list of the specific landform classes in which the transects in this study were located.

- A. Mountain (Reef Complex) - Canyon - Terrace Bench
- B. Mountain (Reef Complex) - Canyon - Toe Slope of the Canyon Wall
- C. Mountain (Reef Complex) - Upland - Upper Half of the Ridge
- D. Mountain (Reef Complex) - Upland - Lower Half of the Ridge
- E. Mountain (Reef Complex) - Upland - Park Site (Swale)
- F. Bajada - Upper Bajada - Ridgetop
- G. Bajada - Upper Bajada - Lower Third of the Slope
- H. Bajada - Middle Bajada - Ridgetop
- I. Bajada - Middle Bajada - Upper Third of the Slope
- J. Bajada - Middle Bajada - Middle Third of the Slope
- K. Bajada - Middle Bajada - Bottom Site

APPENDIX G: SITE ASPECT FACTOR CLASSES

1. south to southwest facing sites
2. north to northeast facing sites
3. east to southeast facing sites