Recreational Trails Impact Assessment in the Cactus Forest Area and Development of Recreation Monitoring Protocols

DSCESU Report for Trail Impacts Project

April 2006

SONORAN INSTITUTE

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ON THE COVER
From top then left to right: Pink Hill and Loma Verde trail Intersection; Wildhorse and Carrillo trail Intersection, Loma Verde trail, Saguaro NP AZ.
Photographs by Jason Welborn and Cheryl McIntyre, Sonoran Institute.

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Introduction

Saguaro National Park is currently developing a General Management Plan and a complimentary Trail Management Plan. Trails are important to the park; they provide visitor access to maximize visitor enjoyment while minimizing impacts to natural and cultural resources. Many of the park's current trails are concentrated in desert areas that are perceived to be ecologically fragile; therefore, the park has expressed a need to determine if, and the extent to which significant visitor impacts are occurring in these areas. The primary objective of this project is to evaluate impacts of trails on natural resources in the Cactus Forest Area of the park's eastern unit, the Rincon Mountain District (RMD). We focus on resources that are most important to the park's mission and most likely to be impacted: saguaros, other native vegetation, and soils. Data gathered during this pilot project will inform management strategies developed for the park's planning efforts. This project is designed to provide a quantitative assessment of the spatial extent of impacts from trails to park natural resources that can be applied to the entire study area.

This pilot project has additional application for the NPS Sonoran Desert Inventory & Monitoring Network, which is currently in the protocol development phase of its monitoring effort. The protocols it develops for each of its park ecosystem "Vital Signs" will be applied to each of its eleven Network parks where appropriate. This project will serve as a pilot for the development of several of these protocols. Soil quality is one of the Vital Signs in development, to be addressed through soil compaction, soil aggregate stability, biological soil crusts, and soil cover measures. This project also contributes to the advancement of a non-destructive visual method for evaluating biological soil crusts. Vegetation impact data collected during this research aids in the refinement of the vegetation protocols. In addition to assisting the ongoing Inventory and Monitoring activities of the Sonoran Desert Network, the findings and benefits of the protocol development work will be shared with the other federal and state agencies through the Regional Monitoring Partnership led by the Sonoran Institute.

The impact of recreation on soils and vegetation, largely caused by trampling, is well documented for trails and campsites. Many studies have experimentally studied the effect of trampling by humans and livestock on vegetation and soils. Trampling causes abrasion of vegetation typically reducing plant reproduction and vigor. On the trail, where trampling is intense, species richness, diversity, and biomass significantly decrease (Cole 2004). Trampling also causes changes in soil properties through soil compaction. Compaction leads to reduced pore size, increased bulk density, reduced infiltration, increased runoff, and increased erosion. Changes to soils and vegetation due to compaction are depicted in Figure 1 (Liddle 1997). Areas adjacent to the trail experience impacts similar to those caused by trampling (Cole 2004). A modest number of papers have addressed impacts to vegetation and soils adjacent to the trail. The research on adjacent impacts has focused on forests, woodlands, and alpine areas in Montana, Colorado, Indiana, Texas, and Virginia (Cole 1978, Bright 1986, Hall and Kuss 1989, Benniger-Traux et al. 1992, Adkison and Jackson 1996). Few studies have addressed adjacent impacts in the arid southwest. Most research in the forested and woodland areas has studied the alteration of plant diversity and species composition along trails and is based on the assumption that a gradient exists from the trail to areas of undisturbed vegetation (Hall and Kuss 1989). Past studies used quadrats or small plots to sample vegetation at two or three locations along the gradient; (1) adjacent to the trail; (2) near the trail (typically 2m from the trail): and (3) away from the trail (5m or 10m from the trail), and have produced varying results. In some cases, studies found greater cover adjacent to trails (Hall and Kuss 1989) while other studies found decreased cover (Cole 1978). Adkison and Jackson (1996) found increased soil compaction adjacent to the trail and while Hall and Kuss (1989) measured penetration resistance as a complimentary measure, they did not report their results on compaction.

This project aims to determine if a gradient exists from a position adjacent to the trail to a position 10m from the trail for soil cover, soil compaction, and soil surface aggregate stability. The area 10m from the trail is assumed to be undisturbed by the trail. Impacts to giant saguaro cactus (*Carnegiea gigantea*) recruitment and saguaro vandalism by the presence of trails are also investigated. Impacts to the trail are studied by measuring trail width, depth, and cross-sectional area. Historic land use, current recreation use, and distance from access points are considered as factors influencing the potential impacts.

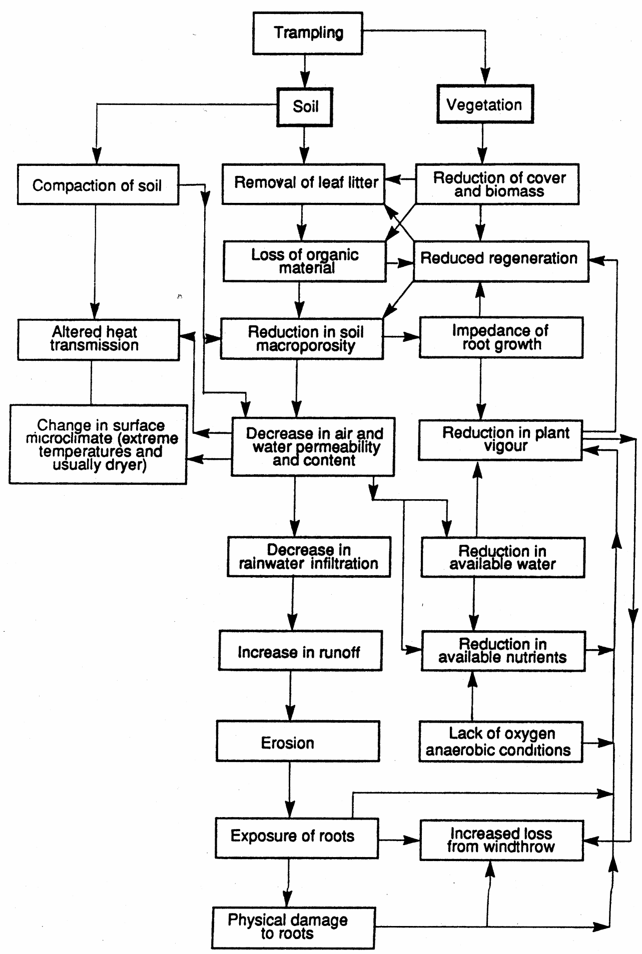

Figure 1. Changes in vegetation and soils from trampling (Liddle 1997)

Study Area

Saguaro National Park's Rincon Mountain District (RMD) unit, established in 1933, is located to the east of Tucson, Arizona (2003 population estimate of 500,000).The Tucson Mountain District, located west of Tucson and established in 1961 complements RMD. The study area is located in the northwest portion of the RMD (Figure 2). It consists of the Cactus Forest trail network, which is bounded to the north by Speedway Boulevard, the east by the Douglas Spring and Carrillo trails, the south by the Cactus Forest Loop Drive, and the west by the Shantz trail. The Cactus Forest trail network encompasses approximately 17 square miles of upper Sonoran Desert scrub vegetation and 37 miles of trail, representing 16 percent of the total area and 31 percent of the total miles of trail in the RMD unit. According to the 2003 soil survey (NRCS 2003), there are ten soil types, with five soil textures, that intersect the trails in the Cactus Forest network (Table 1). Soil in the Cactus Forest trail network is predominantly loamy with sandy soil occurring near major washes. Loamy soils consist of relatively equal amounts of sand, silt, and clay. Terrain in most of study area is fairly level with gently rolling hills. The eastern edge of the Cactus Forest trail network borders the foothills of the Rincon Mountains and contains steeper slopes. Elevation ranges from approximately 2670 to 3480 feet. This is the most intensive concentration of trails within the RMD, and these trails experience high levels of use. Livestock (horses, mules, and donkeys) are allowed on all Cactus Forest network trails, except on the Wildhorse trail south of the Carrillo trail.

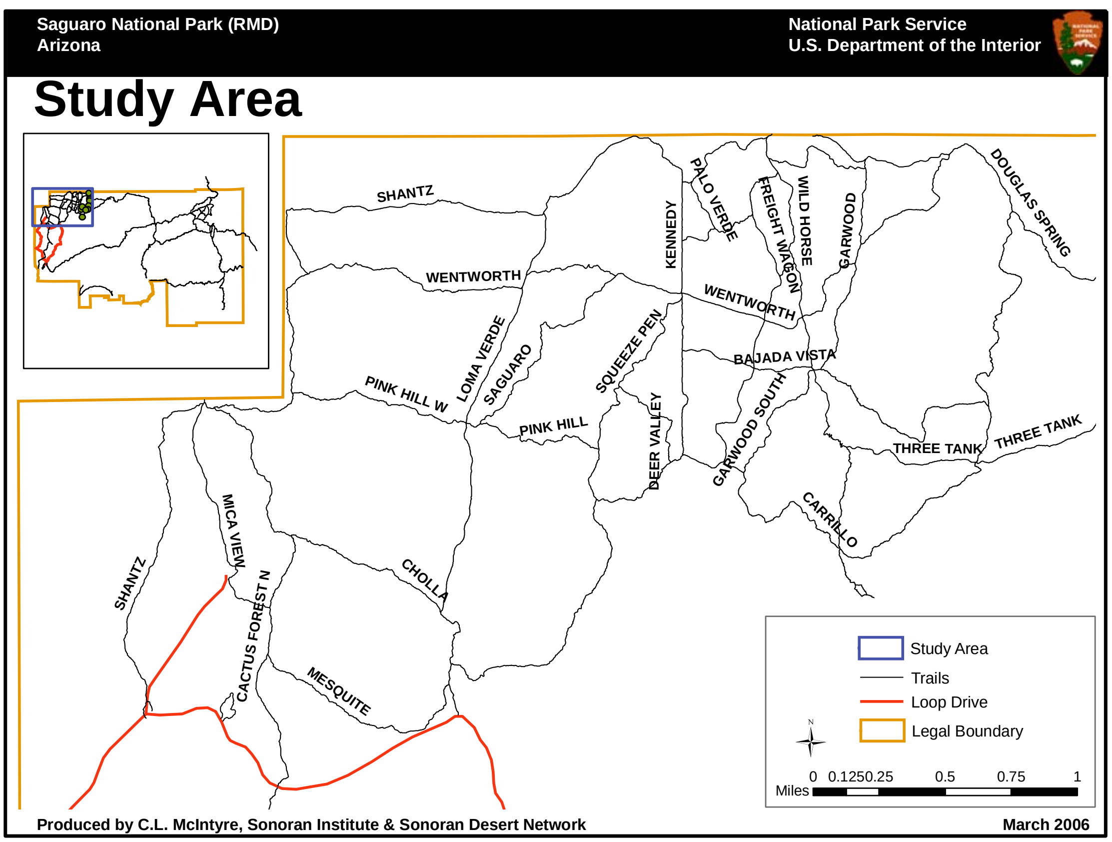

Figure 2. Study location in Saguaro National Park

Table 1. Soil types and textures intersecting Cactus Forest network trails

Soil Type	**Texture**	**Texture Code**
Anthony Fine Sandy Loam, 0 To 3 Percent Slopes	Coarse-loamy, mixed (calcareous)	CLM
Arizo-Riverwash Complex, 0 To 3 Percent Slopes	Sandy-skeletal, mixed	SSM
Cellar-Lehmans Complex, 5 To 25 Percent Slopes	Loamy-skeletal, mixed	LSM
Cellar-Rock Outcrop Complex, 30 To 65 Percent Slopes	Loamy-skeletal, mixed	LSM
Chimenea Very Gravelly Fine Sandy Loam, 5 To 15 Percent Slopes	Loamy, mixed	LM
Lampshire-Romero-Rock Outcrop Complex, 10 To 65 Percent Slopes	Loamy-skeletal, mixed	LSM
Palos Verdes-Jaynes Complex, 2 To 8 Percent Slopes	Fine-loamy, mixed	FLM
Pantano-Granolite Complex, 5 To 25 Percent Slopes	Loamy-skeletal, mixed	LSM
Pinaleno-Stagecoach Complex, 5 To 16 Percent Slopes	Loamy-skeletal, mixed	LSM
Pinaleno-Stagecoach-Palos Verdes Complex, 10 To 35 Percent Slopes	Loamy-skeletal, mixed	LSM

Methods

Initial sampling locations along trails were determined using a stratified random sampling design based on soil type and hillslope with proportional allocation of locations. Geographic Information Systems (GIS) was used to allocate sampling locations. Using ArcGIS 9.0, hillslope was calculated from a 10m DEM. The resulting slope shapefile was intersected with the NRCS soil type coverage (NRCS 2003). The new shapefile was intersected with the trails in the Cactus Forest network and the length of trail for each soil type/hillslope combination was calculated. Using a random point generator in ArcView GIS, sites were generated for each soil type/hillslope combination that represented 10% of trail length within the Cactus Forest trail network. Ninety-six sites were allocated using this method. Forty-eight of those sites were used for the project. Each of the forty-eight sites were sampled in June (pre-monsoon) and October (post-monsoon) of 2005 (Figure 3, Appendix A). After presenting initial results to Saguaro NP staff in October 2004, the staff requested additional sites with steep trail slopes. Sonoran Institute staff hiked the Douglas Spring – Carrillo – Bajada Vista – Three Tank loop (Figure 1) and selectively marked areas with steep trail slopes using a GPS/handheld computer. Ten of these sites were added on sections of trail with trail slopes between ten and eighteen degrees and occurred on soils with loamy-skeletal, mixed texture (Figure 3, Appendix A). Trial profile measurements were collected at the ten steep sites in November (post-monsoon). Each initial sampling location consisted of a 20m transect perpendicular to and centered on the trail (10m = trail center) and a series of belt transects, 5m wide and 100m long, that ran parallel to the trail (Figure 4). At each sampling location three measurements of slope were determined using a clinometer: trail slope, hillslope, and transect slope. The edge of the trail was determined based on readily apparent factors such as bare ground and trampled vegetation. Photographs were taken of the trail and transect.

Trail Profile

The amount of soil that has eroded from the trail at each sampling location was measured using the trail profile method (Cole 1983). During the pre- and post-monsoon sampling seasons, stakes were placed on either side of the trail and a level line was drawn between them. The distance between the ground and the line was measured every 5cm between the stakes. Trail width and maximum trail depth were determined. The cross-sectional area, the amount of soil eroded, was calculated using the Equation 1 where CSA = cross-sectional area, V = the vertical distance measurements, and L = the interval between measurements.

$$CSA = \frac{V_1 + 2V_2 + ... + 2V_n + V_{n+1}}{2} * L \qquad (1)$$

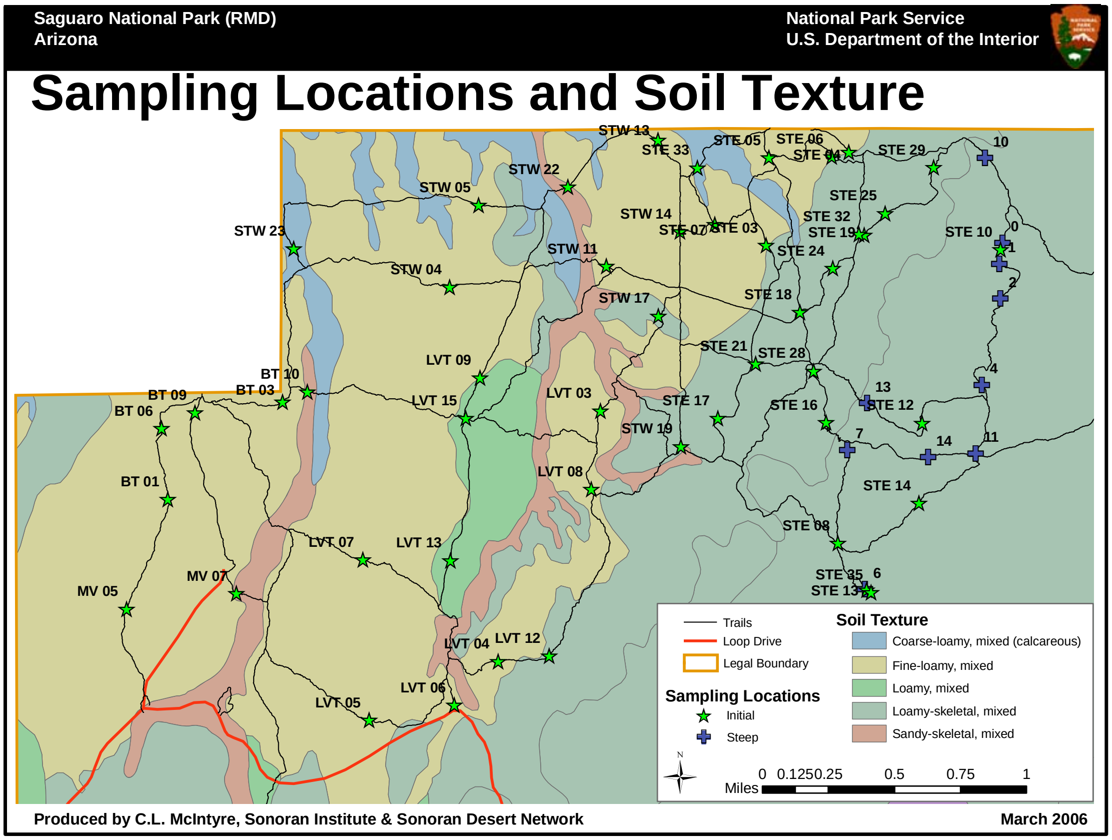

Figure 3. Sampling locations in the Cactus Forest trail network

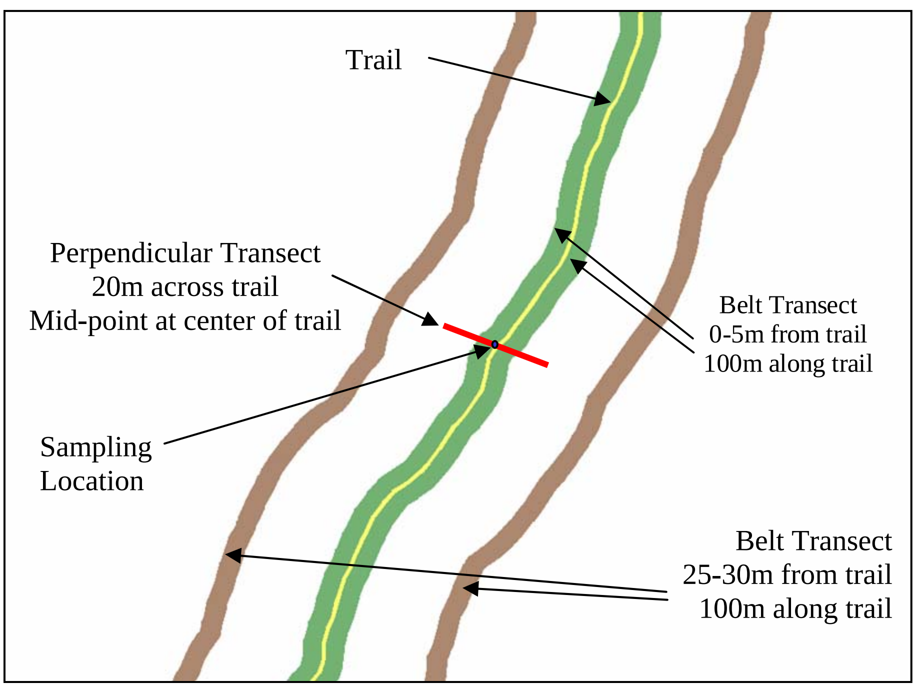

Figure 4. Transect layout at initial sampling locations

Soil Cover

Soil cover was measured using the line-point intercept methods along the perpendicular transect during the pre-monsoon season. The basal cover was recorded every 5cm along the perpendicular transect. Vegetation was identified to lifeform (grass, shrub, tree, etc.) with a small list invasive plants (Table 2) identified to species level. Biological soil crusts were identified to the morphological level (light cyanobacteria, dark cyanobateria, lichen, and moss). Other ground cover types were rock, gravel, litter, and bare ground. During post-processing, the soil and vegetation sampling locations were converted to distance from trail edge as identified during the trail profile sampling.

Table 2. Species identified as invasive for soil cover measurements

Scientific Name	**Common name**
Avena fatua	wild oats
Brassica tournefortii	Saharan mustard
Bromus rubens	red brome
Centaurea melitensis	malta starthistle
Cynodon dactylon	Bermuda grass
Dimorphotheca sinuata	African daisy
Eragrostis cilianensis	stink grass
Eragrostis curvula var. *conferta*	weeping lovegrass
Eragrostis echinochloidea	lovegrass
Eragrostis lehmanniana	Lehmann lovegrass
Erodium cicutarium	redstem filaree
Hordeum murinum ssp. *Glaucum*	wild barley
Lactuca serriola	prickly lettuce
Malva parviflora	cheeseweed
Opuntia lindheimeri	cow's tongue prickly pear
Pennisetum ciliare	buffelgrass
Pennisetum setaceum	fountain grass
Phalaris minor	littleseed canary grass
Polypogon monspeliensis	rabbit foot grass
Rhus lancea	African sumac
Rhynchelytrum repens	natal grass
Salsola australis	Russian thistle
Sisymbrium irio	London rocket
Sorghum halepense	Johnson grass
Tamarix ramosissima	tamarisk
Tamarix sp.	tamarisk

Soil Compaction

Soil compaction was measured by penetration resistance at pre-determined points along perpendicular transect during June 2005 fieldwork. Measurements were taken 1m from the perpendicular transect to avoid interference with the soil cover measurements. A dynamic cone penetrometer was used to measure penetration resistance (Herrick and Jones 2002). The depth reached (cm) after 15 and 30 strikes with a 2kg weight dropped from a height of 50cm was recorded. An increase in penetration depth means a decrease in soil compaction. The soil cover at each point was noted using the classes from the soil cover sampling. Soil compaction measurements were not taken if the soil cover at the pre-determined location was a biological soil crust, if the penetrometer could not be safely operated, or if the soil was too rocky. Soil compaction measurements were conducted at 46 of the 48 initial sampling locations. At each sampling location tested, compaction was measured at nine to twenty points. The compaction sampling points were converted to distance from trail edge for each sampling location based on the trail profile for each site. The depth reached after 15 and 30 strikes was transformed using a cube root transformation to normalize the data. Compaction measurements taken on the trail were excluded from analyses except where noted.

Soil Aggregate Stability

Surface aggregate stability was measured using an aggregate stability field kit and each sample was given a stability rating from one to six with one being least stable and six being most stable (Herrick *et al*. 2001). Ratings above four are considered resistant to wind and water erosion. Soil stability was measured at pre-determined points along but 1m from the perpendicular transect during June 2005 fieldwork. The soil cover at each sampling point was recorded following the rules from the soil cover transect. Any hydrophobic samples were noted but were included in analyses. If a dark cyanobacteria, lichen, or moss biological soil crust was present at the stability sampling point, the sample was rated a six without collecting a sample so the soil crust was not disturbed. If a light cyanobacteria crust was present at the stability sampling point, a sample was collected and rated. Stability on the trail was assumed to be a one rating and samples were not collected on the trail. Soil aggregate stability samples were collected at all initial sampling locations. Ten to twenty-one measurements stability measurements were collected at sampling location. The stability sampling points were converted to distance from trail edge as described above.

Saguaro Recruitment and Vandalism

Saguaro recruitment and vandalism were measured using a two pairs of 5m wide belt transects (Figure 4). The near-trail set of transects counted the number of saguaros by height class within 5 meters of the trail; the away-from-trail transects counted the number of saguaros by height class 25 to 30 meters from the trail. If present, vandalism to any saguaro was noted. Height classes for the saguaros were 0-0.5m, 0.5-1m, 1-2m, >2m, and dead. Saguaro skeletons were recorded as dead regardless of size.

Historic Land Use

Saguaro National Park staff provided copies of historic maps of the study area. Important features, such as boundaries, fences, trails, and roads, were digitized. Current boundaries and features, as well as sampling locations, were overlaid on the historic use layers using ArcGIS 9.0. Park staff also provided GIS layers of the trails that rated the intensity of use, based on a one to five scale, for each trail segment in the study area. Sampling locations were attributed with the use intensity of the trail segment they occupied.

Results

Due to the different allocation method of the initial sampling sites and the steep sampling sites, the resulting data was analyzed and reported separately.

Initial Sampling Sites

Trail Profile

Trail width ranged from 0.5m to 3.5m and averaged 1.3m. On average, trails were rutted 13cm with some trails showing no signs of erosion while others had eroded over 50cm. The mean cross-sectional area was $130cm^2$. The largest cross-sectional area observed was $722cm^2$ at a site with a braided trail near the intersection of Wildhorse and Carrillo (Initial Sampling Location STE 08, Appendix B). Between the pre- and post-monsoon sampling seasons, twenty-three sites aggraded, three sites did not change, and twenty sites eroded (Appendix B). Using linear regression, increases in trail slope resulted in increases in trail width, maximum trail depth, and cross-sectional area. Increases in distance from trailhead resulted in increases in trail with and decreases in trail cross-sectional area. While significantly related, trail slope was found to explain 16% or less of the variability in maximum trail depth and cross-sectional area (Table 3). Soil texture was not found to be significantly correlated with trail width, maximum trail depth, or cross-sectional area using Tukey-Kramer adjusted one-way analysis of variance.

Table 3. Results of regression of trail width, maximum trail depth, and cross-sectional area by trail slope and distance from trailhead.

	Trail Slope			Distance from Trailhead		
	R^2	p-value	Trend[1]	R^2	p-value	Trend[1]
Width	0.024	0.298	increase	0.019	0.345	increase
Max Depth	0.106	0.0237	increase	0.022	0.3144	decrease
CSA	0.162	0.0046	increase	0.009	0.5197	decrease

[1]Trend is the trend in the dependent variable with increasing distance from the trail edge.

Soil Cover

Two invasive forbs (*Erodium cicutarium* and *Sisymbrium irio*) and four invasive grasses (*Bromus rubens, Cynodon dactylon, Eragrostis lehmanniana, Polypogon monspeliensis*) from the invasive species list were found. At least one of the above invasive species was found at nine sampling locations. Soil cover did not exhibit a consistent trend as distance from the trail edge increased. Bare ground, gravel, litter, and invasive species cover decreased with increasing distance from the trail edge (Table 4). Cover of grasses, forbs, and biological soil crusts increased with increasing distance from the trail edge (Table 4). Bare ground, biological soil crusts, litter, and forb cover were all significantly related to distance from trail edge ($p<0.05$, [Table 4]). However, distance from trail edge explained 3 to 15% of the variability in the cover data for those cover types.

Table 4. Results of regression of cover by distance from trail edge.

Cover Type	R^2	p-value	Trend[1]
Bare ground	0.152	<0.0001	decrease
Biological Soil Crust	0.068	0.0004	increase
Gravel	0.015	0.106	decrease
Litter	0.035	0.012	decrease
All Invasives	0.008	0.231	decrease
All Grass (including invasives)	0.003	0.501	increase
All Forbs (including invasives)	0.027	0.028	increase

[1]Trend is the trend in the dependent variable with increasing distance from the trail edge.

Soil Aggregate Stability

Analysis of surface aggregate stability by distance from trail edge using regression showed that stability rating increases with increasing distance from the trail edge for all soil textures except loamy, mixed. Distance from trail edge is significantly related to stability rating for loamy-skeletal, mixed soils. ($p<0.05$, [Table 5]) However, distance from trail edge explained less than 2% of the variability in the stability data for that texture type. Summary statistics for soil aggregate stability were calculated for each site (Table 6). The mean stability ratings were then analyzed using linear regression to test for the influence of distance from trailhead ($p>0.32$).

Table 5. Results of regression of soil aggregate stability rating by distance from trail edge.

Soil Texture	R^2	p-value	Trend[1]
CLM	0.018	0.506	increase
FLM	0.0009	0.567	increase
LM	0.087	0.091	decrease
LSM	0.016	0.039	increase
SSM	0.022	0.305	increase

[1]Trend is the trend in the dependent variable with increasing distance from the trail edge.

Table 6. Summary statistics by site for soil aggregate stability.

Site	Texture	Mean	Std Err	Min	Max
BT01	FLM	5.6	0.2	3	6
BT03	FLM	3.9	0.4	2	6
BT06	FLM	4.4	0.4	1	6
BT09	FLM	3.3	0.4	1	6
BT10	SSM	5.0	0.5	1	6
LVT03	FLM	5.4	0.3	1	6
LVT04	FLM	4.6	0.5	1	6
LVT05	FLM	4.2	0.4	1	6
LVT06	FLM	3.4	0.5	1	6
LVT07	FLM	3.8	0.4	1	6
LVT08	LSM	5.2	0.2	4	6
LVT09	LM	4.4	0.4	1	6
LVT12	LM	4.4	0.4	2	6
LVT13	FLM	3.3	0.2	1	5
LVT15	FLM	4.2	0.5	1	6
MV05	FLM	4.3	0.3	1	6
MV07	SSM	4.8	0.4	2	6
STE03	FLM	4.7	0.5	1	6
STE04	FLM	3.8	0.4	1	6
STE05	FLM	3.8	0.5	1	6
STE06	FLM	5.0	0.3	1	6
STE07	FLM	2.5	0.4	1	6
STE08	LSM	4.0	0.7	1	6
STE10	LSM	4.1	0.6	1	6
STE12	LSM	5.5	0.2	4	6
STE13	LSM	4.9	0.5	1	6
STE14	LSM	5.9	0.1	5	6
STE16	LSM	4.4	0.6	1	6
STE17	LSM	4.7	0.5	1	6
STE18	LSM	5.8	0.2	3	6
STE19	LSM	4.6	0.5	1	6
STE21	LSM	5.4	0.5	1	6
STE24	LSM	4.9	0.4	1	6
STE25	LSM	4.7	0.4	1	6
STE28	LSM	4.0	0.3	2	6
STE29	LSM	4.3	0.5	1	6
STE32	LSM	4.4	0.5	1	6
STE33	CLM	5.2	0.3	2	6
STE35	LSM	3.1	0.7	1	6
STW04	FLM	4.7	0.5	1	6
STW05	FLM	5.3	0.2	3	6
STW11	FLM	2.4	0.4	1	6
STW13	FLM	4.4	0.3	1	6
STW14	FLM	5.0	0.5	1	6

Table 6 (continued). Summary statistics by site for soil aggregate stability,

Site	Texture	Mean	Std Err	Min	Max
STW17	LSM	4.1	0.4	2	6
STW19	LSM	3.9	0.5	1	6
STW22	SSM	4.3	0.5	1	6
STW23	CLM	4.6	0.5	1	6

Soil Compaction

Increases in penetration depth indicate a decrease in soil compaction. Analysis of penetration resistance by distance from trail edge resulted in no soil textures that showed a significant correlation between the presence of a trail and soil compaction (Table 7). There is not a consistent trend in soil compaction with increasing distance from the trail edge (Table 7). Summary statistics for soil compaction were calculated for each site using both the transformed and untransformed data. The untransformed summary statistics are seen in Table 8. The transformed (cube root transformation) mean stability ratings were then analyzed using linear regression to determine that distance from trailhead is not related to soil compaction ($p>0.19$).

Table 7. Results of regression of penetration depth by distance from trail edge.

	15 Strikes			30 Strikes		
Soil Texture	**R^2**	**p-value**	**Trend[1]**	**R^2**	**p-value**	**Trend[1]**
CLM	0.018	0.506	increase	0.124	0.099	increase
FLM	0.0003	0.767	increase	0.008	0.143	increase
LM	0.071	0.189	increase	0.046	0.291	decrease
LSM	0.002	0.487	increase	0.001	0.598	increase
SSM	0.013	0.502	decrease	0.033	0.303	decrease

[1]Trend is the trend in the dependent variable with increasing distance from the trail edge.

Table 8. Summary statistics by site for untransformed penetration depth.

		Depth after 15 strikes (cm)					Depth after 30 strikes (cm)			
Site	**Texture**	**mean**	**std err**	**min**	**max**		**mean**	**std err**	**min**	**max**
BT01	FLM	7.5	0.9	5	16		11.5	1.2	8	23
BT03	FLM	7.9	0.6	5	11		12.7	0.8	7	16
BT06	FLM	8.4	0.9	6	17		11.1	0.5	9	14
BT09	FLM	6.4	1.1	3	17		10.0	1.9	4.5	28
BT10	SSM	19.2	2.8	11	38		27.6	3.3	15	45
LVT03	FLM	11.0	1.2	7	19		14.8	1.4	9	23
LVT04	FLM	11.8	1.2	8	21		17.7	1.3	12	26
LVT05	FLM	13.2	2.6	7	43		18.5	2.7	10	37
LVT06	FLM	8.9	0.9	4	14		15.8	1.9	10	27
LVT07	FLM	9.4	1.1	6	18		16.7	1.4	12	26
LVT08	LSM	10.4	1.6	5	23		14.5	2.0	8	30
LVT09	LM	14.9	2.4	5.5	27		23.5	3.0	10	44
LVT12	LM	15.2	2.5	5	35		28.0	4.4	10	65
LVT13	FLM	8.2	0.5	5	11		13.0	0.8	9	19
LVT15	FLM	6.1	0.6	5	11		9.7	1.0	7	16
MV05	FLM	6.5	0.7	3	15		10.2	0.9	5	18
MV07	SSM	13.9	1.6	8	27		25.6	3.3	14	46
STE03	FLM	7.8	0.6	5	12		11.7	0.6	8	16
STE04	FLM	5.5	0.4	4	8		9.0	0.5	7	12
STE05	FLM	11.3	2.1	4	29		19.3	3.9	5	44
STE06	FLM	16.1	1.3	9	28		26.8	3.1	15	59
STE07	FLM	17.1	1.3	10	26		24.8	1.6	17	40
STE08	LSM	6.5	0.7	3	10		9.8	1.1	5	16
STE10	LSM	10.8	2.4	4	26		14.9	3.0	5	34
STE12	LSM	5.0	0.4	4	10		7.8	0.6	5	13
STE13	LSM	7.9	1.1	5	14		13.3	2.5	8	30
STE14	LSM	7.7	0.4	5	10.5		10.8	0.6	7	14
STE17	LSM	21.0	7.1	4	45		33.5	8.0	22	57
STE18	LSM	9.3	1.5	2	17		15.9	2.4	4	29
STE19	LSM	7.4	0.8	1	13		10.5	1.0	1	17
STE21	LSM	8.4	1.1	5	12		11.6	1.8	6	17
STE24	LSM	5.8	0.5	2.5	9.5		9.0	0.7	5	14
STE25	LSM	6.3	0.5	3	12		8.8	0.5	4	14
STE28	LSM	7.4	1.1	1	25		13.3	2.2	2	42
STE29	LSM	9.1	3.2	4	50		13.2	3.4	5	55
STE32	LSM	9.5	1.0	6	18		11.9	0.8	9	17
STE33	CLM	15.5	1.4	7	28		21.8	1.7	13.5	37
STE35	LSM	32.4	2.4	23	48		39.8	2.9	23	55
STW04	FLM	22.3	2.6	10	37		29.2	3.3	15	49
STW05	FLM	9.9	0.7	3	16		17.8	1.4	4	28
STW13	FLM	15.1	1.2	8	24		22.9	2.2	11	44
STW14	FLM	20.3	1.5	14	26		29.6	2.3	20	40
STW17	LSM	9.5	0.9	5	14.5		13.6	1.1	7	19

Table 8 (continued). Summary statistics by site for untransformed penetration depth

		Depth after 15 strikes (cm)					**Depth after 30 strikes (cm)**			
Site	**Texture**	**mean**	**std err**	**min**	**max**		**mean**	**std err**	**min**	**max**
STW19	LSM	9.7	3.4	1	40		12.4	3.7	2	47
STW22	SSM	33.4	2.4	24	51		44.8	2.4	31	55
STW23	CLM	17.7	2.4	2	37		23.2	2.9	11	40

Saguaro Recruitment and Vandalism

A total of two to thirty-eight saguaros were counted at each sampling location. Saguaro recruitment was not found to be significantly less in areas near the trail than away from the trail (Figure 5). A paired t-test between the two types of transects of saguaros less than 0.5m tall did not show a significant relationship (p=0.32). However, a paired t-test of the two types of transects of saguaros greater than 2m tall showed a significant relationship with distance from trail (p=0.01, [Figure 5]). Vandalism to saguaro skeletons was minimal with five occurrences observed.

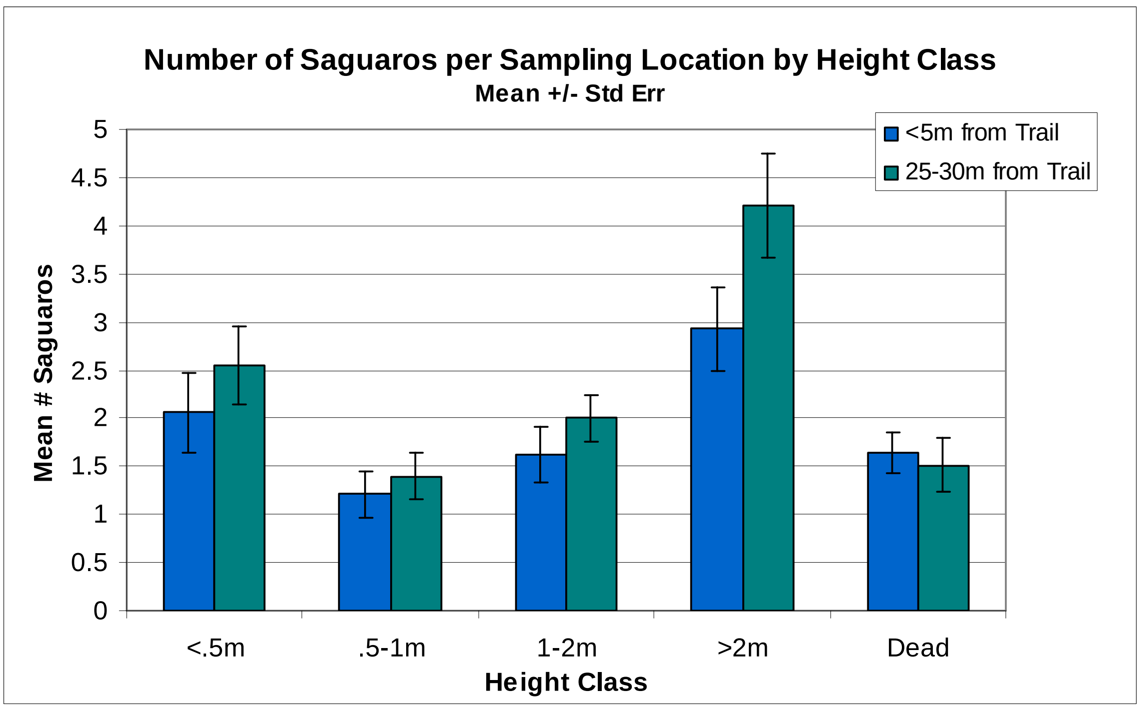

Figure 5. Comparison of number of saguaros per sampling location type by height class

Steep Sampling Sites

Trail Profile

Trail width ranged from 0.75m to 3.5m and averaged 1.4m. On average, trails were rutted 13cm with some trails showing no signs of erosion while others had eroded nearly 40cm. The mean cross-sectional area was 139cm^2. The largest cross-sectional area observed was 598cm^2 at a site with a braided trail along the Carrillo trail (Steep Site #2, Appendix C). This site was also the deepest and widest of the steep sites (Appendix C). Excluding Steep Site #2, the average trail width was 1.2m, the average maximum depth was 10cm, and the average cross-sectional area was 88 cm^2. Trail cross-sectional area, trail width, and maximum trail depth increased with increasing trail slope. Using linear regression, trail slope was not found to be significantly related to trail width, maximum trail depth, or cross-sectional area (Table 8). Soil texture was not found to be significantly correlated trail width, maximum trail depth, or cross-sectional area using Tukey-Kramer adjusted one-way analysis of variance.

Table 8. Results of regression of trail width, maximum trail depth, and cross-sectional area by trail slope and distance from trailhead.

	Trail Slope		
	R^2	**p**	**Trend[1]**
Width	0.226	0.167	increase
Max Depth	0.055	0.514	increase
CSA	0.148	0.273	increase

[1]Trend is the trend in the dependent variable with increasing distance from the trail edge.

Current and Historic Use

The sampling locations are accessed from eight trailheads: Douglas Spring, Wildhorse, Wentworth, Broadway, Mica View, Cactus Forest, and Loma Verde (Figure 2). All sampling locations are within 2.5 miles of a trailhead, which is representative of the Cactus Forest trail network. From early February 2004 through April 2004, seismic counter pads were operated at Douglas Spring, Wildhorse, Broadway, and Wentworth trailheads. A total of 16,666 visitors were estimated to have accessed the Cactus Forest trail network from these four trailheads during the three month sampling period (Gimblett 2004). The Douglas Spring, Broadway, and Wildhorse trailhead were used extensively with 5229, 4862, and 4718 visitors respectively. In contrast, the Wentworth trailhead received only 1857 visitors during the sampling period. Tukey-Kramer adjusted one-way analysis of variance of soil compaction, soil aggregate stability, and trail profile measurements by trailhead did not produce any significant results. The potential relationship between distance from the nearest trailhead on soil quality and trail profile measures was analyzed using linear regression. Soil aggregate stability, soil compaction, and trail profiles were not significantly related to distance from trailhead.

All sampling locations were located in the Twin-Hills grazing allotment (Figure 6), established in 1925. The allotment expanded over time and was grazed until 1956

(Clemensen 1987). Many current trails were dirt roads and used as truck trails and at various times from 1947 to 1976 (Figure 6). Thirteen of the initial sampling locations (27%) were within 25m of historic roads (Figure 6). However, trail width, depth, and cross-sectional area, soil compaction and aggregate stability at sampling locations within 25m of a historic road were not significantly different from sampling locations away from historic roads. Soil compaction on the trail at sampling locations within 25m of a historic road was not significantly different from sampling locations away from historic roads.

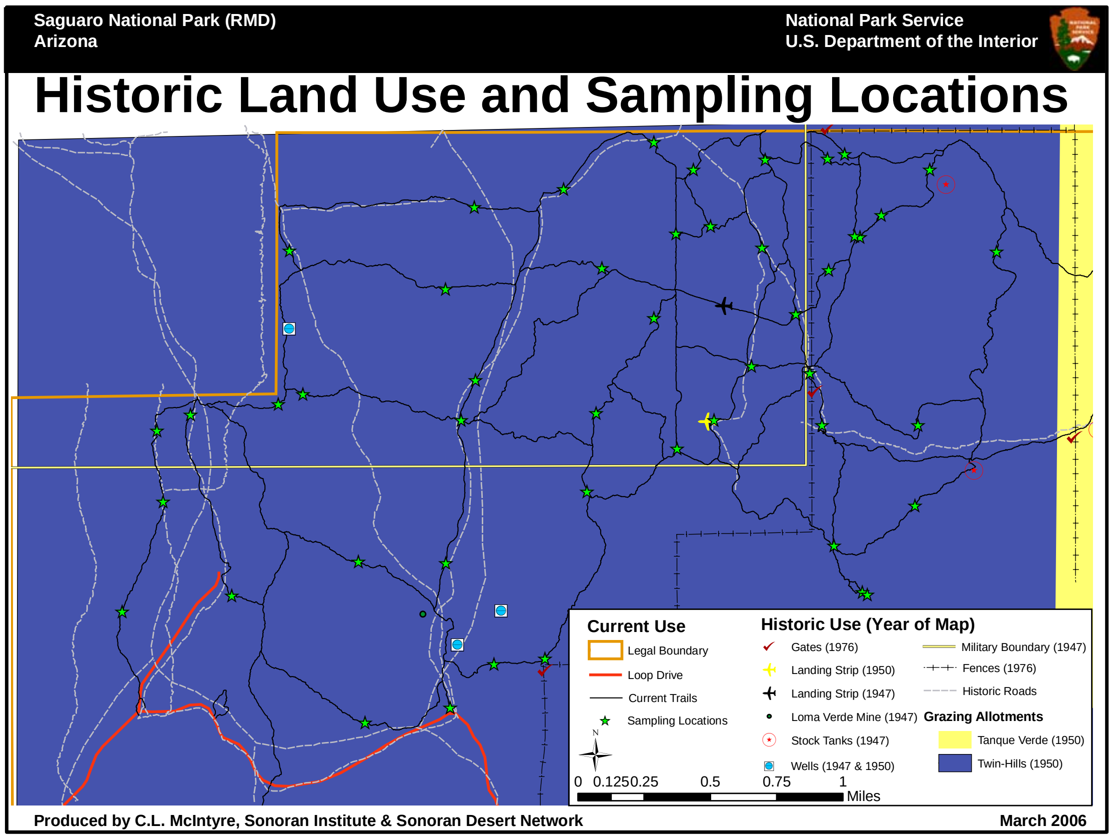

Figure 6. Historic land use and initial sampling points in the Cactus Forest trail network

Discussion

The results presented above show that there is not a gradient in soil cover or soil quality parameters from a position adjacent to the trail to a position 10m from the trail. Bare ground significantly decreased with increasing distance from the trail. However, distance from the trail explained 15% of the variability in the data, which does not support the gradient hypothesis. This result differs from prior studies on impacts to areas adjacent to trails. Visitors may be more confined to the trail in the Cactus Forest network due to the large number of cacti at the trailside, thus limiting adjacent impacts. The methodology used in this study differs from prior studies. Further testing is required to determine if the use of small (0.5m x 1m) quadrats are appropriate for the sparsely vegetated desert to assess impacts to vegetation and soil adjacent to the trail. Measuring vegetation and soil cover using quadrats would be simpler and more efficient than the methods used in this study and would be more sustainable for long-term monitoring. The methods used for aggregate soil stability and soil compaction could also be refined for long-term monitoring. Soil compaction measurements did not show a clear trend when moving away from the trail edge. Small mammal burrows and areas of churned soil were not excluded from soil compaction sampling and may have skewed measurements at some sites. For future monitoring, clear rules must be established on what excludes a point from being sampled, such as the presence of an animal burrow or the number and size of rocks.

There was not a relationship between soil texture or trail slope and trail width, maximum trail depth, and trail cross-sectional area. Nor was there a correlation between the trail from historic land use, current use numbers, or distance from trailhead. This result may be due to the random sampling design. When hiking to sampling locations, the field crew would pass through large sections of trial (>500m) that were not represented by the sampling location (Appendix D). A systematic sampling design of trail profile sites every quarter or half mile would likely capture a more representative picture of trail condition. To monitor all trails, this design would require a large, and perhaps unsustainable, number of sampling locations in the Cactus Forest trail network. However, a systematic sampling design could be employed on a few select trail segments. Another option to aid management decisions regarding trails is locating trail profile sampling locations at known impaired sections of trail or in areas of particular concern.

Conclusion

Soil cover, soil compaction, soil aggregate stability, and saguaro recruitment did not show significant impacts adjacent to the trail compared to away from the trail. Historic land use (grazing and roads) and current recreation use numbers did not correlate with soil quality results. Saguaro recruitment and vandalism were not related to distance from trail. This suggests that the impact of the trail is confined to the obviously impacted area determined to be the trail width. For the Cactus Forest trail network, the average impacted area at a given sampling site is 1.3 meters. Over the entire Cactus Forest trail network this results in 0.03 square miles of area impacted by designated trails. This represents less than 0.2% of the Cactus Forest trail network area.

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Appendix A

Sampling Locations

Coordinates of initial sampling locations

Location Name	Texture Code	Easting	Northing
BT 01	FLM	525579.2019	3564303.6390
BT 03	FLM	526296.1630	3564895.2040
BT 06	FLM	525559.7710	3564734.5370
BT 09	FLM	525762.3629	3564830.9120
BT 10	SSM	526446.5963	3564956.8280
LVT 03	FLM	528226.7076	3564841.2170
LVT 04	FLM	527606.1095	3563317.5260
LVT 05	FLM	526821.9128	3562961.7120
LVT 06	FLM	527339.6240	3563052.7540
LVT 07	FLM	526783.0472	3563936.8230
LVT 08	LSM	528172.6414	3564365.3670
LVT 09	LM	527495.1194	3565043.0390
LVT 12	LM	527914.5915	3563351.5260
LVT 13	FLM	527314.5850	3563932.2420
LVT 15	FLM	527407.8262	3564797.3530
MV 05	FLM	525347.0785	3563637.2600
MV 07	SSM	526014.3659	3563731.4790
STE 03	FLM	529234.7263	3565848.0880
STE 04	FLM	529737.0291	3566415.5210
STE 05	FLM	529252.6188	3566380.2730
STE 06	FLM	529633.5396	3566387.6700
STE 07	FLM	528922.2508	3565976.0090
STE 08	LSM	529671.4634	3564037.7480
STE 10	LSM	530659.9752	3565822.4830
STE 12	LSM	530182.0241	3564767.3050
STE 13	LSM	529845.3748	3563753.6840
STE 14	LSM	530163.1631	3564281.1900
STE 16	LSM	529598.4602	3564770.1710
STE 17	LSM	528942.2412	3564797.3170
STE 18	LSM	529440.2362	3565441.8580
STE 19	LSM	529829.6017	3565910.3290
STE 21	LSM	529171.9605	3565127.6800
STE 24	LSM	529639.3462	3565708.0400
STE 25	LSM	529958.8159	3566041.7990
STE 28	LSM	529523.7915	3565083.6190
STE 29	LSM	530252.4116	3566321.1890
STE 32	CLM	529798.0752	3565915.6310
STE 33	LSM	528816.4293	3566319.6520
STE 35	FLM	529873.8743	3563738.9810
STW 04	FLM	527312.1299	3565593.9390
STW 05	FLM	527488.1159	3566091.4900
STW 11	FLM	528263.3918	3565720.5070
STW 13	LSM	528577.5990	3566486.4130
STW 14	LSM	528711.1554	3565931.8200
STW 17	SSM	528578.7450	3565418.0190
STW 19	CLM	528717.7147	3564625.1540
STW 22	FLM	528029.8838	3566201.9170
STW 23	FLM	526363.5112	3565827.7960

Coordinates of steep sampling locations

Location Name	Easting	Northing
0	530670.0546	3565860.3725
1	530651.7427	3565734.3269
2	530657.0979	3565521.6476
4	530544.2183	3564996.4625
6	529834.3900	3563754.7116
7	529726.9748	3564602.1826
10	530563.2903	3566375.8710
11	530507.2896	3564580.5158
13	529846.4313	3564887.6129
14	530218.6455	3564558.1904