TONTO

PROJECT REPORT

Erosion Assessment of Cultural Resource Sites Using an Index Method

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Cultural resource survey site, Tonto National Monument.

Introduction

Background

Several years ago, Tonto National Monument (NM) began an intensive assessment of archeological site conditions. The assessment was initiated in response to two perceived threats to park resources observed by archeologists at the monument in 2003: vegetation that was adversely impacting standing architecture, and surface erosion caused by large, intense rainfall events. Vegetation impacts were a serious concern at several sites, and during the severe rainstorms, numerous backcountry sites experienced intense surface flow. New gullies formed.

Because unmanaged vegetation growth damages architecture, displaces artifacts, and creates fire hazards, it is necessary to remove and thin vegetation in and around architectural elements in order to protect the structural integrity and information potential of archeological sites. However, removing vegetation can exacerbate erosion problems. Therefore, the purposes of this study were (1) to evaluate the relative risk of site destabilization due to water erosion and (2) to estimate the impact(s) of vegetation removal on water-erosion potential.

To estimate relative site and soil stability, we computed an index score for each archeological site that reflected the sum of factors affecting erosion potential. We then compared these scores within each of three sampling periods (Summer 2006, February 2007, and Fall 2007) to estimate relative erosion potential. Between the Summer 2006 and February 2007 sampling periods, vegetation was cleared to protect structures on the sites. As such, comparing the index scores of any given site between the three sampling periods allowed us to estimate the effect of vegetation removal.

Site and soil stability

Site and soil stability are defined as "the capacity of [a] site to limit redistribution and loss of soil resources . . . by wind and water (Herrick et al. 2005)." For purposes of this study, site stability of the backcountry archeological sites at Tonto NM can be considered as the capacity of each site to limit the loss and movement of cultural resources. Decreases in erosion have been directly correlated with higher stability values, which indicate an increased resistance to soil aggregates' breaking apart in water (Herrick et al. 2005). Both static and dynamic factors determine the susceptibility of a site to water erosion.

Static factors

Static factors are generally not affected by management actions. They include soil parent material, slope, aspect, and climate (Herrick et al. 2005). These factors can be combined to estimate site erosion potential (Davenport et al. 1998). The erodibility of a specific soil is influenced by soil texture, bulk density, soil structure, organic-matter content, and rock-fragment content (Davenport et al. 1998). For example, raindrops easily detach particles from the surface of poorly aggregated soils (Herrick et al. 2005). While static factors are independent of management, they place management decisions into context.

Soil types at Tonto NM include a complex of stable and unstable upland and bajada soils. The bajada, or alluvial fan, soils include older, stable types mapped as Eba and Topawa soils. Less-stable bajada types include Tubac soil and the Tonto family. Upland or mountain soils include

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Biological soil crusts help prevent soil erosion in numerous ways. Cyanobacteria and microfungi secrete sticky mucilage (polysaccharides) around their cells. As they move through the soil when moistened, they leave behind the sticky mucilage and glue soil particles in place. Pictured here is a scanning electron micrograph of cyanobacterial sheath material sticking to sand grains, magnified 90x.

unstable types mapped as Lampshire family, as well as several more-stable, summit soils including the Gadwell, Lemitar, Powerline, and Whitvin families (Lindsay et al. 1994; Nauman 2007). The descriptions of each soil type or family include information on rock-fragment content and texture, which contribute to site stability (Herrick et al. 2005).

Backcountry archeological sites within Tonto NM occur on a variety of slopes and slope positions. Steep slopes allow water running downhill to generate more energy, which increases erosion potential. Because runoff concentrates down slope, sites located near the bottom of longer slopes are more susceptible to water erosion (Herrick et al. 2005).

Dynamic factors

Dynamic factors that affect water erosion include soil disturbance, soil structure, total cover, and plant basal cover. Management actions relative to dynamic factors may alter the susceptibility of a site to erosion.

Soil structure, including porosity, organic matter, and biological soil crusts, affects soil susceptibility to erosion (Herrick et al. 2005). Biological soil crusts secrete polysaccharides that bind soil particles together. In addition to reducing water erosion, the polysaccharides also contribute to soil aggregate structure, which is directly correlated with soil erosion (Belnap 2003; Herrick et al. 2005). Mosses and lichens have small anchoring structures that help them protect the soil surface (Belnap 2003).

The amount of ground cover or total cover is the single most-important dynamic factor affecting water erosion; most soil loss occurs in "unprotected" areas (bare patches) (Herrick et al. 2005; Davenport et al. 1998). The amount of ground cover, and its inverse, the amount of exposed bare ground, are important for estimating erosion potential. As exposed bare ground increases, the erosion rate increases (Davenport et al. 1998). Bare ground that is not protected by plants, litter, gravel, rock, or biological soil crusts—which slow the flow of water and give it more time to soak into the soil—is susceptible to raindrops' breaking apart soil aggregates. In addition, an increase in the amount of bare ground also increases the velocity of surface water flow (Herrick et al. 2005). In the Sonoran Desert, plants play a lesser role in stabilizing soil than in non-desert environments (Belnap et al. 2007).

Methods

Field methods

During Summer 2006, soil stability and ground cover were estimated at 46 of the backcountry cultural sites. Soil and canopy cover were measured using a line-point intercept

Figure 1. A lichen-dominated biological soil crust along a line-point intercept transect.

Figure 2. Soil remaining on screen after five dipping cycles.

method (Herrick et al. 2005). The method was modified to capture canopy-height classes, rock-size classes, and biological soil crust cover by morphological group (light cyanobacteria, dark cyanobacteria, lichen, and moss) along five parallel transects (Figure 1). The transects were ten meters long and spaced five meters apart.

Surface soil aggregate stability was measured using a modified wet aggregate stability method (Herrick et al. 2001). Within each plot, 32 random soil samples of uniform size (2–3 mm thick and 6–8 mm on each side) were sampled from the surface. The samples were placed on a screen and soaked in water for five minutes. After five minutes, the samples were dipped slowly up and down in the water, with the remaining amount of soil recorded as an index of the wet aggregate stability of the sample (Figure 2). Samples were scored from 1–6, with 6 being the most stable (Table 1).

Table 1. Criteria for stability class assignment during soil aggregate stability measurements (Herrick et al. 2001).

Stability class	Criteria for stability class
1	50% of structural integrity lost within 5 seconds of insertion in water
2	50% of structural integrity lost 5–30 seconds after insertion
3	50% of structural integrity lost 30–300 seconds after insertion or <10% of soil remains on sieve after 5 dipping cycles
4	10%–25% of soil remaining on sieve after 5 dipping cycles
5	25%–75% of soil remaining on sieve after 5 dipping cycles
6	75%–100% of soil remaining on sieve after 5 dipping cycles

To create site profile descriptions, slope and distance measurements were taken at the center transect and at all immediately higher slope segments above the site that were visually determined to be contributing runoff (flow-length) to the cultural point of interest. Observed aspect (via compass), landform, and erosion features were also recorded. Photographs were taken as supplementary data.

Vegetation clearing, including cutting away any trees and shrubs from close proximity to site architecture and applying herbicide to stumps to prevent regrowth, took place during the fall of 2006. After vegetation removal, a random subset of 15 sites was re-measured in February 2007 and during Fall 2007.

Index methods

Five indicators, including two static and three dynamic, were used to estimate relative site erosion potential: soil type, slope, soil aggregate stability, exposed bare ground, and biological soil crust presence. Results for each site were assessed against a standard, and each indicator was assigned a 1 for meeting the standard.* Sites were assigned a 0 if they failed to meet the standard. The indicator scores for each site were summed (see "index sum" in Table 2) to produce an index of water-erosion resistance, with higher sums likely corresponding with an increase in erosion resistance. Other parameters considered as

*Because literature reviews did not provide insight into appropriate standards, a standard was established based on expert opinion for each of the five indicators. The standards, and resulting index scores, can be revised as more information becomes available.

Table 2. Results of soil-stability sampling at 46 sites, organized by vulnerability, Summer 2006–Fall 2007.

	Static factors		Dynamiic factors											
Site	Soil type (family)	Average % slope[1]	Average stability[2]			Percent cover exposed bare ground[3]			Mature biological soil crust present[4]			Index sum		
			Summer 2006	February 2007	Fall 2007	Summer 2006	February 2007	Fall 2007	Summer 2006	February 2007	Fall 2007	Summer 2006	February 2007	Fall 2007
41	Lampshire	30	3.69	-	-	0.25	-	-	No	-	-	0	-	-
47	Lampshire	42	3.64	-	-	**0.21**	-	-	**Yes**	-	-	1	-	-
12	**Eba**	33	3.61	-	-	**0.03**	-	-	No	-	-	2	-	-
42	Lampshire	**16**	2.97	3.08	2.82	**0.15**	0.52	0.38	No	No	No	2	1	1
45	Lampshire	**22**	3.79	-	-	**0.17**	-	-	No	-	-	2	-	-
46	Lampshire	41	3.41	3.59	2.05	**0.11**	0.24	**0.09**	Yes	No	No	2	0	1
65	Lampshire	**6**	**5.31**	-	-	0.20	-	-	No	-	-	2	-	-
3	Tubac	**4**	**4.42**	-	-	**0.00**	-	-	No	-	-	3	-	-
14	**Eba**	**14**	3.00	-	-	**0.04**	-	-	No	-	-	3	-	-
28	**Topawa**	**20**	3.94	3.49	3.56	**0.00**	**0.08**	**0.03**	No	**Yes**	**Yes**	3	4	4
48	Lampshire	50	**5.06**	-	-	**0.03**	-	-	**Yes**	-	-	3	-	-
63	Tubac	**10**	3.58	-	-	**0.15**	-	-	**Yes**	-	-	3	-	-
64	**Eba**	31	**4.58**	-	-	**0.03**	-	-	**Yes**	-	-	4	-	-
1	Tubac	**16**	**5.47**	-	-	**0.03**	-	-	**Yes**	-	-	4	-	-
8	**Eba**	**8**	3.86	3.52	2.11	**0.02**	0.21	**0.06**	**Yes**	**Yes**	No	4	3	3
11	**Eba**	**13**	3.76	-	-	**0.08**	-	-	**Yes**	-	-	4	-	-
16	Tonto	**19**	**4.14**	3.83	2.42	**0.00**	**0.06**	**0.01**	**Yes**	No	**Yes**	4	2	3
17	Tonto	**23**	**4.51**	-	-	**0.04**	-	-	**Yes**	-	-	4	-	-
18	Tonto	**10**	**4.55**	-	-	**0.06**	-	-	**Yes**	-	-	4	-	-
23	**Topawa**	48	**4.81**	-	-	**0.03**	-	-	**Yes**	-	-	4	-	-
26	**Topawa**	**13**	**5.22**	-	-	**0.03**	-	-	**No**	-	-	4	-	-
27	Tubac	**14**	**4.50**	**5.45**	**4.06**	**0.09**	**0.05**	**0.08**	**Yes**	**Yes**	No	4	4	3
30	**Eba**	**11**	**4.39**	**4.79**	3.89	**0.00**	**0.09**	0.36	No	No	**Yes**	4	4	3
32	Tubac	**8**	**4.08**	-	-	**0.02**	-	-	**Yes**	-	-	4	-	-
36	**Eba**	**5**	**4.06**	-	-	0.20	-	-	**Yes**	-	-	4	-	-
37	**Eba**	**8**	**4.72**	-	-	**0.04**	-	-	No	-	-	4	-	-
24	**Eba**	27	**4.78**	-	-	**0.09**	-	-	**Yes**	-	-	4	-	-
54	**Gadwell**	27	**5.03**	-	-	**0.12**	-	-	**Yes**	-	-	4	-	-
2	**Eba**	**5**	**5.03**	-	-	**0.02**	-	-	**Yes**	-	-	5	-	-
5	**Eba**	**8**	**4.39**	**4.57**	**4.54**	**0.10**	**0.14**	**0.14**	**Yes**	**Yes**	**Yes**	5	5	5
6	**Eba**	**7**	**4.00**	**4.29**	2.61	**0.11**	**0.08**	**0.01**	**Yes**	**Yes**	**Yes**	5	5	4
7	**Eba**	**7**	**4.75**	**4.85**	3.28	**0.01**	**0.02**	**0.00**	**Yes**	**Yes**	No	5	5	3
9	**Eba**	**19**	**4.61**	3.78	3.58	**0.06**	**0.16**	**0.03**	**Yes**	No	**Yes**	5	3	4
10	**Eba**	**13**	**4.92**	-	-	**0.01**	-	-	**Yes**	-	-	5	-	-
13	**Eba**	**14**	**4.22**	-	-	**0.02**	-	-	**Yes**	-	-	5	-	-
15	**Eba**	**5**	**5.06**	-	-	**0.03**	-	-	**Yes**	-	-	5	-	-
19	**Eba**	**20**	**4.29**	**4.31**	2.75	**0.05**	**0.00**	**0.05**	**Yes**	No	**Yes**	5	4	4
20	**Eba**	**10**	**4.81**	**4.72**	3.50	**0.00**	**0.17**	**0.10**	**Yes**	**Yes**	**Yes**	5	5	4
22	**Eba**	**9**	**5.42**	-	-	**0.05**	-	-	**Yes**	-	-	5	-	-

Table 2. Results of soil-stability sampling at 46 sites, organized by vulnerability, Summer 2006–Fall 2007, cont.

	Static factors		Dynamiic factors											
			Average stability[2]			Percent cover exposed bare ground[3]			Mature biological soil crust present[4]			Index sum		
Site	Soil type (family)	Average % slope[1]	Summer 2006	February 2007	Fall 2007	Summer 2006	February 2007	Fall 2007	Summer 2006	February 2007	Fall 2007	Summer 2006	February 2007	Fall 2007
25	**Topawa**	**11**	**4.03**	-	-	**0.10**	-	-	**Yes**	-	-	5	-	-
29	**Eba**	**9**	**4.31**	-	-	**0.09**	-	-	**Yes**	-	-	5	-	-
31	**Eba**	**10**	**4.11**	-	-	**0.01**	-	-	**Yes**	-	-	5	-	-
33	**Eba**	**14**	**4.28**	**4.94**	2.81	**0.01**	**0.09**	**0.12**	**Yes**	No	**Yes**	5	4	4
34	**Eba**	**6**	**4.06**	**4.26**	*	**0.03**	**0.05**	0.27	**Yes**	**Yes**	**Yes**	5	5	4*
35	**Eba**	**11**	**4.14**	-	-	**0.09**	-	-	**Yes**	-	-	5	-	-
55	**Whitvin**	**20**	**5.41**	-	-	**0.07**	-	-	**Yes**	-	-	5	-	-

Values in bold meet the index criteria for each category. Index sum is the sum of the indicator scores. Lower index sums are expected to be the most susceptible to erosion.

*Soil aggregate stability measurements not conducted due to excess soil moisture. Four is the maximum index sum for site 34.

[1]Sites that had less than an average slope over the contributing hillslope of less than 25% were considered more stable and were assigned a 1.

[2]The average surface stability value was calculated for each site. Sites with average surface stability values greater than 4 were considered more stable and assigned a 1.

[3]Sites with less than 20% exposed bare ground were considered more stable and assigned a 1.

[4]Sites with a mature biological soil crust (composed dark cyanobacteria, lichen, or moss) present were determined to be more stable and assigned a 1.

indicators included plant litter cover, aerial vegetation cover, plant basal cover, and rock cover. However, these parameters are inversely related to the amount of bare ground, and so were not included as indicators.

Results

Of the 46 sites measured during the summer of 2006, one site (41) received an index score of 0, one site (47) scored a 1, five sites scored a 2, and five sites scored a 3. The remainder of the sites scored a 4 or 5 (Table 2).

Following vegetation removal and treatment, 15 of the original 46 sites were re-sampled during February 2007. Of those 15 sites, site 46 scored a 0 on the index score, site 42 scored a 1, site 16 scored a 2, and sites 8 and 9 scored a 3. The remaining 10 sites scored a 4 or higher (Table 2, blue rows).

Upon a revisit during the winter of 2007, two sites (42 and 46) received an index score of 1. Five sites (7, 8, 16, 27, and 30) scored a 3, and the remaining eight sites scored a 4 or higher (Table 2, blue rows).

Discussion

Between Summer 2006 and Fall 2007, 12 of the 15 sampled sites showed a decrease in erosion resistance. (Soil aggregate stability was not measured at site 34 due to excess soil moisture; therefore, an increase or decrease in erosion resistance can not be determined for site 34.) Site 5 did not show a change, while site 28 showed an increase in erosion resistance (Table 2).

While the majority of sites showed a decrease in erosion resistance, the reason for the decrease was not consistent among sites. Overall, soil aggregate stability decreased while exposed bare ground increased. It is possible that trampling contributed to the decrease in stability, in addition to the removal of vegetation, which corresponded with an increase in exposed bare ground. Biological soil crust cover was very low on all sites (<10%). Therefore, a change in the presence or absence of a mature biological soil crust may not be related to disturbance, but may be a result of sampling error.

An overall decrease in erosion resistance was expected, because soil disturbance significantly affects soil and site stability (Herrick et al. 2005). Soil surfaces in the desert are highly vulnerable to trampling, which can cause soil aggregate structure to be lost and biological soil crusts to be crushed, destabilizing the soil (Belnap et al. 2007). The backcountry archeological sites were disturbed by crews clearing vegetation, mapping, and conducting this study. The duration of the impact of this disturbance is unknown at this time. Revisiting the sites in several years may provide insight into the rate of recovery.

While vegetation removal is critical to maintaining the structural integrity of archeological sites, it increases erosion potential. Several options for increasing site and soil stability are available to managers, including building structures that divert water flow away from prone sites or prevent up-gradient cutting of rills and gullies when constructed downhill from sites.

Seeding of native grasses may be an option to mitigate the effect of vegetation removal. Because larger shrubs tend to be a greater threat to site structures, establishing grasses at archeological sites is an alternative to leaving the soil surface exposed to rain impacts after vegetation removal. The resultant increase in plant basal cover would reduce the energy of water flowing across the surface and would decrease its erosive power. Planting perennial native grasses, such as sideoats grama (*Bouteloua curtipendula*), canebeard grass (*Bothriochloa barbinoides*), tanglehead (*Heteropogon contortus*), green sprangletop (*Leptochloa dubia*), bush muhly (*Muhlenbergia porteri*), and cottontop (*Digitaria californica*) may increase site and soil stability.

Restoration using biological soil crusts is another option for increasing site stability. While the ecological role of biological soil crusts has been researched extensively, few studies have investigated their restoration potential. While unassisted recovery of biological soil crusts is a slow process, Bowker (2007) showed that assisted recovery may be appropriate for management projects. The first step in biological soil crust restoration is to determine a "potential condition." This requires finding low-disturbance areas with relict populations of biological soil crusts and achieving a thorough understanding of soil properties at each restoration site. One method of restoring biological soil crusts is inoculation, in which crushed crust material is transplanted in a slurry or dry form. Implementation of this method is limited by the need for a sacrifice area from which material can be removed. However, once a sacrifice area is found, biological soil crusts can be salvaged and stored for long periods of time (Bowker 2007). Identification of a sacrifice area and subsequent storage of biological soil crust material would be two challenges to implementing inoculation at Tonto NM.

Conclusion

This study reinforces previous research describing how soil disturbance can increase erosion potential. Erosion potential increased on archeological sites following vegetation removal and trampling of sites by researchers. The duration of the increase in erosion potential is unknown. Revisiting the sites in several years may provide insight into the rate of recovery. Several options for increasing site stability are available to managers, including the construction of structures, seeding of native grasses, and inoculation of biological soil crusts.

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