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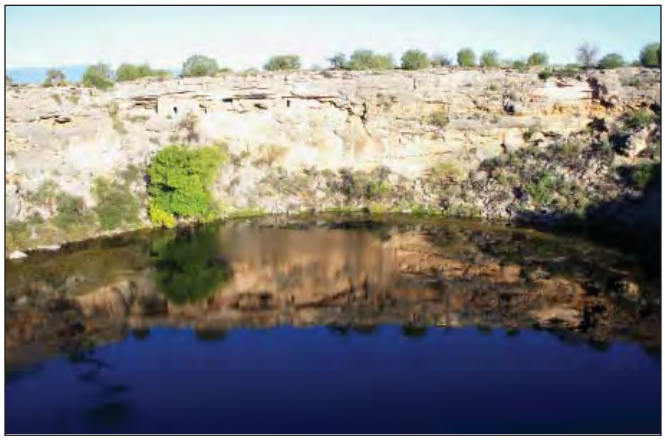
Erosion Assessment for Montezuma Castle and Tuzigoot National Monuments

Natural Resource Technical Report NPS/SODN/NRTR—2010/281



ON THE COVER

Clockwise from left: Tuzigoot National Monument; Montezuma Castle National Monument, Castle unit and Well unit. Photos by Travis Nauman.

Erosion Assessment for Montezuma Castle and Tuzigoot National Monuments

Natural Resource Technical Report NPS/SODN/NRTR—2010/281

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Abstract

In 2009, natural resources staff at Montezuma Castle and Tuzigoot national monuments identified water-related uplands soil erosion as an immediate concern. In response, an erosion assessment of uplands areas in those parks was conducted as part of the National Park Service's Natural Resource Condition Assessment program. Erosion indices and field surveys were completed to support the assessment. Of the 278 hectares surveyed, approximately 11.5 hectares showed signs of active or possibly accelerated erosion. Data collected included GPS locations of active rill, gully, and sheet-erosion features, with ocular estimates of depth, width, and length to help estimate soil loss at those locations. Based on these data, areas of the main ridge at Tuzigoot NM and an alluvial fan at Montezuma Castle NM (Castle unit) were identified as locations with accelerated erosion that may require management attention. The context and severity of other areas exhibiting notable erosion were also documented. Although action was not determined to be necessary in those areas at this time, they do warrant continued observation.

Acronyms

GPS	geographic positioning system
MOCA	Montezuma Castle National Monument
MOCC	Montezuma Castle National Monument (Castle unit)
MOWE	Montezuma Castle National Monument (Well unit)
NDVI	normalized difference vegetation index
SSURGO	Soils Survey Geographic database
TUZI	Tuzigoot National Monument
USPED	Unit Stream Power-based Erosion and Deposition

Terminology

Accelerated Erosion: Soil loss above what might practically be expected given a location's environment and its ability to adapt or re-stabilize. Accelerated erosion is usually associated with a circumstance that triggered excess erosion, and it often creates a negative feedback loop in which erosion causes even more erosion to occur due to environmental degradation (e.g., overgrazing causes erosion due to lack of vegetation, which further stresses vegetation leading to even more erosion).

Active Erosion: Erosional features that indicate recent soil loss, but not at a rate that appears to be degrading the immediate environment beyond its ability to re-stabilize or adapt.

Gully: A large runoff channel that cannot be obliterated by conventional tillage (Soil Survey Staff 1993).

Rill: A small runoff channel that can be obliterated by conventional tillage (Soil Survey Staff 1993).

Scarp: An escarpment, cliff, or steep slope along the margin of a plateau, mesa, terrace, or structural bench. A scarp may be of any height (Jackson 1997).

Sheet Erosion: Erosional process resulting in even soil loss with no channels (Soil Survey Staff 1993). These areas can be visually subtle but are generally indicated by bare-soil exposure with flow patterns sorting particle sizes on the soil surface. Plants in these areas are often slightly raised or pedastalled. The presence of biological soil crust is generally a negative indicator for active sheet erosion unless that crust has also been pedastalled by water eroding around it.

1 Introduction

In 2009, park and Sonoran Desert Network staff initiated a Natural Resource Condition Assessment (NRCA) of Montezuma Castle and Tuzigoot national monuments to ascertain the current status of key natural resources in the context of past and predicted conditions at and around the parks. Potential effects of accelerated soil erosion on fundamental natural and cultural resources were identified as a leading concern during the NRCA scoping process. As a result, a focused soil erosion assessment was conducted at both parks in Autumn 2009.

Upland desert shrubland areas, such as those found in Montezuma Castle and Tuzigoot national monuments, Arizona, can be highly susceptible to water erosion. The arid climate, prone to flash flooding, and easily weathered sedimentary geologies of these areas combine to create a highly erosive landscape. Although erosional processes are a natural part of landscape evolution, they can accelerate under certain conditions (often related to land-use practices), creating problems for park managers charged with preserving cultural and hydrologic resources, as well as flora and fauna.

Both Montezuma Castle and Tuzigoot national monuments preserve cultural sites situated along high cliffs above large drainages fed by perennial water sources. In both parks, sparsely vegetated upland areas are located above the cliffs, cultural sites, slopes, and associated streams. These uplands are dominated primarily by creosote, mesquite, acacia, arid clump grasses, and other smaller shrubs and forbs adapted to the arid climate. These areas tend to have extensive surfaces, with exposed soil between plants. As one of the main contributing factors to soil-erosion potential, these exposed areas, along with the rugged terrain and some areas of fine-grained soils, can help create conditions conducive to accelerated erosion.

The main objective of this project was to map actual erosion on the ground, using a handheld GPS unit, in Tuzigoot National Monument (TUZI) and the two units of Montezuma Castle National Monument: the Castle unit (MOCC) and the Well unit (MOWE). This report documents visual features indicative of active soil erosion due to water. Although wind erosion can also be an issue, and gravity contributes to mass movement on extremely steep slopes, water is the dominant erosional factor in these areas.

2 Methods

Pre-mapping techniques helped to identify areas where erosion might be more likely to occur. An erosion-potential model was created, and an erosion-potential index was devised using Unit Stream Power-based Erosion and Deposition (USPED) methods (Mitasova and Mitas 1999). Base data included (1) a 5-meter-resolution digital terrain model from Intermap Technologies' IFSAR dataset (http://www.intermap.com/digital-elevation-models), (2) a normalized difference vegetation index (NDVI) from an August 21, 2007, Landsat 5 Thematic Mapper image, and (3) soil data from the U.S. Department of Agriculture Natural Resources Conservation Service Soils Survey Geographic database (SSURGO) (http://soildatamart.nrcs.usda.gov/SSURGOMetadata.aspx).

USPED methods modify the Revised Universal Soil Loss Equation (Renard 1997) to include two-dimensional topographic flow patterns. Soil erodibilities were obtained from SSURGO tables. Slope factors were calculated according to the USPED model (after filling sinks to correct noise) and by using Tarboton's (1997) "Deterministic Infinity" flow-routing routine for flow accumulation to replace the slope-length erosion factor. A gridded Cover-Management Factor raster was calculated from Landsat NDVI following Kouli (2007).

Field work included a full roaming survey of upland areas safely accessible on foot. A Trimble GEO XT handheld GPS unit with Terra Sync spatial data-collection software was used for data collection. All areas of sheet erosion, rills, and gullies with signs of active erosion were mapped and attributed with basic dimensional data. Average depth, width, and length of active cutting for each observed feature were recorded in separate attributes attached to a mapped point location. If a feature continued beyond line of sight, the observer continued to follow that feature and either created a new point to continue its representation with the same feature ID or, if the additional area was small, modified the attributes of the original point to include the additional dimensions.†

Depths and widths of less than 5 centimeters were estimated to the nearest centimeter. For all features of 5–75 centimeters, estimates were made to the nearest 5 centimeters. For all features of 75–500 centimeters, estimates were generally made to the nearest 25 centimeters. Estimates greater than 500 centimeters were made to the nearest 100 centimeters.

Lengths of less than 10 meters were estimated to the nearest meter. Lengths from 10 to 40 meters were estimated to the nearest 5 meters, and all observations longer than 40 meters were estimated to the nearest 10 meters. Point features with visual estimates were chosen for the efficiency of data collection and analysis because of time limitations related to covering the entire uplands areas of the parks.

The numbers recorded were all visual estimates, and should be considered as rough estimations of feature size. The same individual made all estimates between September 8 and 22, 2009, so consistency between relative comparisons can be expected. Transects were generally walked in contours perpendicular to the fall-line of any slope present, and spaced apart according to the length of the observer's line of sight. GPS path-tracking was used to help ensure that no areas were missed.

For analysis, mapped features were queried by cross-sectional area (depth × width) to help differentiate areas of accelerated erosion from those of simply active erosion. For sheet erosion, a cross-sectional standard of 0.1 m^2 was established for accelerated erosion. For rills, the standard was set at 0.05 m^2, and for gullies, 1 m^2.

Estimated soil loss was calculated according to the volume of soil (m^3) that would be required to fill the space created by a given erosional feature, based on its recorded measurements.

† The gullies recorded in field mapping were often small to mid-sized washes. These are active ephemeral watercourses in many cases, and part of the natural landscape evolution. Erosion estimates were made to assess active cutting in these channels. Some canyon washes may errantly appear to be gullies. If a wash in a canyon had a stable channel, then no point was taken. However, if there was evidence of even a small amount of cutting (e.g., 30 cm), then a point was taken and the feature was classified as a gully.

3 Results

3.1 Montezuma Castle National Monument: Castle unit

In MOCC, 139 hectares were surveyed, of which 5.4 hectares (3.9%) showed signs of accelerated erosion. Of 541 points mapped, 248 were areas of sheet erosion, 186 were rills, and 107 were gullies. Queries of point records indicating accelerated erosional states showed 204 sheeting areas in excess of 0.1 m^2; 118 rills in excess of 0.05 m^2, and 68 gullies in excess of 1 m^2. There were 419 points that accounted for more than 1 m^3 of soil loss, including 208 sheeting areas, 104 rills, and all of the gullies (107). Gullies dominated in terms of contribution to overall soil loss (Table 3.1).

From the points taken, unique features were identified by combining points with the same feature ID. These unique features included 225 areas of sheet erosion, 165 rills, and 96 gullies. Total estimated soil loss from mapped features was 10,951 m^3. Estimated contribution from different feature types included 1,584 m^3 from sheet areas, 810 m^3 from rills, and 8,557 m^3 from gullies. See Figure 3.1 for a complete map of features.

3.1.1 Northeast fan

A large, toe-shaped sediment fan in the northeast corner of MOCC exhibited extensive, systematic erosion. This erosion begins on the backslope, where gullies and rills flow down from the upland plateau, slows midway down the fan on milder slopes armored with biological soil crust, and resumes in prolific sheet erosion at the lowest apron of the fan. In combination, the long, unbroken slope from the high rim above Beaver Creek, finer sediments on the fan, and large areas of bare soil create this area of accelerated erosion.

3.1.2 Northwest hills

Limestone hills in the northwestern part of the monument show dense numbers of small to mid-sized rill and sheet-erosion features (Figure 3.1.2). Gullies in some of the small drainages associated with these hills probably resulted from high-energy runoff and erosion on adjacent hillslopes.

3.1.3 Southeast gullies

Slopes coming off the highlands in the extreme southeastern part of MOCC showed susceptibility to gully cuts. A series of gullies and associated rilled sideslopes were observed roughly every 30–40 meters along a traverse of the backslope (Figure 3.1.3).

3.1.4 Treatment pond fan

An alluvial fan runs downslope just north of the MOCC treatment ponds. Although the main road, located uphill, serves as an effective flow catch for most of the fan, erosional features showed signs of accelerating in a couple of areas. One gully (g101), which cuts through the center of the fan directly north of the easternmost treatment pond, appears to be significantly lowering the base level of the fan's center. As a result, numerous rills and sheet features were present on slopes to either side of the gully.

3.1.5 Scarps

Although steeper areas along the Beaver Creek floodplain have high geologic erosion rates due to gravitational colluvial movement and high runoff energy, field observations did not yield many signs of acceleration along these slopes. These areas (red diagonal striping in Figure 3.1) exhibit rough, ledge-ridden slopes common to the local limestone outcrops, keeping accelerated

Table 3.1. Estimated numbers of points, erosion features, and associated soil loss, Montezuma Castle NM (Castle unit).

Feature	Points			Features		% of total estimated soil loss
	#	# indicating accelerated erosion	# accounting for at least 1 m^3 of soil loss	#	Attributed soil loss (m^3) estimate	
Sheet erosion	248	204	208	225	1,584	14%
Rills	186	118	104	165	810	7%
Gullies	107	68	107	96	8,557	78%
Total	**541**	**390**	**419**	**486**	**10,951**	**100%**

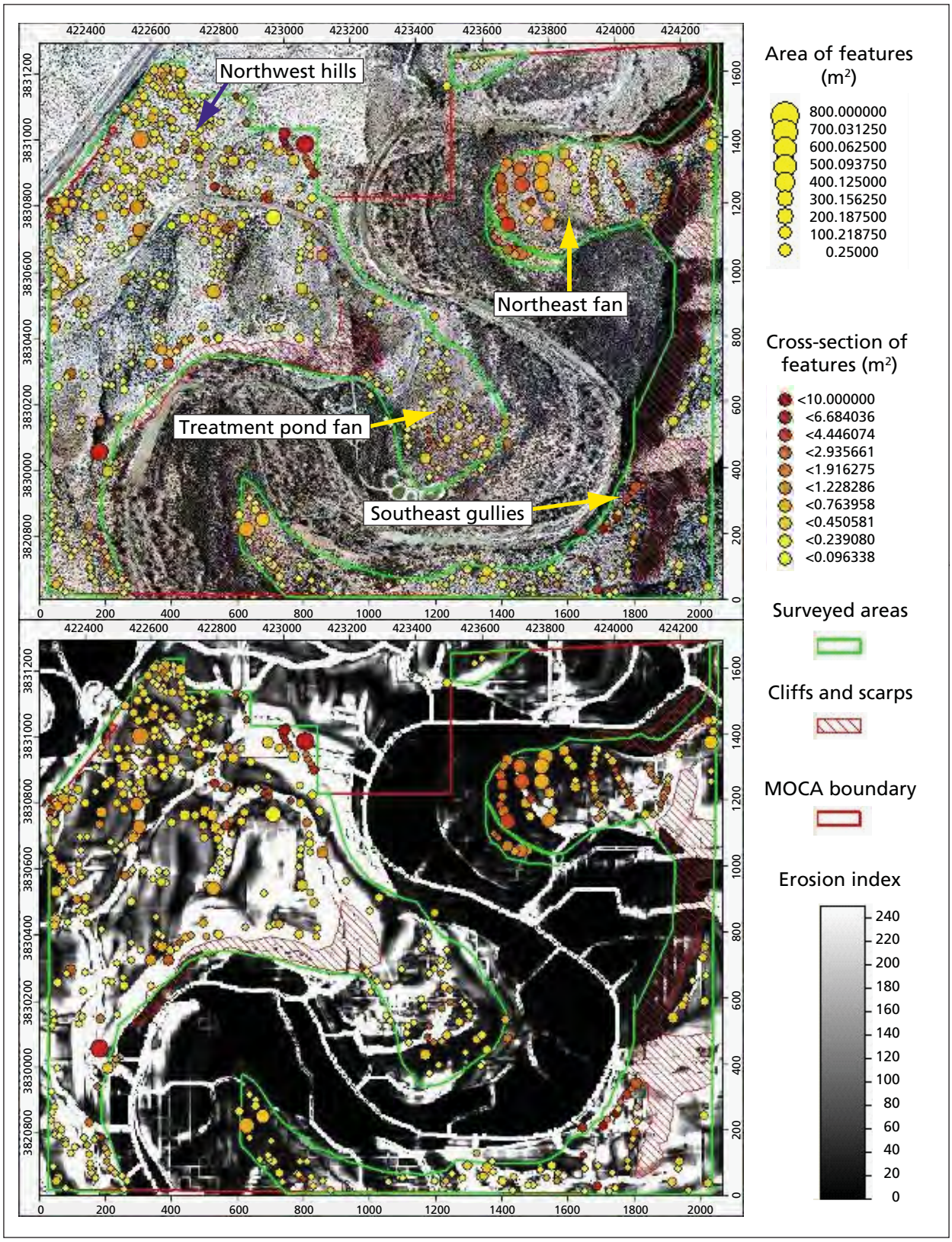

Figure 3.1. Maps showing erosion observations draped over 0.48-meter-resolution aerial photography (top) and a USPED erosion index (bottom). Redder dots have a deeper and wider soil-loss profile. Larger dots correspond to larger areas covered by erosion features. Lighter erosion-index colors indicate higher potential for either erosion or deposition and, thus, represent areas where surface-erosion features were expected in the field. Side ticks on left and top are UTM coordinates in meters. Ticks at bottom and right are scale bars in meters.

Figure 3.1.2. Area of sheet erosion with slightly pedestalled sparse vegetation, located on a slope in the northwestern part of MOCC.

Figure 3.1.3. Gully cutting into slope above Beaver Creek, southeast corner of MOCC.

erosion from proliferating by segmenting flow paths and effectively slowing runoff. One exception was an area of the scarp along the water holding tank road just northeast of the visitor parking lot. From across the drainage immediately west, this slope showed a large bare area, suggestive of many other areas of sheet and rill erosion on similar slopes. Limited time and a steep, unstable route to the spot prevented closer observation.

3.1.6 Stable hilltops and slopes

The rocky hills just north of the castle and along the eastern park border showed few signs of soil loss. The rough materials derived from limestone outcrops and older, cobbly, alluvial deposits that cap the hills deter water erosion due to their coarse particle size. These stand in notable contrast to the finer-grained limestone hills north of the entrance road, discussed earlier in this section.

3.2 Montezuma Castle National Monument: Well unit

Roughly 66 hectares of uplands were surveyed at MOWE, of which 2.2 hectares (3.3%) showed signs of active erosion. Of the 244 points recorded, there were 112 areas of sheet erosion, 103 rills, and 29 gullies. Queries of point records indicating accelerated erosional states showed 85 sheeting areas in excess of 0.1 m^2, 66 rills in excess of 0.05 m^2, and 17 gullies in excess of 1 m^2. Of the points, 181 were estimated to have displaced more than 1 m^3 of soil, including 95 areas of sheet erosion, 57 rills, and 29 (all) gullies. These relative numbers were similar to those of MOCC (Table 3.2).

From the points taken, unique features were identified by combining points with the same feature ID. These unique features included 103 areas of sheet erosion, 99 rills, and 24 gullies. Total estimated soil loss from mapped features was 2,071 m^3. Estimated contribution from different feature types included 549 m^3 from sheet areas, 386 m^3 from rills, and 1,136 m^3 from gullies. See Figure 3.2 for a complete depiction of mapped erosion features in MOWE.

3.2.1 Northwest scarp slope

In the northwest part of MOWE, an elevated rim gives way to steep slopes. These slopes showed dense areas of rilling that often deepened into gullies on the lower backslopes and footslopes. Although relatively rocky, the surface has little ledging or topography to slow water from running off the rim, a situation exacerbated by the presence of fine materials. Because these areas are directly above the road, the catchment structures above the road should be checked after hard rains to make sure they have not washed out.

3.2.2 Northeast gullies and associated fan

A series of gullies has cut through the northeast part of the park just below the Beaver Creek Road. Some are not downcutting as sharply as they may have in the past, but do appear to be widening (Figure 3.2.2). Also, some side gullies and rills have begun to form from the central gully channels.

Because gully cuts tend to move upstream, these gullies probably will not extend down into other parts of the monument, but still may change the hydrology of the area. The small size of the watershed above these cuts will probably not encourage upstream growth, either, but the side branches off the main gully could continue to erode and effectively lower the overall base level of the draw in this area, resulting in large movements of sediment downstream.

Table 3.2. Estimated numbers of points, erosion features, and associated soil loss, Montezuma Castle NM (Well unit).

Feature	Points			Features		% of total estimated soil loss
	#	# indicating accelerated erosion	# accounting for at least 1 m^3 of soil loss	#	Attributed soil loss (m^3) estimate	
Sheet erosion	112	85	95	103	549	27%
Rills	103	66	57	99	386	19%
Gullies	29	17	29	24	1,136	55%
Total	**244**	**168**	**181**	**226**	**2,071**	**100%**

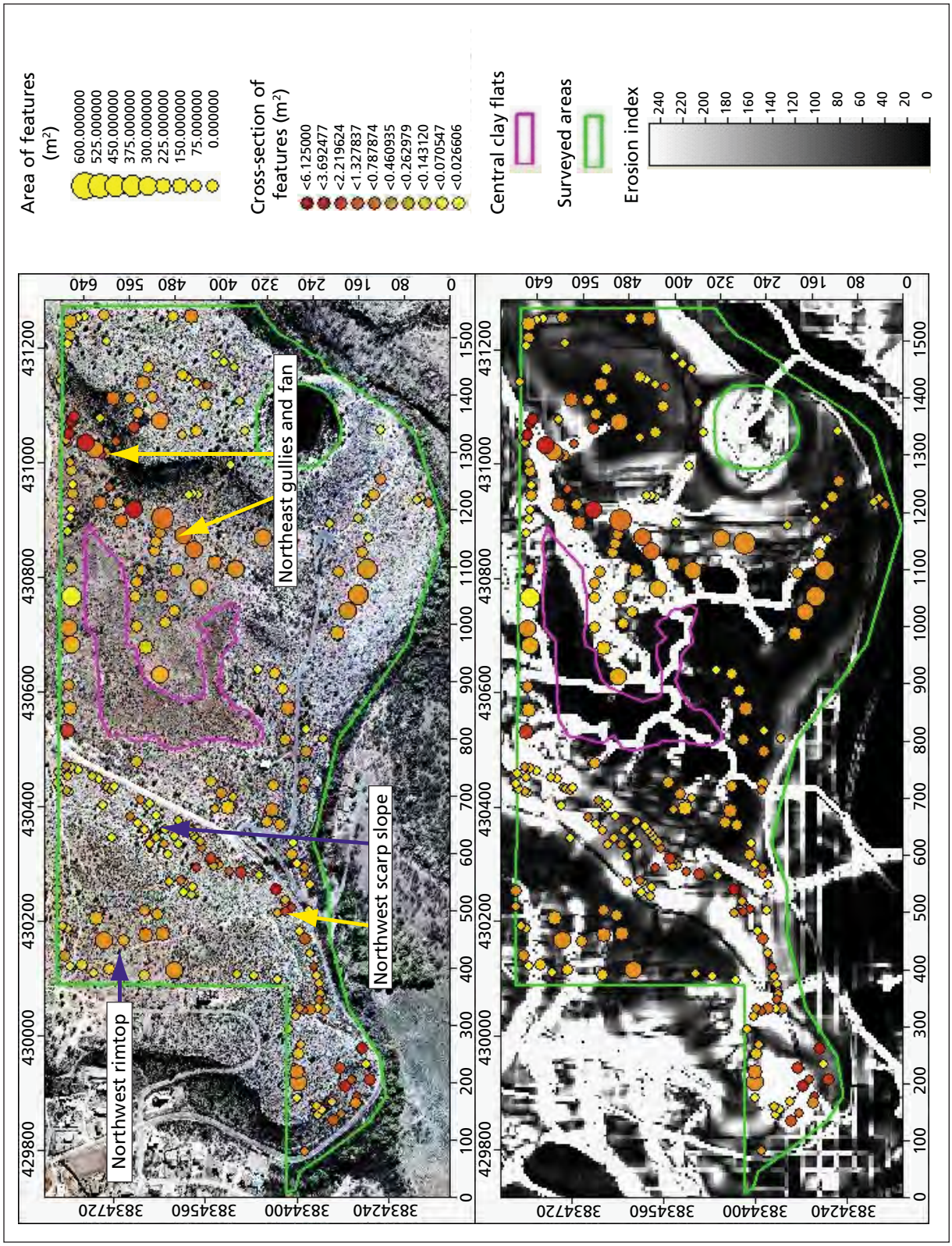

Figure 3.2. Maps showing erosion observations draped over 0.4-meter-resolution aerial photography (top) and a USPED erosion index (bottom). Redder dots have a deeper, wider soil loss profile. Bigger dots represent larger areas covered by erosion features. Lighter erosion-index colors indicate higher potential for either erosion or deposition and, thus, areas where surface-erosion features were expected in the field. Side ticks on left and top are UTM coordinates in meters. Ticks at bottom and right are scale bars in meters.

Figure 3.2.2. This gully, in the northeast corner of MOWE, has begun to widen since its initial downcutting.

Below these gullies, a fan of sediments formed from their deposits is actively moving due to a lack of vegetation that makes the surface susceptible to sheet erosion fed by gully flow. The increased velocity of runoff water carried down the gullies appears to be flushing transported sediments south (toward the monument road) via this sheet flow, which could become problematic if substantial soil loss upstream continues to contribute sediment to the area. However, the small size of the upstream watershed, which only extends to a small saddle just west of the intersection of Beaver Creek and Soda Springs roads, means the amount of area that can contribute sediment is limited. If the gullies in this part of the park maintain their current width and stability level, impacts should be minimal.

3.2.3 Northwest rimtop

This area is characterized by slightly accelerated sheet and rill erosion in some spots and stabilization by vegetation, litter, and biological soil crust in others. Due to large plant interspaces and relatively fine-grained surface soils, these areas erode easily if surface crusts or litter covers are disturbed. Many rimtop areas showed signs of sheet flow slowed by small litter/soil-crust dams that keep levels of both flow energy and sediment transport relatively low (Figure 3.2.3). These areas are so close to becoming erosional that even a couple of people walking through them could disturb the dams and crust enough to allow the next flow event to start displacing surface soil. This situation appears to have already occurred in the extreme northwest corner of the park, where some of the rills and sheet erosion are collocated with a trail evident on the aerial imagery and observed during field efforts.

3.2.4 Central clay flats

Located just south of Beaver Creek Road, after it turns east, are some relatively flat areas with clayey soils that exhibit high shrink–swell activity during dry–wet cycles (Figure 3.2.4). That activity leaves cracks and depressions in the landscape that help to slow surface flow, but also make it difficult for vegetation to establish. This area's lime-rich geology also means that its soils are high in calcium

carbonate and other more soluble minerals. Dissolution is likely occurring along the subsurface cracks, and probably playing a role in creating the depressions, through a process called subsidence. This subsidence, and the extensive animal burrowing observed in these areas, are two factors generally associated with shrink–swell soils and the probable loss of soil minerals dissolved by subsurface water flow. The shrink–swell activity associated with precipitation events makes it difficult to gauge the amount of surface erosion occurring. However, lack of continuous flow patterns in interplant areas, and well-structured, high-activity clays (i.e., very sticky and probably well-flocculated due to high Ca^{2+} concentration) suggest that not much soil is moving via water or wind erosion in these areas (see pink polygon in Figure 3.2).

Figure 3.2.3. This small dam of litter and soil crust is helping to prevent sheet flow from gaining too much energy on the northwest rim of MOWE.

Figure 3.2.4. Area of high-activity clay in central part of park. Only certain grasses and mesquite are lightly established on this soil type, with large areas of bare ground exposed. The cracking and associated macropores and burrows in this soil cause pedastalling around plants and patterns of depressions that help to slow surface flow.

3.3 Tuzigoot National Monument

Of 73 hectares surveyed in Tuzigoot National Monument, 3.9 hectares, or 5.4%, showed signs of active erosion. Some 469 points were mapped, including 128 areas of sheet erosion, 285 rills, and 56 gullies. Queries of points for accelerated erosion states showed 85 sheeting areas in excess of 0.1 m^2, 180 rills in excess of 0.05 m^2, and 26 gullies in excess of 1 m^2. Of the points, 295 were estimated to have displaced more than 1 m^3 of soil. All 56 gullies accounted for at least 1 m^3 of soil loss observed, while only 82 (of 128) sheet-erosion areas and 157 (of 285) rills accounted for more than 1 m^3 of loss (Table 3.3).

From the points taken, unique features were identified by combining points with the same feature ID. These unique features included 118 areas of sheet erosion, 250 rills, and 50 gullies. Total estimated soil loss from mapped features was 10,274 m^3. Estimated contribution from different feature types included 889 m^3 from sheet areas, 3,426 m^3 from rills, and 5,959 m^3 from gullies. See Figure 3.3 for a complete map of mapped features.

3.3.1 Main ridge

This area includes the monument's primary attraction, where ruins are located along a ridgetop. Both the western and eastern slopes of the southern three-quarters of the main ridge exhibited extensive rilling and sheet erosion (Figure 3.3.1). Areas on the steep slopes on either side of the main pueblo showed some of the most prolific rilling in the monument, along with general hillslope instability.

3.3.2 Mesquite shrubland

Footslope areas below the visitor center showed signs of extensive sheet and rill erosion from runoff that flows off of the main ridge. This area includes large areas of exposed bare ground with soils rich in fine sands and silts that are easily washed away by overland water flows. Without vegetation cover or rock content, soils are left vulnerable to impacts from rainfall and overland flows that originate upslope.

3.3.3 Northwestern drainages

Washes in the northwestern part of TUZI have cut into the higher upland areas and appear to have triggered large numbers of gully cuts and rilling of associated backslopes (e.g., Figure 3.3.3). In these areas, the well-defined cliffline, such as that found along the monument's eastern side, has eroded away to create topography and slopes more susceptible to soil loss. Weathering on the resulting hillsides has left finer materials exposed on the surface. These materials are highly erodible in the absence of vegetation to stabilize slopes.

3.3.4 Southeastern canyons

Like the northwestern corner of TUZI, the southeast corner includes some smaller side canyons that cut into upland areas. These drainage slopes are often steep, making it difficult for vegetation to become established. Slopes along these drainages exhibited significant rilling and sheet erosion. The active channels of washes also showed some accelerated gully-cutting that could help transport significant sediment pulses from upstream to the valley floodplain and marsh areas.

Table 3.3. Estimated numbers of points, erosion features, and associated soil loss, Tuzigoot NM.

Feature	Points			Features		% of total estimated soil loss
	#	# indicating accelerated erosion	# accounting for at least 1 m^3 of soil loss	#	Attributed soil loss (m^3) estimate	
Sheet erosion	128	85	82	118	889	9%
Rills	285	180	157	250	3,426	33%
Gullies	56	26	56	50	5,959	58%
Total	**469**	**291**	**295**	**418**	**10,274**	**100%**

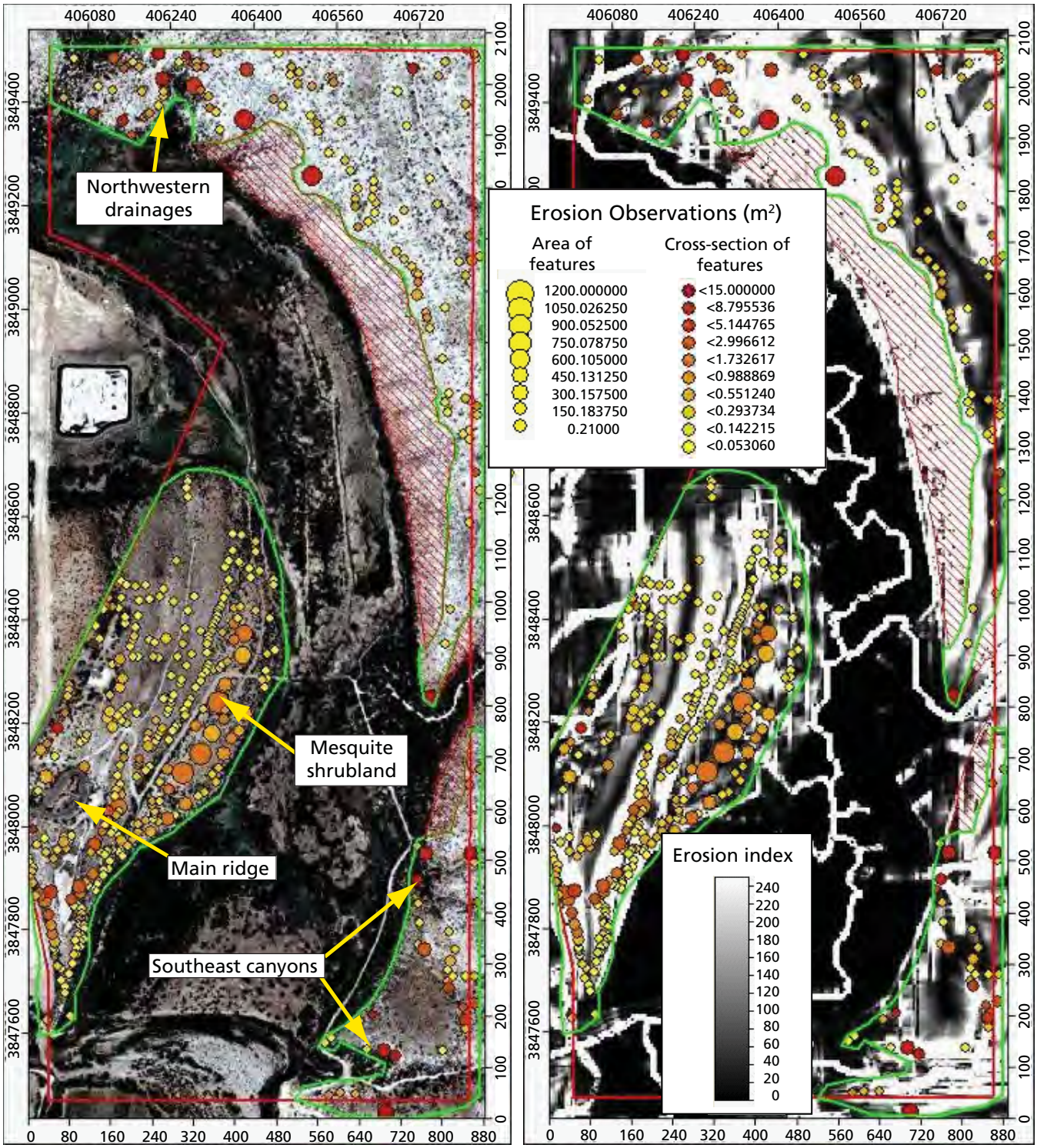

Figure 3.3. Maps showing erosion observations draped over 1-meter-resolution aerial photography (left) and a USPED erosion index (right). Lighter erosion-index values indicate higher potential for either erosion or deposition and, thus, areas where surface-erosion features were expected in the field. Green polygons show areas surveyed. The red polygon is the TUZI legal boundary. The red diagonal fill pattern represents upland areas that were not directly surveyed due to dangerous terrain. Side ticks on left and top are UTM coordinates in meters. Ticks at bottom and right are scale bars in meters. The white meandering lines of the USPED index in the middle of the map should be ignored; they are an artifact of a flow-forcing portion of the algorithm that has problems in areas that are flat or in depressions.

Figure 3.3.1. Rilling on southwest side of the main ridge.

Figure 3.3.3. Gully in the northwestern-drainages area, showing an unstable sideslope above the actual cut.

3.3.5 Eastern scarps

The steep slopes and cliffs that line the east side of Tavasci Marsh were too dangerous to traverse in most places. These areas typically experience high rates of soil and rock movement due to their steepness. In most of the steepest areas on the rim directly above these cliffs, a lack of small side-canyon cuts and gullying indicated limited acceleration of soil loss above natural rates. However, some large rock movements and rilling were observed in the red sandstone deposit beneath the limestone deposits along the scarp (Figure 3.3.5).

Figure 3.3.5. Limestone–Sandstone interface on scarp. This spot showed evidence of accelerated slope movement in the less-stable sandstone layer, where some large boulders have recently detached.

4 Discussion

Although many signs of active and accelerated erosion were found in all three park units, it is important to note that these areas are naturally erosive landscapes. All the predictive models showed that the uplands areas to be mapped were expected to be actively changing due to water erosion. In most cases, signs of erosion were found in areas that pre-mapping predicted would be unstable. The coarse scale of soils data may not have included sufficient information on rock content to fully elucidate the differences between some unstable and stable areas.

However, a couple of areas did stand out during these surveys as having the potential to become degraded, even in this erosion-adapted environment. Potential risk to cultural resources and infrastructure was an additional consideration. While the other features documented here are worth monitoring and perhaps some active management, the areas described below seemed to be most susceptible to negative and lasting impacts.

4.1 TUZI main ridge and mesquite shrubland

Erosion levels in these areas were surprising, given the rocky character of the slopes and presence of the park road, which might be expected to block or at least slow runoff from the mesquite shrubland. Under current conditions, it is possible that the slopes could eventually undercut sidewalks and infrastructure, especially below the ridgetop walkways. This is a particular concern given the number of cultural artifacts concentrated in this area. Some of the steep slopes in this area are off-limits to visitors; keeping that rule in place will benefit both visitor safety and the area's natural and cultural resources. In addition, regular inspection of slopes, from the walkways, may be warranted after storm events.

Another concern, more pertinent to the east side of the ridge, is the protection of unexcavated structures. Many of the rills on this slope were catalogued near these structures, and are in the process of reshaping those sites.

Erosion activity on the mesquite shrubland east of the ridge is probably related to the amount of sediment and flow coming off of the ridge. The new sediment deposits are easily reworked by surface flow, and the continuous change complicates plant establishment. Some flow-obstructing structures have already been built in this area. A re-vegetation program to reduce bare soil surfaces and overland flow rates while increasing infiltration rates would be a positive next step for potential restoration.

4.2 MOCC northeast fan

Except for its very center, most of this fan appeared to be caught in an intense accelerated erosional cycle, with signs that the fan's relatively flat foot has become destabilized. In multiple areas, swales the size of basketball courts have developed, caused by sheet erosion. More than one-quarter meter of soil depth has likely been lost in just the last few years. Vegetation is sparse and losing its foothold in these areas, with lost sediment ending up directly in Beaver Creek. The impact on the creek is difficult to determine, but some of the local pools showed significant sediment build-up. Nutrients in sediments can alter the oxygen levels and chemistry of streams. If possible, it would be beneficial to restore vegetation cover here and slow overland runoff with small structures in key areas.

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