IMPACT OF HORSE TRAFFIC ON TRAILS

IN ROCKY MOUNTAIN NATIONAL PARK

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1978

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Analagous to Lull's (1959) conclusions on grazing animals, what is needed is an animal that can give trail rides with its feet off the ground.

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INTRODUCTION

Horses have been used for work and pleasure in Rocky Mountain National Park since its founding in 1915. Today, horses are permitted only on designated trails, although there are no restrictions controlling the density of traffic within these areas.

The effects of horse use range from negligible impact on trails to substantial morphologic changes. These qualitative observations suggest that quantitative information on geomorphic changes is needed to facilitate proper management and maintenance of representative areas on the landscape.

This study assessed the impact of horse traffic in the Park by determining the physical change and rates of change occurring on trails and by defining those areas on the landscape which are least (and most) susceptible to trail deterioration. Hopefully, the findings and recommendations from this study will provide guidelines for trail location and maintenance and enable sound management decisions to be made.

APPROACH

In late May of 1977, three sections of trail were selected to represent horse trails subject to varying degrees of horse use, e.g. from less than 800 to 8000 horses per season. Thirty permanent sites were randomly established and geomorphic changes were monitored.

Data collected during the 1977 season showed that changed had occurred but the amount of change varied considerably and was not always dependent upon the density of traffic. These observations suggested that other factors must be effective in controlling directly or indirectly the amount of trail deterioration. Therefore, in addition to monitoring the permanent sites, other biophysical parameters were measured on about 40 sections of trail during the 1978 season. The semi-quantitative measurements defined those factors interacting with horse traffic on trails, while the quantitative monitoring method provided precise information on actual changes on specific sites through time. Together, these two methods of investigation were valuable in assessing the complex and variable effects of horse traffic.

STUDY AREA

Horse trails on the east side of the Park were included in the impact study. The specific test sections are located near Moraine Park Livery on Beaver Meadows Trail, along the Big Thompson on Tuxedo Park Trail, and on Lawn Lake Trail (Figure 1). These trails are of different ages and subject to varying intensities of horse traffic except for the control sites on Lawn Lake Trail used by hikers only. The area included in the survey during the second season is bounded by Wild Basin in the south, Bridal Veil Falls in the north, and the continental divide.

The geology and soils of the three test sections are described in Appendix I. Most of the areas are underlain by glacial deposits or granite. The mean depth of the surface horizon (A horizon) is 11

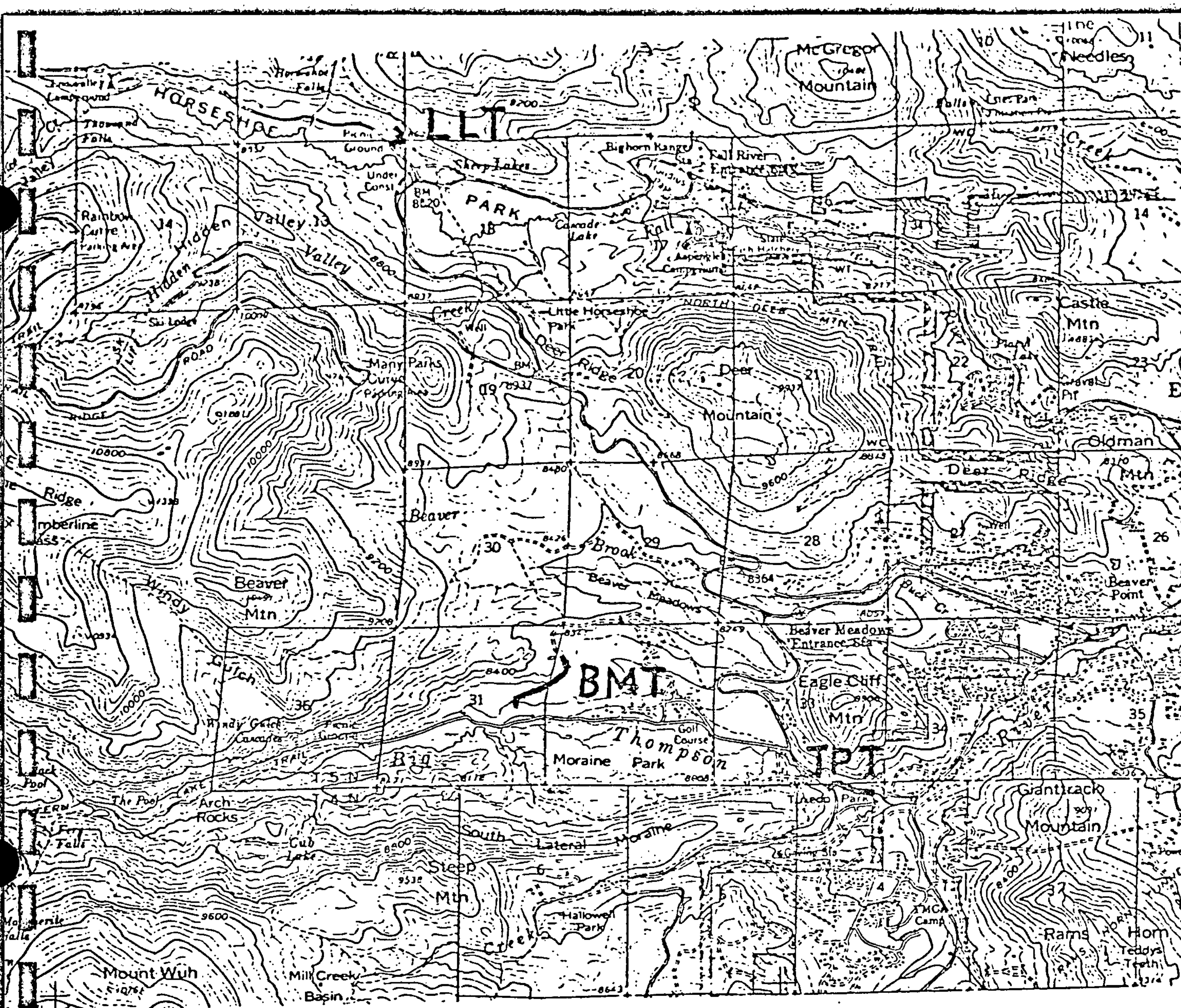


Figure 1. LOCATION OF TEST SECTIONS

centimeters, while the mean depth of the subsurface soil (B horizon) is 40 centimeters.

Usage data from private stables indicate that the first season of monitoring for part of Tuxedo Park was also the first season of use (1977). Part of Lawn Lake Trail was in use three seasons and Beaver Meadows Trail has been used at least since the time of the establishment of the Park liveries in the 1960's.

PART I: SPECIFIC SITE EVALUATION OF GEOMORPHIC CHANGE

Introduction

Geomorphic changes on 30 sites were measured during the 1977 and 1978 summer seasons. The objectives were to monitor erosional processes acting on horse trails and to determine the amount and rate of change occurring annually.

Methods

Designated sections of trails, 300 to 500 meters long, were chosen to represent "low" (less than 600 horses), "moderately high" (2000-6000 horses), and "high" (6000-8000 horses) use trails (Appendix IIIv). Each test section started at a randomly chosen point uptrail from the designated trailhead. Permanent sites were established by mechanically dividing each section into 10 equally-spaced segments.

Four different techniques were employed on the sites during the two seasons of monitoring. These morphometric measurements were repeated at the beginning and end of each season (June and September).

Surface Profile

The surface profile is measured by first attaching a taunt tape measure to permanent stakes outside the trail as shown in Figure 2. The distance from this tape (reference level) to the ground surface is measured and these data together represent the cross-sectional profile. All measurements begin at the left hand stake and proceed along the uptrail side of the tape to the right hand stake. A plumb bob is used to assure that the distance measured is perpendicular to the ground. In evaluating the changes, a difference of two centimeters or less is considered negligible to allow for a margin of error in measurement.

Trail Widening

Erosion and deposition along the trail edge are measured by emplacing nails (15 centimeters long) perpendicular to the sides of the trail. The nailheads are level with the ground surface and their locations along the reference level are recorded (Figure 2). Nails completely exposed or removed from the soil are replaced and their positions are recorded.

Compaction

A penetrometer is used to measure the pounds per 1/20 square inch required to force a pointed nozzle into the soil. Two types of measurements are taken depending on the degree of soil compaction : (1) depth of penetration after applying 100 pounds of force, or (2) force required to insert the instrument 10.5 centimeters into the soil. The first measurement is usually used inside the trail which is more compacted, while the second measurement is used outside the trail (Figure 3).

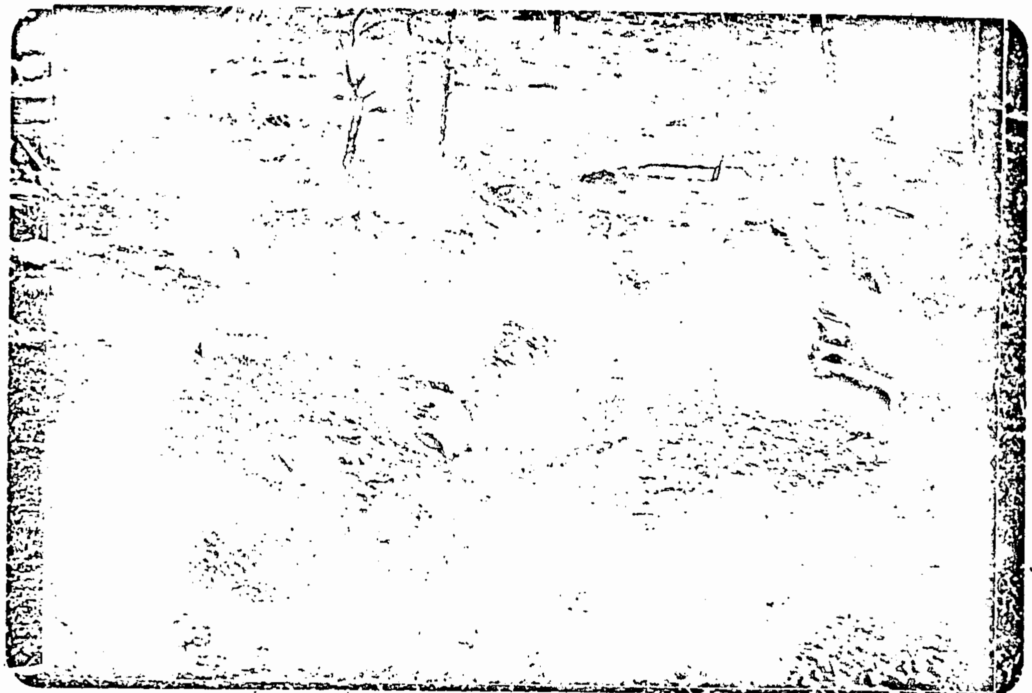


Plate 1. Beaver Meadows Trail: Lower Alluvial-Colluvial Fan. Spring snowmelt and runoff saturated these organic soils. One horsehoof incised 20 cm into the trail. Bainbridge (1974) reported hoof imprints 20 in (51 cm) deep in a wet meadow.

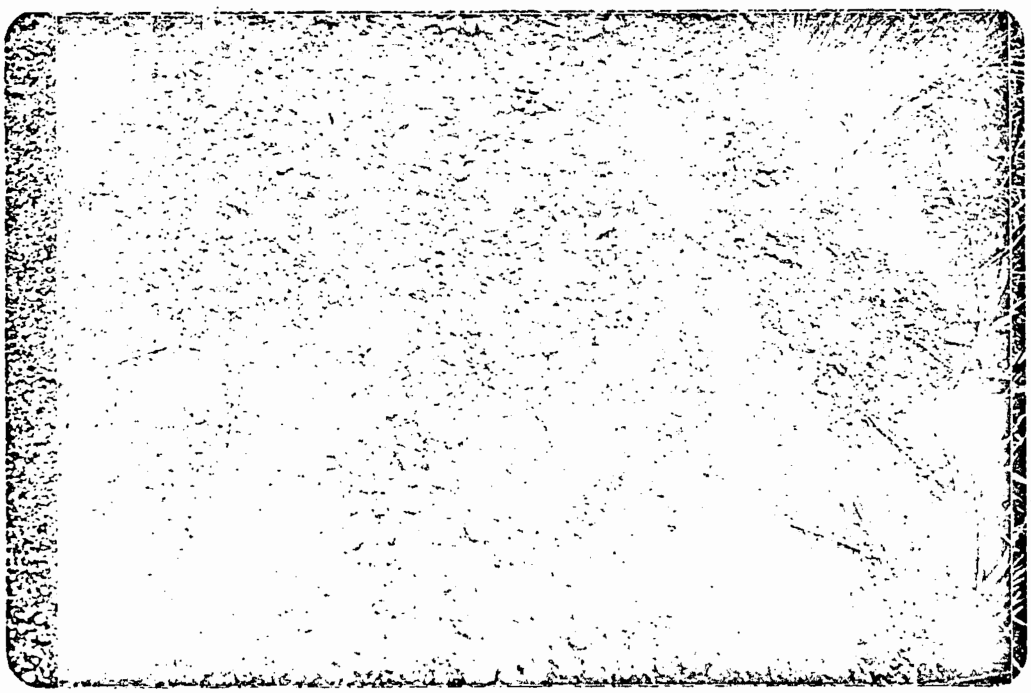


Plate 2. Tuxedo Park Trail: Colluvial Slope. Eroded soil from this new section was 23-61 cm wider and 3-10 cm deeper by the end of the first season of use.

Pebble Movement and Surface Armoring

Movements of pebbles and stones are recorded by placing a wooden frame on the site and periodically photographing the trail surface. The area within the square meter frame which is covered by stones (surface armor) is calculated. Photos are taken 150 centimeters above the position shown as an asterisk in Figure 4. The designated "X" and "Y" distances are recorded so that the frame can be repositioned and photographed at a future date.

Pebbles, 1 to 2 centimeters in diameter, are placed in a band 10 centimeters wide across the trail (Figure 4). This band is photographed repeatedly to observe how quickly it is eradicated.

Results and Comments

Surface profile

Beaver Meadows is an excellent example of a "high" use trail which erodes differentially over the landscape. No measureable change occurred during the first season on sites located on alluvial-colluvial fans[1]. During the second season, these sites eroded and gullies formed during heavy spring runoff (Plate 1). A new trail was cut and the permanent stakes were dislodged. Sites on level, well drained areas widened five centimeters and were incised one to three centimeters each season. On steep sites (15° slope) located on glacial deposites, the trail widened 25 centimeters and was incised an average of nine centimeters (Figure 5).

[1]Alluvium is rock and soil material transported by water. Colluvium is material which has moved downslope by gravity.

Figure 2. Surface profile and erosion pins (cross-sectional view of site).

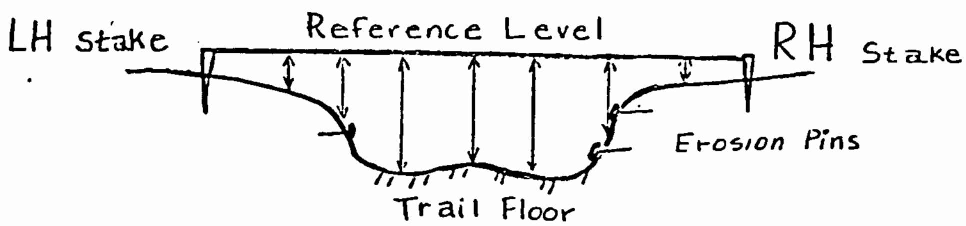


Figure 3. Compaction (cross-sectional view site).

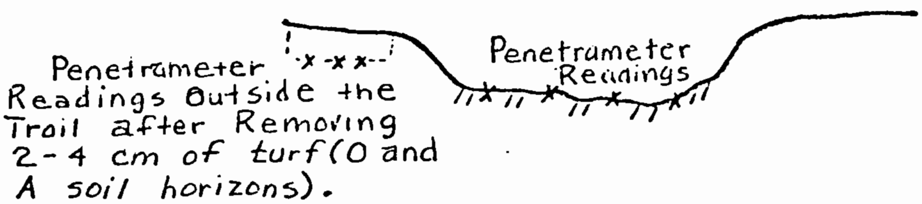
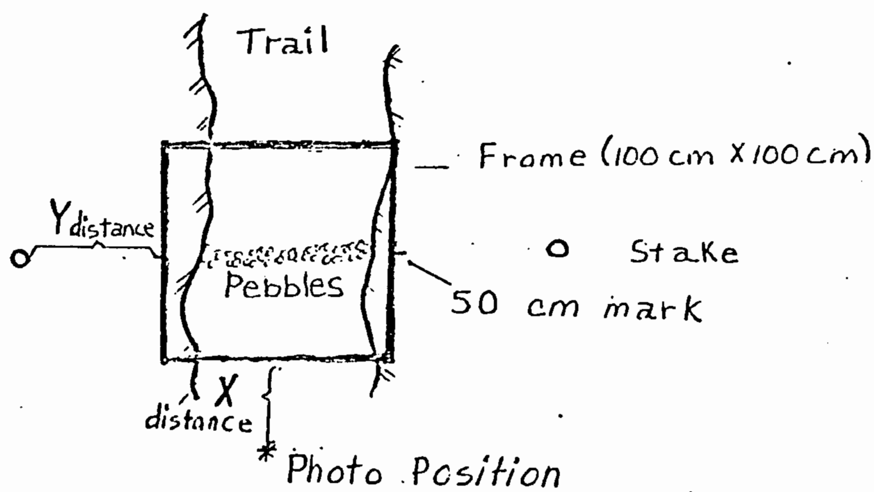


Figure 4. Pebble movement and surface armoring. (Planview of site).



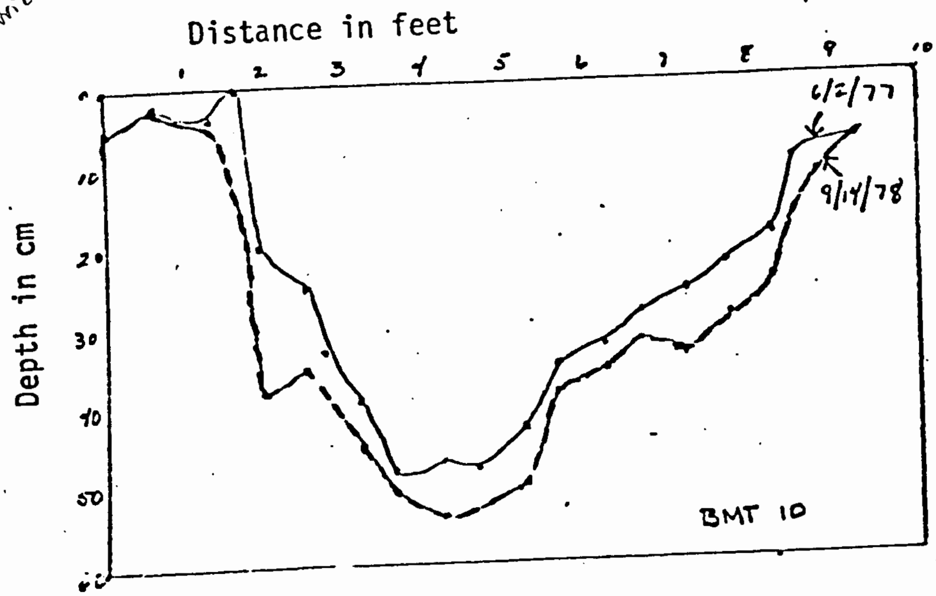


Figure 5. Beaver Meadows trail, site 10. The profile shows an average incision of nine centimeters after two seasons of "high" use (6000-8000 horses per season). The trail was approximately sixteen centimeters deeper at one point.

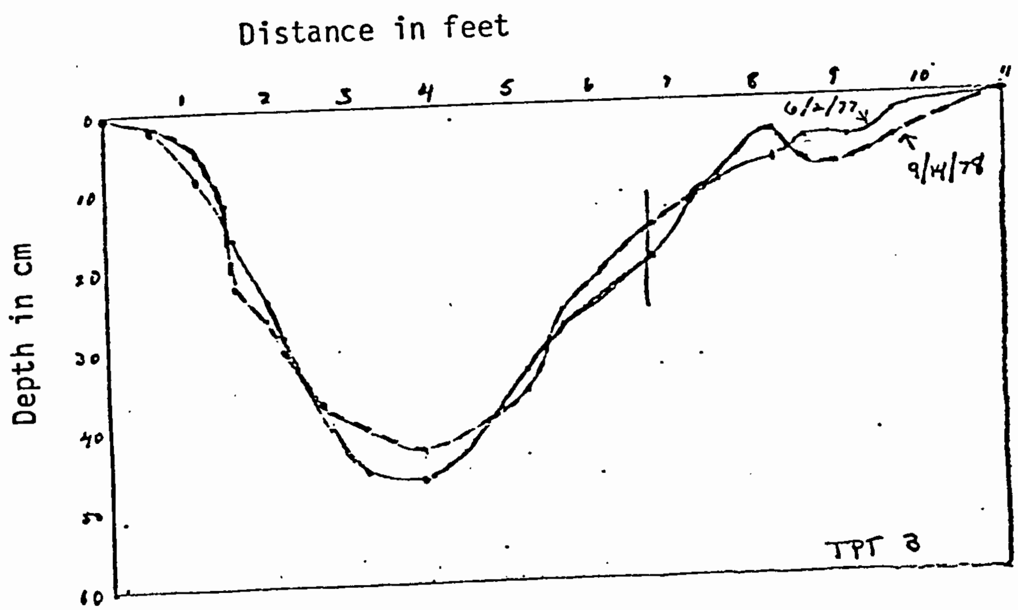


Figure 6. Tuxedo Park Trail, site 3. Deposition has occured within the abandoned trail and a new trail (upper right) was cut during the second season. The vertical line at 6'7" marks the right edge of the original trail. The lateral disturbance now extends out to eleven feet, increasing the width of disturbance by 4'5" (1.8 m).

Tuxedo Park Trail is a "moderately high" use trail, part of which is a new section. The new part is located on a level terrace and widened 30 to 100 centimeters during the first season. These sites stabilized by the end of the second season, although the width of the trail was twice as wide as is necessary for horses, based on two years observations. Sites located on a gravelly colluvial fan deposit widened 23 to 61 centimeters as levees of soil material eroded from the trail and accumulated on the sides (Plate 2). These sites were incised three to ten centimeters each season. One site was abandoned during the second season and a new trail was cut, causing the width of disturbance to increase from 168 to 324 centimeters. At a similar site, four centimeters of deposition occurred within the abandoned trail (Plate 3 and Figure 6).

Sites subject to foot traffic only and horse traffic on Lawn Lake Trail were incised three to five centimeters during the first season and were stable during the second season. Profiles on the hiking section did not widen, while profiles on the riding section widened during the first season only. Summer thunderstorms were common during the first season and caused small debris flows from steep sideslopes to erode the upper sites on the horse trail.

Trail Widening

The position of erosion pins complimented the surface profile measurements in providing evidence of trail widening. Approximately ten per cent of the pins were completely removed and lateral erosion occurred. Approximately 70 per cent were in place and covered by six centimeters of soil or almost entirely exposed.

Plate 3. Tuxedo Park Trail, site 3. The trail on the right (with the meter stick on the trail edge) was abandoned and a new trail was cut (left) during the second season of monitoring. Figure 6 illustrates how the morphology of the trail changed.

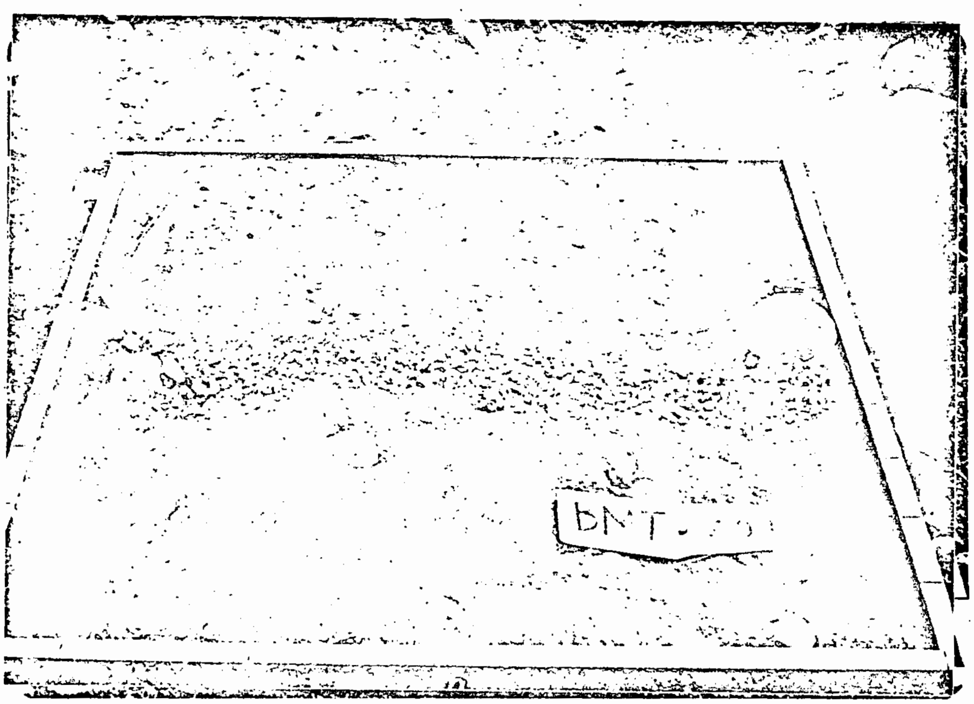


Plate 4. Beaver Meadows Trail, site 10, June, 1977. A pebble band placed across the trail was scattered within two days. Glacial till (stones carried by a glacier) covers about 5.5 dm^2 (square decimeters) within the square meter frame.

Compaction

Soil compaction was difficult to measure because stony soils caused the measurements to be faulty and nonreproducible. Because the penetrameter was not sensitive to the range of compaction found inside and outside the trail, measurements were discontinued during the second season of monitoring.

The following conclusions are based on the first season of monitoring. Soil inside Beaver Meadows and Lawn Lake Trails were 13 to 26 times as compact as soil outside the trail. Soil compaction inside and outside the new section of Tuxedo Park Trail was equal, suggesting that after trails are used a number of seasons, the soil remains compacted throughout the year.

Pebble movement and surface armoring

Results of the pebble band observations showed that bands on all trails were eradicated after two days of use. There was no difference with regard to the amount of use or on the "hiking only" section of trail.

Repetitive photographs of the sites over time showed that surface armoring did not significantly change on most sites. The only sites which showed a change were the stony sites on upper Beaver Meadows Trail (Plates 4 and 5). Surface armoring increased by a factor of three from June to September.

Summary

1. Measurements of the changes in trail profile, width, compaction, and pebble movement and surface armoring were made on 30 permanent sites over two seasons of use.

Plate 5. Beaver Meadows Trail, site 10, September, 1977. Till covers about 19 dm^2.

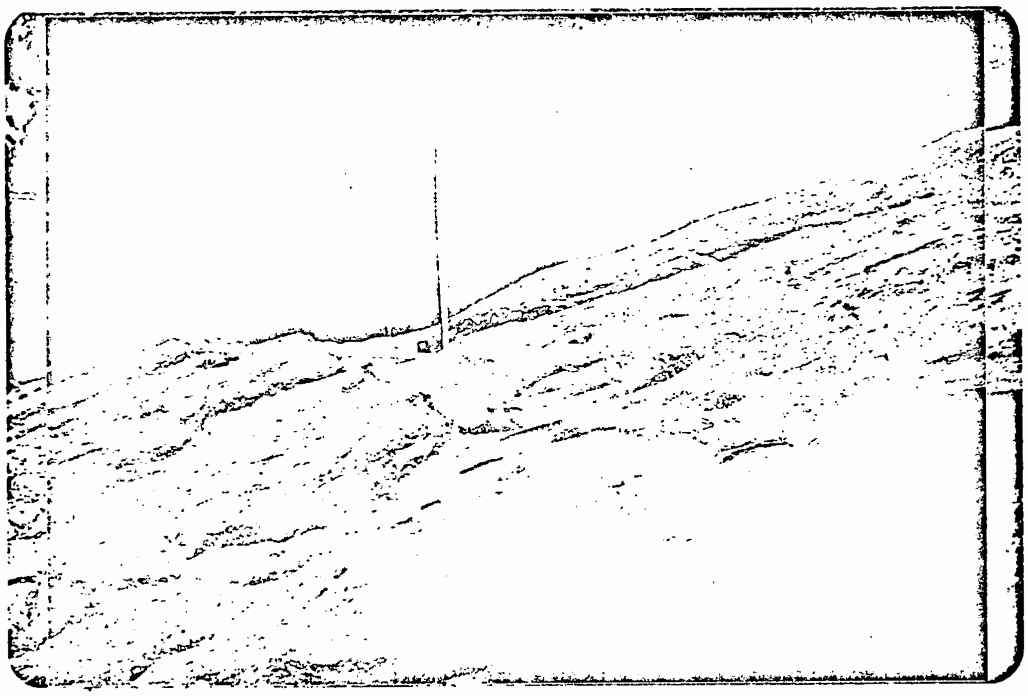


Plate 6. Storm Pass Trail: Bedrock. This trail is in the "negligible" erosion class. The only observed changes are the lack of lichen cover and abraided rock in the trail. Note position of meter stick.

2. Morphometric measurements demonstrated that a constant amount of horse use results in a range of erosional impacts depending upon the landform over which a trail traverses.

3. Sites on well-drained, level areas showed negligible amounts of incision, regardless of the amount of traffic. The predominant impact was on trail width which increased at a rate of five centimeters per season on "high" use sites. After the first season of use on a new section, sites widened 30 to 100 centimeters. However, these sites stabilized and remained unchanged during the second season.

4. Sites crossing gentle sideslopes increased in width by as much as 45 centimeters and three to ten centimeters of incision occurred.

5. Sites on Lawn Lake Trail had the least amount of horse traffic of the three sections and showed the least amount of erosion.On a comparable landform, the "high" use section deepened and widened significantly. These sites were also covered by three times as many stones at the end of one season of use.

6. Pebble bands placed on the trails were disrupted within two days on all sites, including the hiking sites.

7. Measurements of trail compaction are not conclusive due to insensitive equipment and stony soils. Tentative results suggest that after several seasons of use, regardless of the intensity of use, soil compacts 13 to 26 times their original condition and remain compacted throughout the year.

PART II: TERRAIN AND TRAIL SURVEY OF BIOPHYSICAL CHARACTERISTICS

Introduction

After evaluating the specific site measurements taken in 1977, it became apparent that other factors, not accounted for by the monitoring method, were influencing measurable changes or, conversely, lack of change, on horse trails. Therefore, a terrain and trail survey was conducted during the 1978 summer season. The biophysical characteristics over a wide variety of terrain were observed and about 40 sections of trails on the east side of the Park subject to varying amounts of horse use were quantitatively measured. These biophysical parameters included elevation and aspect, parent material (geologic substrate), width, depth, and grade of trail, length and angle of sideslopes, texture of trails and sideslope, depth and color of surface horizon, depth of "C" horizon, stoniness and rockiness, vegetation, landform, mass movement, drainage, traffic, and apparent state of erosion. The "C" horizon is altered geologic material which does not show evidence of soil development, e.g., clay and organic accumulation.

This type of survey provided a means of comparing the quality and present stability of trails located on various geomorphic surfaces. In addition, information can be extrapolated to other trails on similar landforms and can be used to formulate guidelines for trail locations, maintenance, and rehabilitation.

Methods

Biophysical characteristics were measured and use (traffic) statistics were compiled over a wide range of terrain conditions. The field format (Appendix II) and criteria for evaluating trail deterioration (Appendix III) were utilized in an effort to standardize a technique for describing parameters controlling the impact of trails upon the surrounding terrain. These data were grouped into nine landform units (Appendix IIIi) which provided a logical means of evaluating the complex mountainous terrain over which trails traverse. The trails were then placed into erosion classes which are categories reflecting the present erosional state of the trail and the amount of physical disturbance incurred, compared to the surrounding terrain (Appendix IIIiv). Key biophysical factors were then correlated with erosion classes to determine how trail deterioration varied with traffic and landforms.

Results and Comments

Results of the correlations between landform, use, significant biophysical parameters, and erosion class are shown in Table 1. These correlations suggest which landforms are most or least desirable for locating trails. Sections of trail are classified under different erosion classes depending on the landform.

Before considering these correlations, it must be kept in mind that erosion classes are broad categories reflecting a variety of geomorphic

TABLE 1. Correlation of Landforms with Use, Biophysical Factors, and Erosion Classes
(Refer to Appendix III for explanation of categories)

LANDFORM*	TRAIL	EROSION CLASS	USE	SIGNIFICANT BIOPHYSICAL PARAMETERS	COMMENTS
1. Outcrop A. Unweathered bedrock (Granite; Gneiss)	Fern Lake	N	M	-Hard surface; no soil development -Trail grade: 0-20°	Bedrock control is significant in limiting trail deterioratio Some incision from horseshoe impact (less than 10 cm) can occur on fractured, crumbly bedrock.
	Storm Pass		MH		
	Ouzel Lake		L		
	Gem Lake		M		
	Bridal Veil Fls		L		
	Chasm		L		
B. Weathered Granite	Mill Creek Basin	N	L	-Vegetation: Open Ponderosa Pine -Texture of trail and sideslope: sandy loam, loamy sand, sand, and gravel -Sideslope angle: 0-20° -Well drained -Trail Grade: 0-10°	Trails are very stable due to the highly permeable substrate and high infiltration capacities. If a sandy loam soil develops, the trail may compac and pond water. Subsequent widening of the section of trail may occur (2 to 3 m).
	Beaver Meadows		H		
	Deer Junction		H		
	Gem Lake		M		
	Mill Creek Basin		L	-Organic-rich A horizon; 20-30 cm. thick -Trail grade: 10-20° -Sideslope angle: >30° -Sideslope length: >50 m. -Vegetation: aspen	2 to 4 cm of surface soil overlie deeply weathered granite (greater than 1 m)
	Gem Lake	L	M	-Trail grade: 10-20° -Sideslope angle: 0-20° -Vegetation: Ponderosa Pine	Depth to resistant bedrock is usually less than 40 cm.
	Mill Creek Basin		L		
	Beaver Meadows		H		
	Lawn Lake	N-L	L	-Till and bedrock parent material -Sideslope angle: >30°; sideslope length: >5m -Trail grade: 0-10°	Cobbles from till are easily moved to the sides and trail widens as much as 2 meters.
	Wind River		L		
	Chasm		L		
	Storm Pass		H		

* Generally refers to areas below treeline unless indicated

TABLE 1. Correlation of Landform with Use, etc. (continued)

	LANDFORM	TRAIL	EROSION CLASS	USE	SIGNIFICANT BIOPHYSICAL PARAMETERS	COMMENTS
2.	Talus Slope	The Loch	N	H	-No soil; 100% stones -Sideslope angle: >30° -Vegetative cover: <20% -Trail grade: 0-10°	Talus, like bedrock, limits trail deterioration. Loose stones which are deposited on the down-slope side of the trail cannot usually be distinguished from the talus slope.
3.	Terrace	Tuxedo Park	L	MH	-Trail grade: 0-10° -Sideslope angle: 0-20° -Texture of trail and sideslope: gravelly sandy loam, and loamy sand -Well drained	Alluvial parent material is usually permeable and resistant to incision, although trail widening may occur on poorly marked trails.
		Ouzel Falls	N	L		
4.	Flood Plain-Glacial Lake	Mill Ck. Basin	N	L	-Trail grade: 0-5° -Sideslope angle: 0-20° -Texture of trail and sideslope: silty loam. -Moderately drained	Compacted, organic-rich soil may pond water during wet seasons; subsequent widening may occur.
		Hallowell Park		L		
		Ouzel Falls		L		
		Cub Lake		MH		
		The Pool		MH		
		Mills Lake		M		
5.	Moraine Outwash Terrace	Ouzel Falls		L	-Stoniness of sideslope: .01-.1% -Texture of trail and sideslope: loamy sand, loam -Sideslope angle: 20-30°; side-slope length: >50 m. -Trail grade: 0-10° -Well-drained	Naturally occurring aggregates of organic-rich, loamy soil appear to stabilize steep slopes; however, trails steeper than 10° will erode.
		Beaver Meadows	L-M	H	-Trail grade: 10-20°	

TABLE 1. Correlation of Landforms with Use, etc. (continued)

LANDFORM	TRAIL	EROSION CLASS	USE	SIGNIFICANT BIOPHYSICAL PARAMETERS	COMMENTS
6. Moraine A) Sideslope	Aspenglen	M	H	-Soil depth: 10 cm to stony substrate -Trail grade: 0-10° -Sideslope angle: 20°-30° -Sideslope length: >50 m -Stoniness of trail: <20%; stoniness of sideslope: 1-15%	Fine material is eroded away causing incision and undercutting of trail. Springs are commonly intercepted, creating wet, slippery conditions.
	Bierstadt		H		
	Fern Lake		M		
	South Lateral Moraine (north aspect)		M		
	Beaver Meadows	H	H	-Trail grade: 10-20° -Sideslope angle: 20°, sideslope length: <10 m to >50 m -Soil depth: 30-50 cm to stony substrate -Stoniness of trail: 20-50% -Stoniness on sideslope: .1 to ≥.5%	Runoff from long, steep sideslopes concentrates in trails and subsequent erosion occurs. Cobble-sized rocks (10-15 cm diameter) may cover 50% of trail.
	Sandbeach Lake		M		
	Sprague Lake		H		
	Storm Pass		H		
	Bierstadt		H		
	Chasm	M-H	M	-Trail grade 0-10° -Silty, sandy loam soil -Sideslope angle: 10-20° -Soil depth: 50 cm to stony substrate	Leached forest soil horizons (low organic matter content) are easily pulverized and eroded by horse traffic.
	South Lateral Moraine (south aspect)	N	M	-Elevation: 8600 feet -South aspect -Sideslope angle: 30° -Trail grade: 0-5° -Vegetation: sage	With increased trail grade, braiding occurs around boulders. Trail width increases from 60 cm to 3 m in some sections.
		L		-Trail grade: 5-10°	
B) Top	Bierstadt	N	H	-Trail Grade: 0-5° -Silty, sandy, loam soil	The soil appears to compact and stabilize.
	Sprague Lake		H		
	Sand Beach Lake		M		
	Tuxedo Park	N-L	MH	-Sandy loam, sandy clay, loam subsoil	The soil is incised to 20 cm and then widening occurs.
	Chasm	L	L	-Trail Grade: 5-10°	
	Fern Lake		M		

TABLE 1. Correlation of Landforms with Use, etc. (continued)

LANDFORM	TRAIL	EROSION CLASS	USE	SIGNIFICANT BIOPHYSICAL PARAMETERS	COMMENTS
C) Alpine Moraine	Chasm	M-H	M	-Soil depth: less than 20 cm to stony substrate. -Trail grade: 0-10° -Stoniness of trail: 10-20% -Stoniness of sideslope: stones 1.5-10 m apart	Widening of trail occurs when stony substrate is encountered. Vegetation is inhibited by cold temperatures and wind which removes fine materials.
		H	M	-Stoniness of trail: 80% -Stoniness of sideslope: stones .75-1.5 m apart	The trail is 260 cm wide and stones piled on the sides disturb an additional 1 m on each side of the trail.
7. A) Colluvial Slope	Beaver Meadows	L-M	H	-Moderately drained -Sideslope angle: 10-30° -Trail grade: 5-20° -Bedrock on trail: 0-30%	Outcrops of bedrock on trail and sideslope reduce the availability of erodible material but may increase runoff.
	Lawn Lake		L		
	Tuxedo Park		MH		
	Aspenglen	H	H	-Sideslope angle: 20°; sideslope length: >50 m -Trail grade: 0-20° -Obvious evidence of mass movement on entire sideslope	Oversteepened sideslope is geologically unstable. Because the trail is undercutting the toe slope, it is widening and eroding, even on a level gradien
8. Alluvial-Colluvial Fan A) Upper fan below treeline	Beaver Meadows	M-H	H	-Trail Grade: 5-10° -Poorly to moderately drained -Aspen -Sideslope angle: 10-20° -Silty loam texture of sideslope -Dark, organic-rich soil	Organic soil and a high water table induce bog and bog-like conditions which result in incision and trail widening.
	Storm Pass		MH		
	Tuxedo Park		MH		
	Bear Lake				

TABLE 1. Correlation of Landforms with Use, etc. (continued)

LANDFORM	TRAIL	EROSION CLASS	USE	SIGNIFICANT BIOPHYSICAL PARAMETERS	COMMENTS
B) Lower fan below treeline	Beaver Meadows Storm Pass	H	H MH	-Dark, deep, organic-rich soil -Trail grade: 0-5° -Marsh vegetation -Poorly drained	
C) Alpine fan	Chasm Flattop	H	M M	-Poorly drained -Trail grade: 0-10° -Soil texture: silty loam -Vegetation: sedges, march marigold, willow	Disturbance caused by trails o organic-rich soil in wet meado is immediate and obvious. Even very low numbers of horse cause substantial and long lasting degradation because these soils have a low bearing capacity.
9. Alpine Colluvial fan Plaination Surface	Chasm Flattop	M	L M	-Trail grade: 0-5° -Well drained -Sideslope angle: <10° -Stoniness of trail: <10% -Vegetation: Carex, aven, cushion	After the turf is initially trampled and broken by traffic it continues to erode upslope due to effects of wind and freeze-thaw activity.
	Chasm	H	M	-Sideslope angle: >10° -Trail grade: 5-10°	

changes such as incision, widening, compaction, and changes in microtopography (Appendix IIIiv). The erosion classes in Table 1 are assigned to trails based on evidence of past erosion and present conditions. Therefore, the potential for future erosion and trail deterioration can only be speculated upon because the effects of continued or increased use is not known.

Optimum locations for trails, regardless of the intensity of horse use, is on Outcrops (Table 1-1). Unweathered or slightly weathered granite and gneiss form hard, resistant surfaces and stable sideslopes (Plate 6). If the trail grade is greater than approximately 10°, the trail may become slippery and potentially dangerous for horses.

Highly weathered granite forms a gravelly, permeable material called "grus" which is also in the "negligible" erosion class. A sandy loam soil sometimes develops on level areas and compacts due to horse use over time. For example, seasonal ponding occurs where compacted subsoil is particularly impermeable on Beaver Meadows Trail, a "high" use trail. Nevertheless, only a few impermeable sections of the trail have widening during the wet season.

In steep terrain (greater than 30°), the amount of trail incision is a function of the thickness of grus and, to a lesser extent, horse use. If the grus layer is thin, water accumulates above the impermeable bedrock surface and the trail is incised to this surface. Trail degradation is minimal because the sides of the trail blend into the sparsely vegetated terrain, thereby negating visible impact (Plate 7).

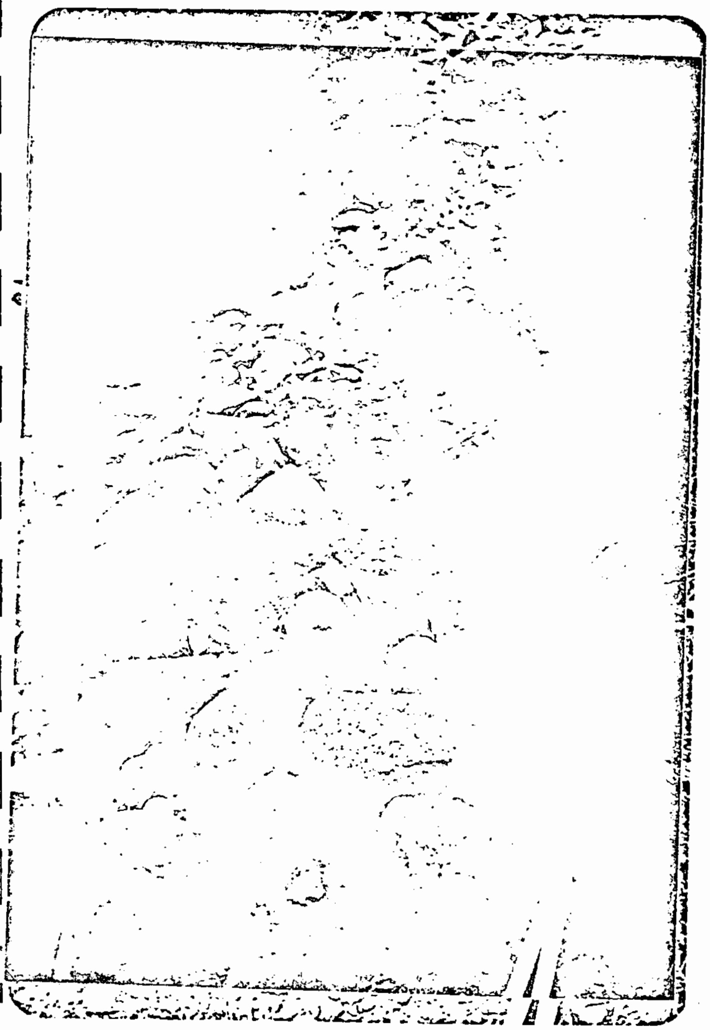


Plate 7. Gem Lake Trail: Weathered bedrock (grus). Bedrock stops further erosion of this "moderate" use trail. Visible impact is minimal due to the similarity of the surrounding sparsely vegetated. terrain.

Plate 8. Beaver Meadows Trail: Sideslope of Moraine. Glacial till armors this "high" use trail. The trail is usually braided if stones cover over 40% ofthe trail. Each section of the scale is 1 dm (decimeter).

On the other hand, if grus is relatively deep (greater than about 1 meter), rainfall and snowmelt quickly percolate downward and surface runoff does not occur. Where grus is deep on the Mill Creek Basin Trail, erosion conditions are "negligible" despite the fact that the trail and sideslopes are very steep (17°). Due to the steep terrain, any increase in traffic may create unstable conditions and a marked increase in erosion.

A Talus Slope (Table 1-2) is a suitable trail location if the slope is at an angle of repose, i.e., geologically stable. The slope on the Loch Trail is presently stable and only a very slight disturbance of the landform is perceptible.

Each talus slope must be considered individually to determine if it is stable. For example, an increase in moisture or disturbance of the talus could create a temporarily unstable slope which should be avoided until conditions stabilize.

Terraces are also optimum landforms because level, well-drained trails resist the impact of traffic, although widening occurs unless trail borders are clearly defined. Table 1-3 indicates that increased traffic is correlative with increased degradation.

One cyclic process which appears to be active is the loosening of soil by horse traffic and subsequent transport and redistribution of material down the trail by runoff. This "conveyor belt" system, whereby the trail is constantly being covered by uptrail material, has stabilized the Ouzel Falls Trail and deepening has not occurred.

Most Floodplain-Glacial Lake landforms are in the "negligible" erosion class, due primarily to a low, constant slope angle and moderate drainage conditions. Observations on the Ouzel Falls Trail (Table 1-4) suggest that increased horse use will probably not cause additional degradation because the trail floor appears to be compacted and stable. Albeit, degradation is proportional to traffic on short sections of trail where water ponds during brief, wet periods. Consequently, the trail widens where riders circumvent these bog-like "wet spots."

Terrace materials occurring within Moraine-Outwash Terrace landforms often have a high proportion of sand and gravel in the subsoil, few stones compared to moraines, and well aggregated, loamy soils. These factors tend to prohibit infiltration and percolation on less than 30° sideslopes and inhibit incision and downslope movement of surface material. "Negligible" erosion occurs on trail grades less than 10°, and "low-moderate" erosion occurs if the trail grade is from 10° to 20°. More data showing the effect of increased horse traffic are needed before determining the relative impact of varying degrees of use on these trails.

Sideslopes on Moraine landforms are steeper, more stony, and contain more clay-sized material compared to Moraine-Outwash Terraces. Trails on Moraines (Table 1-6) are in higher erosion classes because runoff from sideslopes erodes and transports fine material downslope. The net effect on trail grades less than 10° is a "moderate" amount of erosion, accompanied by some deposition. Stones in subsoils are exposed to more erosion, and subsequently trails are incised. Trails at grades of 10° to 20° are "highly" erosive because poorly consolidated material is eroded away leaving a concentration of stones on the trail floor (Plate 8). This is especially prevalent where trails steepen slightly and cross the crest of a moraine. If stones are removed during maintenance operations, the remaining fine material is eroded away, exposing another armor of stones. If the stones are left in the trail, horse traffic sometimes causes them to move downslope or to concentrate them in the center of the trail. Incision then begins along the sides of the trail.

Sideslopes of Moraine landforms appear to be more directly affected by the impact of horse traffic compared to other landforms, although data are insufficient to determine the amount of degradation associated with "low" and "moderate" use. Spragues Lake Trail is an example illustrating the effect of increased horse traffic on a "high" use trail (Plate 9). Traffic increased from 6,000 to 8,000 horses from 1975 to 1977. The trail is incised as much as 1 meter and is still eroding today.

Interesting examples of "moderate" to "high" erosion conditions which appear stable are the Sand Beach Lake, South Lateral Moraine, Storm Pass, and Bierstadt Trail. Sections of these trails cross slopes which are relatively unstable as evidenced by a slope angle greater than 30°, pistol-butted tree trunks (curved tree trunks due to downslope movement of soil), gullying, and a sparse vegetative cover. Two meters of incision have occurred yet the visual impact is low because eroded trails

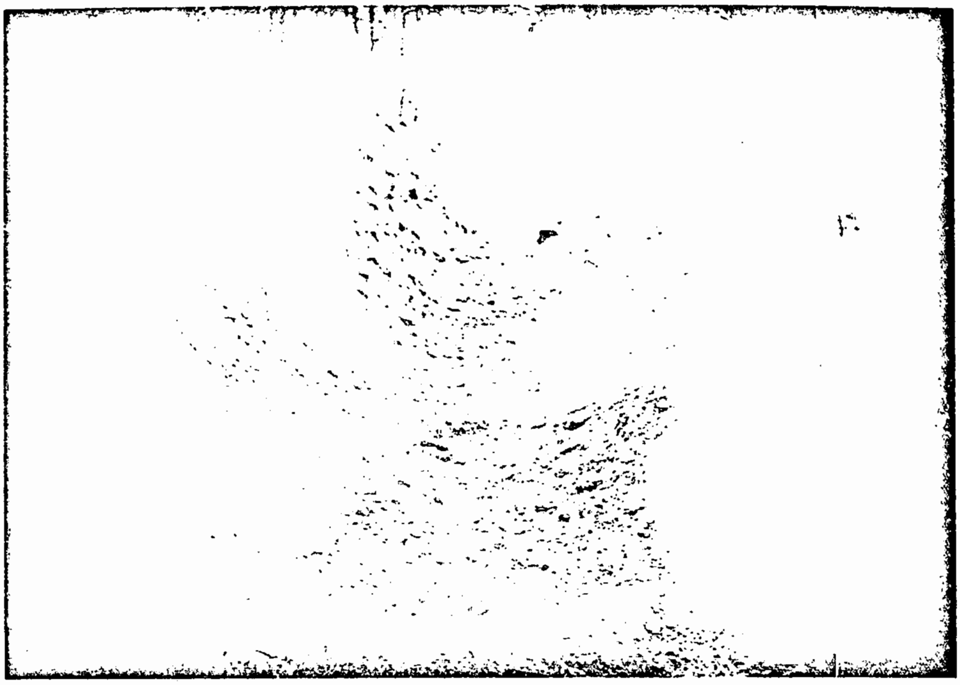


Plate 9. Spragues Lake Trail: Sideslope of moraine. Trail depth is 1m; trail grade is 12°- 15°; horse use is "high"(6000 -8000 horses per season).

Plate 10. Spragues Lake Trail: Top of Moraine. The trail is 7m wide and .1m deep. During dry periods, dust is 8-10 cm deep.

blend into the surrounding terrain. These trails are stable during dry seasons but are highly susceptible to debris flows and avalanches during periods of high precipitation. The impact of one horse hoof on saturated soil can induce small debris flows onto the sideslope.

The south aspect of the South Lateral Moraine is exceptional because it is within the "negligible" erosion class and yet the sideslope is steep (30°) and composed of bouldery till. The stability of this landform is attributed to the aspect which is warm and dry compared to the north aspect, the sage brush vegetative community which stabilizes the steep slope, and low use. The combined effect of these factors results in a stable trail which may or may not change if use is increased.

Trails on the top of Moraine landforms are in the "negligible" and "low" erosion classes and appear to be stable, regardless of the amount of use (Table 1-6b). Sandy loam soils are well developed and sometimes contain dark, organic-rich horizons which are apparently resistant to extensive runoff and erosion. The trail in Tuxedo Park is incised 20 centimeters to a highly resistant, compacted, sandy clay loam subsoil.

"Low" erosional conditions develop on "moderate" and higher use trails when accumulations of pulverized sandy loam soils with few stones (less than 40%) create extremely dusty conditions. Because of the level terrain, dusty material remains within the trail or is kicked to the sides. Trail widening is prevalent where riders circumvent thick dust during dry periods and mud during wet periods (Plate 10).

Trails on alpine tundra Moraine landforms appear to widen upon impact, compared to a general deepening of trails below treeline. For example, the Chasm Lake trail (below treeline) has a mean width of .9 meter, and depth of 1 meter. This is compared to a width of disturbance of 2.5 to 6.5 meters and a depth of .2 meters above treeline (Plate 11). This trend is probably due to the occurrence of a very stony substrate (greater than 50% stones by volume) within 20 to 40 centimeters of the tundra surface. Further incision is minimal, but stones are kicked to the sides of the trail and subsequent widening occurs. Recovery rates of trampled vegetation are usually imperceptibly low because the harsh alpine climate inhibits growth and high winds remove fine materials. Willard and Marr (1971) and Willard (1978) suggest that climax vegetation require several hundred to one thousand years to reestablish itself.

The inherent (geologic) stability and angle of a slope control the quality of trails on Colluvial Slopes. Trails with grades of less than 20° and sideslope angles of 10-30° are in the "low" to "moderate" erosion classes (Table 1-7). Outcroppings of bedrock on these slopes tend to stabilize trails. The amount of traffic does not appear to be directly related to erosion classes, since "low" use trails, like Lawn Lake, show some evidence of degradation.

New trails near Bear Lake and in Tuxedo Park are in the "low" erosion class after being used for one season. These trails are approximately .7 meter wide, but levees of soil accumulate along the sides of the trail, increasing the width of disturbance by .5 to 1 meter (Plate 2).

Plate 11. Chasm Lake Trail: Alpine moraine. The trail is incised .2 m and is .7 m wide. An additional 1.5 m of tundra is disturbed on each side.

Plate 12. Aspenglen Trail: Colluvial slope. Trail is 1.5 m wide and actively eroding. Evidence of unstable slope conditions are fresh scarps on the sideslope, gullies, (right side of trail), fresh levees of soil bordering the trail, mass failure of sideslope (extreme background on right side of trail), and pistol-butted trees. A two m stick is used for scale.

Colluvial slopes greater than 30° show evidence of mass movement, and trails are highly erosive, even if the trail grade is level. The Aspenglen Trail traverses a hillslope which is geologically unstable and shows evidence of downslope movement of soil, geologic material, and vegetation (Plates 12 and 13). This trail is undercutting the lower part of the slope, thereby creating a steeper slope and more unstable conditions. Slick, yellow, clayey material commonly associated with unstable slopes occurs along the trail.

Alluvial-Colluvial Fan landforms are in "medium" and "high" erosion classes. Bog conditions prevail due to poor drainage and high water tables. Trails crossing bogs and bog-like areas result in incision, widening, and massive damage to soil and vegetation (Plate 1). Aspen, rushes, and sedges are indicators of wet meadow and marshy conditions which are extremely sensitive to disturbance. Silty loam, organic-rich soil has a low bearing capacity and is very fragile, particularly when a trail undercuts the lower fan and intercepts springs. The data in Table 1-8 show that "medium high" as well as "high" use trails are in the "high" erosion class. There are insufficient data to determine if "low" use would also cause extensive deterioration, although Helgath (1975) and Knapik (in press) showed that boggy terrain is highly erosive, regardless of the amount of traffic.

Alpine Alluvial-Colluvial Fans are also extremely susceptible to small amounts of use (Plate 14). Trail erosion increases with increasing soil moisture and the presence of frozen ground and patchy permafrost at

Plate 13. Aspenglen Trail: Colluvial slope. The impact of "high" use results in a wide trail (3 m) and roots exposed to abrasion and dehydration. A 15 cm ruler is used for scale.

Plate 14. Chasm Lake Trail: Alpine alluvial-colluvial fan. Organic soils on dry and wet meadows are sensitive to loading and impact. Traffic erodes trails down to a shallow, stony substrate and creates islands of turf between braided paths.

these elevations (greater than 11,500 feet or 3500 meters). Knapik (1978) and other workers noted that wet meadows are the most fragile landform, relative to other tundra landforms, but often recover the quickest when trails are closed.

The impact of trails on Alpine Colluvial Slope-Plaination Surface[1] landforms is similar to Alpine Moraines because sides of trails erode headward into the slope and mass wasting, e.g., earth slumps and debris flows, results (Plates 15-16). Once the turf is disturbed, exposed soil is highly susceptible to wind and water erosion and freeze-thaw processes. Preliminary results from ongoing research suggest that the susceptibility of soil to raindrop splash erosion is twice as high on dark, well-developed surface soils in well-drained areas compared to other tundra soils.

The effects of stones on tundra trails are mixed. As noted earlier, stones are commonly removed from trails on moraines and colluvial slope-plaination surfaces and piled on the sides. This disturbs vegetation but may protect the turf from eroding back into the slope. Trails deepen as fine material erodes away and more stones are exposed. Stones too large to remove become an obstacle which induces trail braiding (Plate 16).

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[1] Alpine plaination surface is a general term used to describe a relatively flat flat surface which is a remnant of an ancient erosion surface or the result of periglacial processes e.g. freeze-thaw and solifluction.

Plate 15. Flattop Mountain Trail: Alpine colluvial fan-plaination surface. Turf is undercut along trail edges as soil is eroded by wind, water, and traffic.

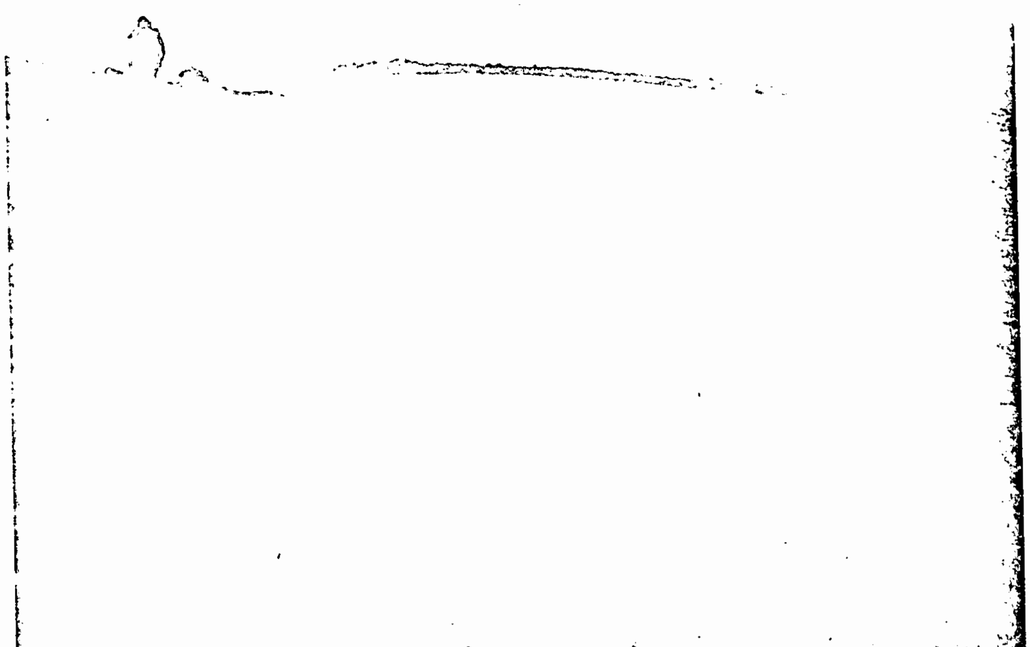

Plate 16. Flattop Mountain Trail: Alpine colluvial fan-plaination surface. Turf is actively being eroded away, exposing surface soil, subsoils, and boulders. Slumping of material is evident in lower right-hand corner.

Summary

The following is a summary of information collected during two seasons of monitoring and observing sections of trails within the Park:

1. The amount of horse traffic is not directly correlative with trail deterioration; rather, traffic and biophysical characteristics of the terrain interact to produce highly variable degrees of impact on trails.

2. Significant biophysical factors governing the degree of trail deterioration in the study area are parent material, gradient of the trail and sideslope, soil texture and organic matter, rockiness, stoniness, vegetation, and drainage.

3. Outcrops and Talus Slopes have a very low susceptibility to trail deterioration and are, therefore, optimum locations for trails.

4. Terrace and Floodplain-Glacial Lake landforms are stable locations for trails, although seasonal bog-like conditions may lead to "low" erosion, depending upon the amount of traffic during wet periods.

5. Level areas on Moraine-Outwash Terraces and tops of Moraines are least susceptible to the impact of "high" horse use in glaciated areas.

6. Sideslopes of Moraines and Colluvial Slopes are ubiquitous landforms in the Park but are poor locations for trails. "Low" use trails on nearly level grades actively erode, and erosion increases with increasing grade, use, and elevation. Incision is especially pronounced on moraines where the trail steepens slightly before reaching the top. Wet, muddy conditions occur where trails intercept springs on steep slopes.

7. Where bog-like conditions prevail on Alluvial-Colluvial Fans, trails are easily incised and are highly erosive regardless of the amount of use. Alpine fans are particularly sensitive and revegetation is very slow.

8. Trails on Alpine Colluvial Fan-Plaination Surfaces are highly sensitive to small amounts of traffic because natural plant invasion is very slow or non-existent and because surface soils are highly erosive. As on other alpine landforms, trails degrade quickly, suggesting that these landforms are the least desirable sites for trails compared to landforms below treeline.

RECOMMENDATIONS

Based on the above information the following recommendations are given:

1. Utilize landform descriptions to identify limiting bio-physical factors which affect management of horse trails and to evaluate the susceptibility of various landforms to different amounts of horse traffic.

2. Avoid locating trails on slopes which are inherently (geologically) unstable. If a slope must be transversed, cross on the upper slope when possible to avoid under-cutting the toeslope and to decrease the length of the sideslope draining onto the trail.

3. Utilize vegetative indicators when possible for evaluating landforms. For example, sage and open ponderosa pine often indicate optimum sites, while aspen and wet meadow species indicate sensitive and erosive sites which should be avoided when possible.

4. Define boundaries of trails, particularly on level terrain and on the tundra to reduce the amount of trail widening and destruction of vegetation.

5. Consider alternative methods of maintenance before cate-gorically removing stones from trails because underlying, fine material may erode away, exposing more stones.

6. Exercise particular care in locating and maintaining trails on the alpine tundra because even small amount of traffic create long lasting disturbances. Any disturbance of vegetation and soil is critical because plant recovery and soil development is slow at best. The current use allowed should be reevaluated and possibly reduced until further progress is made regarding high altitude revegetation.

7. Develop construction guidelines such that new trails will be no wider than .7 meter, will have well marked boundaries, and will be located on optimum units whenever possible.

8. Implement a survey of riders and hikers to determine what qualities constitute an acceptable trail and what conditions of the trail itself make a ride or hike an unacceptable experience.

9. Continue to monitor specific trail transects so that the dynamics of long-term changes and trail stability can be quantitatively evaluated.

CONCLUSIONS AND DISCUSSION

This study has confirmed findings of others (Lucas, 1974; Little, 1975; Helgath, 1975) that horse traffic is not the single, dominant process active on trails, nor is trail degradation always a direct result of horse use. Amounts and rates of trail deterioration is a function of the biophysical characteristics of the terrain interacting with traffic in varying degrees. Knowledge of these factors provides a sound basis for decisions on locating, maintaining, and rehabilitating trails and for predicting possible implications of increasing horse use.

The need for long-term monitoring of trail morphology on permanently located transects cannot be overemphasized. This will provide a key for determining rates of change through time.

Besides the biophysical features and processes noted in this study, other factors may also be important when evaluating the overall quality of horse trails. These are hiker-related factors: volume of horse manure, thickness of dust, general aesthetics, olfactory assaults, and inconveniences associated with either stepping aside for horse trains or hiking past a slow train[1]. Trahan (1977) reported that 65 per cent of hikers in heavily used areas in Rocky Mountain National Park disapproved of horse usage of trails. The Wildland Research Center (1962) found that one third of the users in the Sierras were annoyed by horse smells and droppings. It is probable that serious consideration

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[1]The convenience factor is also a morphologic factor. Trail braiding commonly occurs in large horse groups because the trail guide has less control over the group.

for future management will have to be given to complete separation of riders and hikers as is done in certain Canadian National Parks (Knapik, 1978).

Scientific methods of quantitatively measuring trail and terrain parameters are well established, but evaluating the quality of a trail is still an art. Future comprehensive management decisions will be made only when biophysical and use parameters are closely integrated with the "social" factors to produce acceptable standards of trail quality.

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APPENDIX I

DESCRIPTION OF FIELD AREAS

A. Beaver Meadows Horse Trail (BMT)

Location: Moraine Park Livery

Elevation: 8,080-8,120 feet

Use: This trail is subject to heavy use relative to other horse trails within the Park. An average of about 7,000 horses traverse it during the summer season.

Geology: Morainal and glacial-fluvial deposits; valley fill composed of highly weathered granitic bedrock.

Soil Profiles:

Profile 1. Located within fill valley; very deep, well developed, dark soil.

Profile 2. Located in ponderosa pine in valley between bedrock outcrops; red subsoil; well developed; more compacted and less cumulative than Profile 1.

Profile 3. Located on boulder slope; shallow, droughty soil; black, organic horizons overlying red-yellow, sandy subsoil.

[redacted] CE [redacted] EA [redacted] AD [redacted] # [redacted] OIL [redacted] DE [redacted] RIP [redacted] ON [redacted]

1. SOIL SE	TYPE, PHASE	MAP SYMBOL	CLASSIFICATION	MOI	OR INTEGRADE TO	DATE 5/27/77	BY RS	PH NO.	STOP NO.
2. AREA ~70 m. from trailhead ; near site 1	FOREST Ponderosa	RANGER DISTRICT	STATE	COUNTY	LOCATION SEC. T. R.		
3. PARENT ROCK colluvium; med-cogrn granitic material	FORMATION NAME Silver Plume Granite	MINERALS	TEXTURE	FAULTING	WEATHERING Bedrock deeply weathered + oxidized (rind-2-3cm)	SURFACE STONE AND ROCK <5 %	
4. LANDFORM Fill in small drainage	SLOPE 8°	SINGLE	COMPLEX	ASPECT S30E	ELEVATION 8100'	EROSION	GULLIES	ALKALI	SALINES
5. CLIMATIC ZONE (veg.)	PRECIP. Inches	AV. TEMP. °F	LITTER TYPE	INFILTRATION 10-30	BARE GRD	PERCOLATION	STORAGE	DRAINAGE CLASS	WATER TABLE (Ft.)

6.

HORIZON	DEPTH cm	COLOR (Dry, Moist, Crushed) M	Mottling	TEXTURE	STRUCTURE	CONSISTENCE (Dry, Moist, Wet, Cem.)	Clay Films	Stone Rock % Vol.	Roots	Pores	P	REACTION (pH)	BOUNDARY	PERCOLATION CLASS
O	½-0	partially decomposed litter											c s	
A_{11}	-3	5 YR 2/2		SiL	wk gr vf	fr NS			man vf		NP		c w	
A_{12}	-7	5YR 2/1		SiL+	mod gr fine	fr NS			~~com~~ man ~~fm~~ vf		NP		c w	
BA	-17	5YR 2/2		SL	mod gr-SAB f-med	fi SS		5	com f-m		SP		c w	
B_{21}	-28	5YR 2/2 10YR 2/2 D		SCL	mod SAB med	fi SS	very faint on ~~ped~~	5	com med		SP		g w	
B_{22}	-44			+ SCL-	mod SAB-col co	fi SS-S	faint on peds	5	com co		SP-P		g i	
B_3	44+	5YR 2/2		SL	mod SAB f-m	fi SS		30-50	fine few		SP			
	Hit ROCK/BOULDER													

+ HYDROMETER TEST B_{21} — 7.02 % om by weight (Dry combustion)
B_{22} — 6.68% om

[redacted] A - [redacted] or [redacted] ICE [redacted] BEAVER MEADOWS [redacted] #2 [redacted] SOIL [redacted] DESCRIPTION [redacted]

1. SOIL SERIES	TYPE, PHASE	MAP SYMBOL	CLASSIFICATION	MOI	OR INTEGRADE TO	DATE	BY	PH NO.	STOP NO.
						5/27/77	RS		

2. AREA	FOREST	RANGER DISTRICT	STATE	COUNTY	LOCATION SEC. T. R.
~150 m. from trail head; within valley between Bedrock otcps	Ponderosa				

3. PARENT ROCK	FORMATION NAME	MINERALS	TEXTURE	FAULTING	WEATHERING	SURFACE STONE AND ROCK
granitic - med.-co grn	Silver Plume Granite?					5 %

4. LANDFORM	SLOPE	SINGLE	COMPLEX	ASPECT	ELEVATION	EROSION	GULLIES	ALKALI	SALINES
fill Between ridges	3			S10E	8140'				

5. CLIMATIC ZONE (veg.)	PRECIP. Inches	AV. TEMP.	LITTER TYPE	INFILTRATION	BARE GRD	PERCOLATION	STORAGE	DRAINAGE CLASS	WATER TABLE (Ft.)
ponderosa		45@30cm	needle-grass	50					

6. HORIZON	DEPTH	COLOR Dry, Moist, Crushed — M	Mottling	TEXTURE	STRUCTURE	CONSISTENCE Dry, Moist Wet, Cem.	SPECIAL FEATURES: Clay Films	Stone Rock % Vol.	Roots	Pores	P	REACTION (pH)	BOUNDARY	PERCOLATION CLASS
O	½–0	partially decomposed litter						-					a s	
A_{11}	0-2	7.5YR 3/2	SiL	SiL	wk gr vf	fr NS		-	f com		NP		a w	
A_{12}	-5	10YR 3/2	SiL	SiL	mod gr f	fr NS		-	f com		NP		a w	
B_1	-9	10YR 2/3	SiL	SiL	mod gr-SAB med	fi NS		-	med com		NP		c w	
B_{21}	-24	7.5YR 3/2 10YR 2/2 D	SL	SL	str SAB m-co	fi SS		<5	med-co few		SP		c w	
B_{22}	-41	7.5YR 4/4 7.5YR 3/2 (inside ped)	SL+	SL+	str SAB-B co	fi SS		5-10	med few		SP		g i	
B_{23}	48+	10YR 3/2 D 7.5YR 5/4	LL-	SL-	str SAB M	fi SS		10-30	med few		NP		g i	
		Hit Boulder @ 48												

[redacted] DTM 1 Profile 3 SOIL DESCRIPTION

1. SOIL NO.	TYPE, PHASE	MAP SYMBOL	CLASSIFICATION	MOI	OR INTEGRADE TO	DATE	BY	PH NO.	STOP NO.
						5/23/77	RS		

2. AREA	FOREST	RANGER DISTRICT	STATE	COUNTY	LOCATION
upper end of testsection (switch backs)	Ponderosa; Limber? Juniper				SEC. T. R.

3. PARENT ROCK	FORMATION NAME	MINERALS	TEXTURE	FAULTING	WEATHERING	SURFACE STONE AND ROCK
till (Bull Lake?)						10%

4. LANDFORM	SLOPE	SINGLE	COMPLEX	ASPECT	ELEVATION	EROSION	GULLIES	ALKALI	SALINES
slope (footslope	15°			S50W	8180				

5. CLIMATIC ZONE (veg.)	PRECIP. Inches	AV. TEMP. °F	LITTER TYPE	INFILTRATION	BARE GRD	PERCOLATION	STORAGE	DRAINAGE CLASS	WATER TABLE (Ft.)
Current bushes, cactus		45.5 @20	grass bush	20–40				well	

6.

HORIZON	DEPTH	COLOR Dry, Moist, Crushed	Mottling	TEXTURE	STRUCTURE	CONSISTENCE Dry, Moist Wet, Cem.	Clay Films	Stone Rock % Vol.	Roots	Pores		REACTION (pH)	BOUNDARY	PERCOLATION CLASS
and + O	0–3	7.5YR 5/3 (sand	sandy material (armor) colluvium or weathered granite pebbles and partially decomposed litter										c w	
A	-9	7.5YR 2/2		SL	wk gr fi	fr SS		<2	vf man		SP		c w	
AB	-28	7.5YR 4/2.5 7.5YR 2/2		gL & pockets of sand	wk gr to SG med	Lo NS		5	f com		NP		D c	
B_{21}	-31	7.5YR 4/3		gr LS+	wk SAB med	fr NS		8	vf co		NP		c c	
B_{22}	-41	7.5YR 4/4		gr LS+	mod SAB-COL med	fr NS	very faint on peds	20-40	vf co		NP		g c	
B_3	-45	7.5YR 6/6		gr LS	wk SAB v co	v fr NS		50	f few		NP		c w	
C	77+	10YR 4/6 Rock/STONES		gr sd 20% gr.	SG to med gr vco	Lo NS			—		NP		c w	

VARIATION: 2 m. away – Large BOULDER/BEDROCK @ 14 cm
Profile – 2-0 O
0-6 A + sd si
6-12 B (abrupt Δ to yellow hue)

2500-1 (4-70

B. Tuxedo Park Horse Trail (TPT)

Location: Tuxedo Park near Moraine Park Highway Bridge

Elevation: 7,820-7,900 feet

Use: Sites 1-3 -- old trail

Sites 4-5 -- new trail (first season's use); revegetated area on LH side and relatively undisturbed to partially disturbed vegetation on RH side.

Sites 6-10 - new trail; within revegetated area.

This trail is subject to medium-high use, relative to other horse trails. About 2,500 horses are reported annually from late May through early October.

Geology: Glacial-fluvial deposits.

Soil Profiles:

Profile 1. Cumulative, organic rich, dark soils; trail appears to be entrenched 20-50 centimeters below surface.

Profile 2. Cumulative soil below shrubs; not as dark as Profile 1.

Profile 3. Incipient soil in revegetated area; thin, A horizon; buried horizons occur below gravelly surficial deposits.

Profile 4. Sandy, alluvial soils on flat terrace; drill-seeded but subsoil appears undisturbed.

US[redacted] FOR[redacted] SER[redacted] Tuxedo Park Profile I SOIL [redacted] DESCRIPTION

- **SOIL SE TYPE, PHASE:**
- **MAP SYMBOL:**
- **CLASSIFICATION:**
- **MOI OR INTEGRADE TO:**
- **DATE:** 5/28
- **BY:** RS
- **PH NO.:**
- **STOP NO.:**

- **AREA:** TPT North side of trail at designated trail head
- **FOREST:** PONDEROSA
- **RANGER DISTRICT:**
- **STATE:**
- **COUNTY:**
- **LOCATION:** SEC. T. R.

- **PARENT ROCK:** moraine; Boulder; schist, gneiss, granites
- **FORMATION NAME:** Pinedale ?
- **MINERALS:**
- **TEXTURE:**
- **FAULTING:**
- **WEATHERING:**
- **SURFACE STONE AND ROCK:** 10 – 25 %

- **LANDFORM:** Cumulative area on slope
- **SLOPE:** 7°
- **SINGLE:**
- **COMPLEX:**
- **ASPECT:** S70E
- **ELEVATION:** 7900'
- **EROSION:** hummocky, may be creeping downslope
- **GULLIES:**
- **ALKALI:**
- **SALINES:**

- **CLIMATIC ZONE (veg.):** grass, sage, aspen, bushes
- **PRECIP.:** Inches
- **AV. TEMP.:** 52 @20 °F
- **LITTER TYPE:** grass pine needles
- **INFILTRATION:** 5 Bare GRD
- **PERCOLATION:**
- **STORAGE:**
- **DRAINAGE CLASS:** mod.
- **WATER TABLE (Ft.):**

HORIZON	DEPTH cm	COLOR (Dry, Moist, Crushed) M	Mottling	TEXTURE	STRUCTURE	CONSISTENCE (Dry, Moist, Wet, Cem.)	Clay Films	Stone Rock % Vol.	Roots	Pores	P	REACTION (pH)	BOUNDARY	PERCOLATION CLASS
0	½-0	Undecomposed-partially decomposed Litter <5											a s	
A11	-3.5	7.5YR 4/2		(Si) SiL	Sg	vfr NS	-	<2	vf com		NP		c w	
12	-9.	7.5YR 4/2		L-SL	Sg-wk, gr, fine-med	fr NS-SS	-	<2	f-m com		NP		g c	
13	-38	7.5YR 2/2 & 3/3		L+	mod gr med-co	fr SS	-	<2	oo com		SP		d b	
C(?) h	77+	10YR 3/2	organic staining on grns	LS	Sg – wk. gr, co	vfr NS	-	5-15	f-c few		NP			
	Rock or stone													

* possibly eolian material + fluvial

[redacted] A - [redacted] T [redacted] CE [redacted] T[redacted]E[redacted]PA[redacted] [redacted] 2 [redacted] [redacted] OIL [redacted] D[redacted]RI[redacted]ON [redacted]

1. SOIL SE	TYPE, PHASE	MAP SYMBOL	CLASSIFICATION	MOI	OR INTEGRADE TO	DATE	BY	PH NO.	STOP NO.
						5/28/77	RS		

2. AREA	FOREST	RANGER DISTRICT	STATE	COUNTY	LOCATION
50, of trail in ... willow-bushes before area of revegetation.	willow-bush				SEC. T. R.

3. PARENT ROCK	FORMATION NAME	MINERALS	TEXTURE	FAULTING	WEATHERING	SURFACE STONE AND ROCK
GLACIAL TILL - otwash						5 %

4. LANDFORM	SLOPE	SINGLE	COMPLEX	ASPECT	ELEVATION	EROSION	GULLIES	ALKALI	SALINES
morainal - hillslope - colluvium possibly	18			S20E	7870	POCKET GOPHERS. "BIOTURBATED AT LEAST 60cm Black Dirt!"			

5. CLIMATIC ZONE (veg.)	PRECIP.	AV. TEMP.	LITTER TYPE	INFILTRATION	PERCOLATION	STORAGE	DRAINAGE CLASS	WATER TABLE (Ft.)
	Inches	°F	grass	20% BARE GRD			mod - well	

6.

HORIZON	DEPTH cm	COLOR (Dry, Moist, Crushed) M	Mottling	TEXTURE	STRUCTURE	CONSISTENCE (Dry, Moist, Wet, Cem.)	Clay Films	Stone Rock % Vol.	Roots	Pores	P	REACTION (pH)	BOUNDARY	PERCOLATION CLASS
O	½-0	undecomp - partially decomposed grass-root mat							vf com				a w	
*A11	0-2	10YR 3/3		LS	sg	Lo NS		<2	vf com		NP		c w	
*A12	-7	7.5YR 4/3		SL+	wk gr fine	vfr NS		<2	vf ma		SP		a w	
B1	-16	10YR 3/4		sL	med gr / wk SAB med / fi	vfr-fr NS		5	f com		SP		c w	
B21	-25	10YR 3/3		SiL-L	mod SAB - col. med	fr-fi NS		5	vf-f few		NP		c w	
B22	-65	10 YR 3/2		SL	wk SAB fi	fr SS		<2	vf-co few		NP		d b	
B3	-80	10 YR 3/3		LS - gr LS	sg - wk SAB co	vfr NS		5	–		NP		d b	
Cox	-103+ STONE/ROCK	10YR 3/3 10YR 3/3 D		+ grLS	sg	NS					NP			

* cumulative horizons — + HYDROMETER

1.71% om By weight (Dry Combustion)

[redacted] SERVICE TUXEDO PARK - 3 [redacted] SOI[redacted] DESCR[redacted]IO[redacted]

1. SOIL SE[redacted] TYPE, PHASE	MAP SYMBOL	CLASSIFICATION	MOI	OR INTEGRADE TO	DATE	BY	PH NO.	STOP NO
					5/29/77	RS		

2. AREA	FOREST	RANGER DISTRICT	STATE	COUNTY	LOCATION
SLOPE BEFORE: FLAT LOWER TERRACE; DRILLSEEDED w/GRASS	PONDEROSA (BUSHES)				SEC. T. R.

3. PARENT ROCK	FORMATION NAME	MINERALS	TEXTURE	FAULTING	WEATHERING	SURFACE STONE AND ROCK
GLACIAL-FLUVIAL DEPOSITS	GNEISSIC BEDROCK TONO					10 %

4. LANDFORM	SLOPE	SINGLE	COMPLEX	ASPECT	ELEVATION	EROSION	GULLIES	ALKALI	SALINES
REGRADED ROAD	17				7840'	-			

5. CLIMATIC ZONE (veg.)	PRECIP.	AV. TEMP.	LITTER TYPE	INFILTRATION	BARE GRD	PERCOLATION	STORAGE	DRAINAGE CLASS	WATER TABLE (Ft.)
PONDEROSA-JUNIPER-GRASS, SAGE	Inches	55 @ 20cm °F But only 3/4 Buried	grass	60				well	

6.

HORIZON	DEPTH cm	COLOR (Dry, Moist, Crushed) M	Mottling	TEXTURE	STRUCTURE	CONSISTENCE (Dry, Moist, Wet, Cem.)	Clay Films	Stone Rock % Vol.	Roots	Pores	P	REACTION (pH)	BOUNDARY	PERCOLATION CLASS
O+GR	1-0	30% partially decomp. litter; 70% Gr. armoring											a w	
Ai	-2	10YR 3/2		grLS	wk gr vf	Lo NS		-	few vf		NP		a s-w	
C	-18	10YR 4/4		gravel	sg	Lo NS		-	fi few	NP	NP		c w	
** IIAb	-24	10YR 3/4 & 2/1 *	mixed w/ gravel from C	SL	wk gr fine / wk SAB fine	vfr/fr NS		-	few-com fine	NP	NP		c i	
IIB2b	-31	10YR 3/2		SL-L	mod SAB med	fi NS	wk skins pebbles	-	few f	NP	NP		c i	
IIB3b	-40	10YR 3/1.5		LS	wk SAB - med / fi gr med	fr NS		-	few fi	NP	NP		g i	
IIC	-51+ Rock/Stone	10YR 3/3		grS - S	sg/wk gr fi			25	ø	NP	NP			

* aggregates of lower horizons are disturbed (probably due to compaction

** Not true "b" horizons (By definition, buried horizons must be covered by 50cm of material)

USDA - FOREST SERVICE — TUXEDO PARK - 4 — SOIL DESCRIPTION

1. SOIL SE	TYPE, PHASE	MAP SYMBOL	CLASSIFICATION	MOI	OR INTEGRADE TO	DATE	BY	PF NO.	STOP NO.
			Fluvent (?)			5/28/77	RS		

2. AREA	FOREST	RANGER DISTRICT	STATE	COUNTY	LOCATION
ON FLAT TERRACE BEFORE EAST BRIDGE (horse + Foot Bridge - No side of trail)	Ponderosa - (Bushes)				SEC. T. R.

3. PARENT ROCK	FORMATION NAME	MINERALS	TEXTURE	FAULTING	WEATHERING	SURFACE STONE AND ROCK
Fluvial S + G, floodbasins sediments	GNEISSIC BEDROCK TO NO					5-10 %

4. LANDFORM	SLOPE	SINGLE	COMPLEX	ASPECT	ELEVATION	EROSION	GULLIES	ALKALI	SALINES
Terrace (THIS AREA IS DRILL SEEDED)	2°			S	7825				

5. CLIMATIC ZONE (veg.)	PRECIP.	AV. TEMP.	LITTER TYPE	INFILTRATION	PERCOLATION	STORAGE	DRAINAGE CLASS	WATER TABLE (Ft.)
ponderosa, juniper, grass sage	Inches	51 @ 20 cm °F	grass - sage	20-30 BARE GRD			well	

6.

HORIZON	DEPTH cm	COLOR Dry, Moist, Crushed: M	Mottling	TEXTURE	STRUCTURE	CONSISTENCE Dry, Moist Wet, Cem.	Clay Films	Stone Rock % Vol.	Roots	Pores	P	REACTION (pH)	BOUNDARY	PERCOLATION CLASS
O	½-0	partially decomposed litter and gravel armoring											c w	
A	-4	10YR 2/3		gr LS	wk gr fi	vfr NS				fine cor	NP		c w	
C1	-15	10YR 3/4		gr S	sg	lo NS					NP		g i	
C2	-34+	10YR 3/4, 10YR 2/1*		gr S w/pockets of L*	sg	lo NS					NP			
	stones-pebbles													
		* mud clasts - gravel to pebble size.												

C. Lawn Lake Foot and Horse Trail (LLT)

Location: Lawn Lake Trailhead, Fall River Road

Elevation: 8,590–8,660 feet

Use: Sites 1-3 — used for two summers

Sites 1-6 — footpath only

Sites 7-10 - foot and horse path

This trail is subject to light use relative to other horse trails. About 250 horse trips are reported annually on this trail from late May to early September.

Geology: Bouldery till (Pinedale moraine).

Soil Profiles:

Profile 1. Dark, organic rich, soil on slope; variation of this soil included in the description.

Profile 2. Organic rich soil similar to Profile 1; located on open grassy slopes.

Profile 3. Soil under ponderosa pine; red, distinct subsoil.

USDA - FOREST SERVICE LLT - Profile 1 **SOIL DESCRIPTION**

1. SOIL SE	TYPE, PHASE	MAP SYMBOL	CLASSIFICATION	MOI	OR INTEGRADE TO	DATE	BY	PH NO.	STOP NO.
						5/30/77	RS		

2. AREA	FOREST	RANGER DISTRICT	STATE	COUNTY	LOCATION
upper part of Test section					SEC. T. R.

3. PARENT ROCK	FORMATION NAME	MINERALS	TEXTURE	FAULTING	WEATHERING	SURFACE STONE AND ROCK
Moraine - Till						50-65 %

4. LANDFORM	SLOPE	SINGLE	COMPLEX	ASPECT	ELEVATION	EROSION	GULLIES	ALKALI	SALINE
Side of lateral (?) moraine	30°			S 8E	8660'				

5. CLIMATIC ZONE (veg.)	PRECIP.	AV. TEMP.	LITTER TYPE	INFILTRATION		PERCOLATION	STORAGE	DRAINAGE CLASS	WATER TABLE (Ft.)
Grassy - Some ponderosa	Inches	51 °F @8cm	grass-pine	20-40%	Bare GRD			well	

6. HORIZON	DEPTH cm	COLOR Dry, Moist, Crushed	Mottling	TEXTURE	STRUCTURE	CONSISTENCE Dry, Moist Wet, Cem.	Clay Films	Stone Rock % Vol.	Roots	Pores	Plastic	REACTION (pH)	BOUNDARY	PERCOLATION CLASS
O	¼-0	10YR 2/3 M partially decomposed grass + needles						**					c w	
A11	0-2½	10YR 1.7/1 M w/ grains of 5/4		gr SL	mod gr vf-f	v fr NS	-		fine few-plen		NP		g w-c	
A12	-8	10YR 3/3 M		SL	wk gr vf	v fr NS	-		fine few-plen		NP		c w	
B&A*	-12	10YR 4/3 + 10YR 2/3 M		L+grL	wk gr vf & wk SAB, vf	v fr. SS	-		fine plent		SP		c Ir	
B2	-25	7.5YR 2/1 M		L+	wk-mod SAB med-co	fr SS	faint		fine plent		SP			
R or Stone														

* on slope; therefore this horizon is highly variable

** No estimate of % S OR R; Highly variable

☆ VARIATION: 35cm soil pit downslope.
B2 horizon from 4 to about 30 (including a B3 horizon)
30→35 cm - Fragmental Textural high % voids)

USDA FOREST SERVICE [redacted] Profile — same as #1 — SOIL DESCRIPTION

- **1. SOIL SE TYPE, PHASE:**
- **MAP SYMBOL:**
- **CLASSIFICATION:**
- **MOI... OR INTEGRADE TO:**
- **DATE:** 5/30/77
- **BY:** RS
- **PF NO.:**
- **STOP NO.:**
- **2. AREA:** Near Jct of Horse trail Entrance
- **FOREST:**
- **RANGER DISTRICT:**
- **STATE:**
- **COUNTY:**
- **LOCATION:** SEC. T. R.
- **3. PARENT ROCK:**
- **FORMATION NAME:**
- **MINERALS:**
- **TEXTURE:**
- **FAULTING:**
- **WEATHERING:**
- **SURFACE STONE AND ROCK:** 50 %
- **4. LANDFORM:** grassy open slope
- **SLOPE:** 25°
- **SINGLE:** S 8 E
- **COMPLEX:**
- **ASPECT:**
- **ELEVATION:** 8620
- **EROSION:**
- **GULLIES:**
- **ALKALI:**
- **SALINES:**
- **5. CLIMATIC ZONE (veg.):**
- **PRECIP.:** Inches
- **AV. TEMP.:** 52 °F @ 8 cm
- **LITTER TYPE:** grass
- **INFILTRATION:** 50–80% BARE GRD
- **PERCOLATION:**
- **STORAGE:**
- **DRAINAGE CLASS:**
- **WATER TABLE (Ft.):**

6. HORIZON	DEPTH	COLOR Dry, Moist, Crushed: Moist	Mottling	TEXTURE	STRUCTURE	CONSISTENCE Dry, Moist, Wet, Cem.	Clay Films	Stone Rock % Vol.	Roots	Pores	Plas	REACTION (pH)	BOUNDARY	PERCOLATION CLASS
O	1/4-0	10YR 7/3 + 5/2	undecomposed - partially decomposed Litter					**				None ↓		
O+A	0-10	O- as above ROOT MAT; A- 10YR 3/3	cumulative interlayered horizon	gr LS-SL	mod gr fine + sg	fr.	-	-	vf abund		NP		gr broken	
A1	10-18	10YR 3/3		gr SL	mod gr vf-f	ffr NS			vf pl		NP		cl w	
A3	18-23	10YR 2/2		SL	mod gr fine	fr NS			f pl		NP		cl w	
B2	-36	10YR 3/2		L+ to grL+	wk-mod SAB fine	fr SS			fine few		SP		gr c	
B3	-50r	10YR 3/2		SL	wk gr-SAb med-fine	vfr SS			fine few		NP			
R	or Stone													

* all horizons stony; variable %

[redacted] A. [redacted] OF [redacted] ICE [redacted] L [redacted] 3 [redacted] OIL [redacted] CR [redacted] UN [redacted]

1. SOIL SE	TYPE, PHASE	MAP SYMBOL	CLASSIFICATION	MOI	OR INTEGRADE TO	DATE	BY	PH NO.	STOP NO
						5/30/77	RS		

2. AREA	FOREST	RANGER DISTRICT	STATE	COUNTY	LOCATION
under Ponderosa Pine - Below #1 + #2					SEC. T. R.

3. PARENT ROCK	FORMATION NAME	MINERALS	TEXTURE	FAULTING	WEATHERING	SURFACE STONE AND ROCK
						50 - 60 %

4. LANDFORM	SLOPE	SINGLE	COMPLEX	ASPECT	ELEVATION	EROSION	GULLIES	ALKALI	SALINES
	13			S44E	8600				

5. CLIMATIC ZONE (veg.)	PRECIP. Inches	AV. TEMP. °F	LITTER TYPE	INFILTRATION	PERCOLATION	STORAGE	DRAINAGE CLASS	WATER TABLE (Ft.)
		44 @ 8cm	90% needles 10% grass	Bare grd			well	

6. HORIZON	DEPTH	COLOR Dry, Moist, Crushed: M	Mottling	TEXTURE	STRUCTURE	CONSISTENCE Dry, Moist Wet, Cem.	SPECIAL FEATURES: Clay Films	Stone Rock % Vol. **	Roots	Pores	Plast.	REACTION (pH)	BOUNDARY	PERCOLATION CLASS
O_1	2½-2	10YR 7/3	undecomposed needle + pine cones + grass						–			none	ab sm	
O_2	2-0	5YR 4/6 3/3	partially decomposed Litter (as in O_1)						–				ab sm	
A_{11}	0-1	7.5YR 3/3		SiL	SG	lo NS	none		vf few		NP		a w	
A_{12}	-3	10YR 2/2		L+	mod gr-SAB vf	fi SS			vf few		SP		c w	
B_2	-7	10YR 4/4		SL+-SCL	mod SAB fine	fi SS			f p'		SP		g. c	
C_1	-54	10YR 5/4		SL-SCL	massive	lo SS		–	f-co few	–	SP			
C_2	54+	Boulders and material as in C_1.						60-80%						

** variable although in this profile stones were not observed until C_1 horizon.

APPENDIX II

CHARACTERISTICS OF TERRAIN AND TRAILS: FIELD FORMAT

TERRAIN AND HORSE TRAIL CHARACTERISTICS FIELD SEASON 1978 ROCKY MOUNTAIN NATIONAL PARK (R.M. SUMMER)

PARAMETER					
ELEVATION					
ASPECT					
PARENT MATERIAL					
WIDTH OF TRAIL					
DEPTH OF TRAIL					
TRAIL GRADE (1-5) (<5:5-10: 0-20:20-30:>30 degrees)					
SIDESLOPE ANGLE (1-5)					
LENGTH (1-3) (<10m:10-50:>50m)					
SOIL TX UPPER 5-10 cm					
TX TRAIL FLOOR					
O HORIZON DEPTH					
COLOR					
DEPTH TO C (1-3) (<10:10-20:>20 cm)					
ROCKINESS (SIDESLOPE) (0-5)					
STONINESS (TRAIL) %/ROCK %					
SIDESLOPE, 0-5					
VEGETATIVE COVER %					
TYPE					
LANDFORM					
MASS MVMT EVIDENCE GULLY:RILL:PISTAL BUTT: MUDFLOW:FAN:OVERHANG. TURF					
DRAINAGE CLASS (W:M:P)					
TRAFFIC					
EROSION CLASS (N:L:M:H)					

APPENDIX III. Categorical Divisions Used During Field Data Collection

i. Landform Class

Landform	Parent Material
1. Outcrop (bedrock)	granite, quartz diorite, biotite, schist and gneiss, granitic gneiss.
2. Talus slope	talus (broken fragments of bed-rock), colluvium
3. Terrace	alluvium, (water-laid material), fluvial deposits (river deposits).
4. Floodplain-glacial lake	overbank deposits (fine material on floodplains of rivers), lacustrian deposits (lake sediments).
5. Moraine-Outwash terrace	till (rocks and fine material deposited by glaciers), glacial-fluvial deposits (glacial and river deposits).
6. Moraine	till
a. sideslope	
b. top	
c. alpine moraine	
7. Colluvial slope	colluvium (rock and soil transported by gravity).
8. Alluvial-Colluvial fan	alluvium, colluvium, organic material
a. upper fan	
b. lower fan	
c. alpine fan	
9. Alpine colluvial fan-plaination surface	colluvium, in situ, weathered material*

*High altitude plaination surfaces may be remnants of ancient glacial or periglacial landscapes which have since been eroded and uplifted.

ii. Rockiness (bedrock)

Class	Average distance Between rocks (meters)	%
0	> 100	< 2
1	30 - 100	2 - 10
2	10 - 30	10 - 25
3	3 - 10	25 - 50
4	< 3	50 - 90
5	outcrop	> 90

iii. Stoniness (8-26 cm in diameter)

Class	Average distance Between stones (meters)	%
0	> 30	< .01
1	10 - 30	.01 - .1
2	1.5 - 10	.1 - 3
3	.75- 1.5	3 - 15
4	< .75	15 - 90
5	paved	> 90

iv. Erosion Class

N - Negligible	No marked disturbance within trail; some gravel and soil may be moving imperceptibly [soil creep]; relatively stable.
L - Low	Some deepening and/or widening of trail; cobbles and soil may begin to accumulate along trail edge.
M - Moderate	Noticeable deepening and widening; hoof prints less than 5 cm deep: boulders and cobbles may or may not show evidence of movement; soil and vegetation disrupted.
H - High	Very noticeable deepening and widening; hoof prints greater than 5 cm deep; boulders and cobbles obviously moved down slope or beyond trail edge; soil and vegetation disrupted and moved downslope.

v. Use (traffic)

Class	Average annual # of horses
L - (low)	< 800
M - (medium)	800 - 2000
MH- (medium high)	2000 - 6000
H - (high)	6000 - 8000

vi. Drainage Class

P - Poor

M - Moderate

W - Well

vii. Vegetation

Tree:		Shrub:		Grass/Forb
	Ponderosa Pine		Bitterbrush	
	Aspen		Squaw current	
	Blue Spruce		Thimbleberry	
	Douglas Fir		Juniper	
	Engelmann Spruce		Sage	
	Subalpine Fir			
	Lodgepole			
	Limber Pine			