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Soil Erosion And Causative Factors at Vandenberg Air Force Base, California

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Joel B. Butterworth
The Bionetics Corporation, Kennedy Space Center, Florida

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ABSTRACT

In this study, areas of significant soil erosion and unvegetated road cuts were identified and mapped for Vandenberg Air Force Base, California. One hundred forty-two eroded areas (most greater than 3 ac [1.2 ha]) and 51 road cuts were identified from recent color infrared aerial photography and ground truthed to determine the severity and cause(s) of erosion.

Comparison of the present eroded condition of soils (as shown in the 1986 photography) with that in historical aerial photography indicates that most erosion on the base took place prior to 1928. However, at several sites accelerated rates of erosion and sedimentation may be occurring as soils and parent materials are eroded vertically.

The most conspicuous erosion is in the northern part of the base, where severe gully, sheet, and mass movement erosion have occurred in soils and in various sedimentary rocks. Past cultivation practices, compounded by highly erodible soils prone to subsurface piping are probably the main causes of erosion in this area. Improper range management practices following cultivation may have also increased runoff and erosion. The 1986 aerial photography shows that no appreciable headward erosion or gully sidewall collapse have occurred in this area since 1928.

Extensive areas of South Base have partly vegetated soils, probably due to the natural consequences of steep slopes, resistant parent materials, erodible soils, and fire. Other mapped areas of the base are moderately to severely eroded; conditions that are due to a variety of causes, including (but not limited to) past cultivation and grazing practices, steep slopes, and borrow pit construction. Some areas are in need of immediate rehabilitation, particularly several road cuts that supply sediment to drainage systems or may present a hazard to vehicles.

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INTRODUCTION

Soil erosion is "the wearing away of the land surface by running water, wind, ice, or other geological agents and by such processes as gravitational creep" (Shipman 1981). Erosion occurs as a natural process in nearly all environments; however, the rate and magnitude of erosion vary from one environment to another (Howard 1982). In undisturbed environments, erosion is governed primarily by geology, topography, climate, and vegetative cover, and by the influence these factors have on soil physical and chemical properties. Erosion that occurs in undisturbed environments is referred to as geologic or natural erosion.

In managed environments, erosion is controlled by the factors above and especially by the effects of various land use practices on soil and slope conditions. Erosion is termed "accelerated" when the rate of soil removal exceeds that of soil formation; the rate of soil formation at any point in time is governed by the factors of parent rock material, topography, climate, and vegetation (Jenny 1980). Accelerated erosion may also be defined as "erosion much more rapid than normal, natural, or geologic erosion primarily as a result of the influence of the activities of man..." (Glossary Committee 1970).

The purpose of this study is to identify the type and magnitude of significant erosion sites on Vandenberg Air Force Base and to determine the cause(s) of erosion. The distribution and severity of erosion occurring at road cuts are also identified. A digital map derived from a geographic information system (GIS) is produced showing the distribution and magnitude of eroded areas and road cuts. These data should be useful in managing the soil, hydrologic, and biologic resources of the base.

METHODS

Soil Surveys and Related Work

The soils of Vandenberg have been mapped as parts of two soil surveys by the Soil Conservation Service (SCS) (Cole et al. 1958, Shipman 1972). The soil survey maps show soil types that had been eroded at the time the field survey was conducted, but do not indicate directly whether soils were then eroding. The soil maps do not show soil or land types smaller than approximately 5 ac (2.0 ha), and some of the soils mapped as not eroded may have considerable areas within them that are moderately to severely eroded.

Soils designated by the SCS as eroded are those that have lost 25 to 75% of the original A horizon, and may be cut by occasional, shallow gullies. Soils designated as severely eroded have lost more than 75% of the original A horizon, and commonly part or all of the B horizon. Areas mapped as Gullied land are eroded to the point where the original soil profile has been destroyed except in small areas between the gullies (Soil Survey Staff 1951).

A previous study of erosion on Vandenberg was conducted by San Diego State University (Reilly et al. 1976), which identified and mapped areas of potentially high soil erosion and unstable vegetation. Those areas were defined according to the occurrence of steep slopes, eroded soils, and the presence of annual grassland vegetation and/or "unsuitable" land types. Causes of erosion were not determined in the study, and areas were mapped at a rather coarse resolution of 23 ac (9.3 ha) cells.

Interpretation of Aerial Photography

The identification of eroded areas and unvegetated road cuts was based on aerial photography. Color infrared photography (1:32,200 approximate scale) acquired December 1986 was selected for use because it provided the most recent depiction of current soil conditions, and because it allowed for maximum discrimination between vegetated and bare soils. The initial mapping of eroded sites was accomplished by overlaying clear acetate onto the photographs and drawing polygons around areas having spectral characteristics (generally white or light gray colors) indicative of eroded soils or bare rock. Each polygon was then assigned a unique delineation number. Except in a few cases, eroded areas smaller than the minimum mapping unit size of 3 ac (1.2 ha) were not mapped; however, road cuts (normally smaller than 2 ac [0.8 ha] but often significant erosion phenomena) were mapped as points, and were also numbered. The delineation numbers for all sites range from 2 to 194. The letter C follows each road cut delineation number to facilitate discrimination of road cuts from eroded areas. Individual gullies were not mapped, except for those with unusually wide channels or those that were connected by areas of sheet erosion. Because gully erosion occurs throughout most drainages on Vandenberg, it would have been impracticable to map such phenomena.

Ground Truthing and Ancillary Data Analysis

After the preliminary erosion sites were identified from aerial photography, each was ground truthed to assess the type, probable cause(s), and severity of erosion. Erosion was classified according to six types: sheet, rill, gully, wind, mass movement, and excavation. The last type, excavation, was applied to areas in which soil and/or rock material has been removed from borrow pits or rock quarries. Although gully erosion is invariably the dominant erosion type associated with excavated sites, not all excavated sites are eroded or eroding in a conventional sense.

In some cases, two types of erosion are present within a single mapped area; in these situations both types are listed in the accompanying map legend (Appendix 1), with the dominant type given first.

For road cuts, where the nature of disturbance is self-evident, the data are limited to a delineation number and a severity rating.

The causes of erosion were determined by observing site characteristics and conditions and by analysis of historical aerial photography, geologic maps, and soil survey reports and associated data. In most cases, the cause(s) of erosion were not immediately apparent. Aerial photography dated 1928, 1938, 1943, 1954, 1967, and 1974 (see Table 1 for descriptions) was viewed to determine if certain land use practices could be linked to the initiation of accelerated erosion at individual sites. Photography was analyzed for evidence of cultivation, grazing, road construction, burning, firebreaks, and other such activities that are known to induce accelerated erosion.

To determine if eroded areas were actively eroding or healing, the 1986 photography was optically superimposed onto the historical aerial photography using a Bausch and Lomb Zoom Transfer Scope. The photography was then compared to determine if revegetation was occurring, or if the lateral dimensions of the eroded area had increased over time. Geologic maps (Dibblee 1950, Woodring and Bramlette 1950, Muir 1964) and a map showing the locations of some borrow pits and rock quarries (Strategic Air Command 1986) were reviewed. Soil Survey reports (Cole et al. 1958, Shipman 1972) and associated data (Soil Survey Staff 1972) were studied to determine the intrinsic erodibility of soils. The K factor[a] from the Universal Soil Loss Equation

[a]The erodibility factor, K, is a measure of the susceptibility of soils to erosion by water (Shipman 1981). K factor values range between 0.001 and 1.0; the higher the value, the greater the erodibility. On Vandenberg, soil K factors range between 0.15 and 0.43 (Soil Survey Staff 1972). Erodibility is controlled primarily by soil texture, structure, organic matter content, and permeability (Mitchell and Bubenzer 1980).

Table 1. Aerial photography used for analysis of soil erosion.

Year	Date	Coverage[1]	Scale	Flight Number[2]
1928	----	P	1:12,000	C-307 A,B,C; C-311D
1938	Jan	C	1:40,000	C-5140
1943	21 Sep	P	1:20,000	BTM 1944
1954	20 Feb	C	1:20,000	BTM 1954
1967	14 May	P	1:20,000	BTM1967
1974	20 May	C	1:14,000	AF74-9
1986	6 Dec	C	1:32,200	Access 03613, 87-040 (B/W, color, and CIR)

[1]C=Complete coverage; P=Partial coverage

[2]All imagery is B/W print, and is part of the University of California, Santa Barbara Map and Imagery Laboratory collection. Exceptions are the 1928 photos, which are part of the Fairchild Collection at Whittier College, and the 1986 photos, which are owned by the U.S. Air Force.

for each eroded soil type was used to identify those that are particularly erodible. An arbitrary threshold was set to distinguish soils having high erodibility: soils with a K factor of 0.37 or higher were considered to be highly susceptible to erosion.

A variety of causes of erosion at Vandenberg were observed:

1) road or facility construction (from cut slopes or vegetation removal);
2) concentration of runoff from roads or facilities;
3) gravel or borrow pits, or mining activity;
4) demolition;
5) past improper grazing practices;
6) past improper cultivation practices;
7) burning;
8) steep slopes and/or high erodibility (geologic erosion);
9) off-road vehicle (ORV) activity;
10) concentration of runoff from firebreaks; and
11) unknown.

In a number of cases, two factors are responsible for the initiation and/or the continuation of erosion. In these situations both factors are listed in the map legend; as with erosion types, the dominant factor is given first.

Severity of erosion was determined using a flexible set of criteria. With regard to eroded soil areas (not road cuts), factors considered in this assessment included: 1) the size of the eroded area; 2) whether the area was actively eroding or healing; 3) whether there was a potential for future erosion; and 4) the presence of significant on- and off-site negative impacts. Note that a rating of high does not necessarily connote an erosive condition that warrants immediate rehabilitation measures. Many of the areas rated as high severity were those in which all or nearly all the soil material has been removed.

However, to identify areas having high erosion and sedimentation rates would have required long-term measurements at each site, and therefore was beyond the scope of this study.

For road cuts in particular, the severity rating was based directly on the apparent rate at which soil or rock material is being removed from the cut slope and/or accumulating in culverts or on roads. Therefore, the severity rating for road cuts can be viewed as an indication of the urgency with which rehabilitation measures should be considered for individual sites.

Map Digitization

Following the completion of ground truthing, the delineations of the eroded sites were transferred from the photographs to the Base Master Planning maps (1:9600 nominal scale) using a Zoom Transfer Scope.

Each polygon and point was then digitized with ERDAS (Earth Resource Data Analysis System) software using the DIGPOL and DIGBND programs. Because the scale varies among planning maps, the scale of each map was calculated using three different axes to minimize error (ERDAS allows a test of map accuracy set-up prior to digitization). The data were then converted from vector to raster format using the GRDPOL program, with a spatial resolution of 98.425 ft (30 m) on a side. The acreage of each eroded area was then determined by using the BSTATS program. The polygons and points were assigned new data values (using the RECODE program) so that the severity class for each could be identified by color codes on the map of eroded sites. In some instances, individual delineations appear to run together. This condition occurs due to the cartographic generalization inherent to raster-based mapping.

RESULTS

Areal Extent of Eroded Soils

One hundred ninety-three soil erosion sites were mapped; 142 were mapped as polygons, and 51 were mapped as point data (road cuts). The general distribution of these sites is shown in Figure 1.

The frequency of erosion type and the total areal extent for each eroded area (polygon) are listed below:

Erosion Type	Frequency	Total Areal Extent (ac)
Gully	49	628.5
Excavation	45	402.4
Sheet	38	486.1
Mass movement	4	73.6
Gully/sheet	3	22.5
Gully/mass movement	1	5.6
Rill	1	3.8
Wind	1	12.7
Total	142	1635.2

A breakdown of erosion types according to severity rating is provided in Table 2. The majority of eroded areas and road cuts were classified as having a low severity rating. However, several of the sites classified as high severity are in obvious need of immediate rehabilitation; these particular sites are discussed in the following section.

The list of key erosion areas (Appendix 1) contains the full information for each mapped site: delineation number, planning sheet number, erosion type(s), severity, cause(s), areal extent, and in some cases, remarks about characteristics peculiar to individual sites.

The GIS files were constructed in such a way that eroded areas and road cuts can be displayed separately or together; a list of GIS filenames and descriptions is given in Appendix 2.

Figure 1. Map showing general distribution of eroded areas and unvegetated road cuts. Redrafted from composite ERDAS-generated map. See Butterworth (1987) for detailed maps.

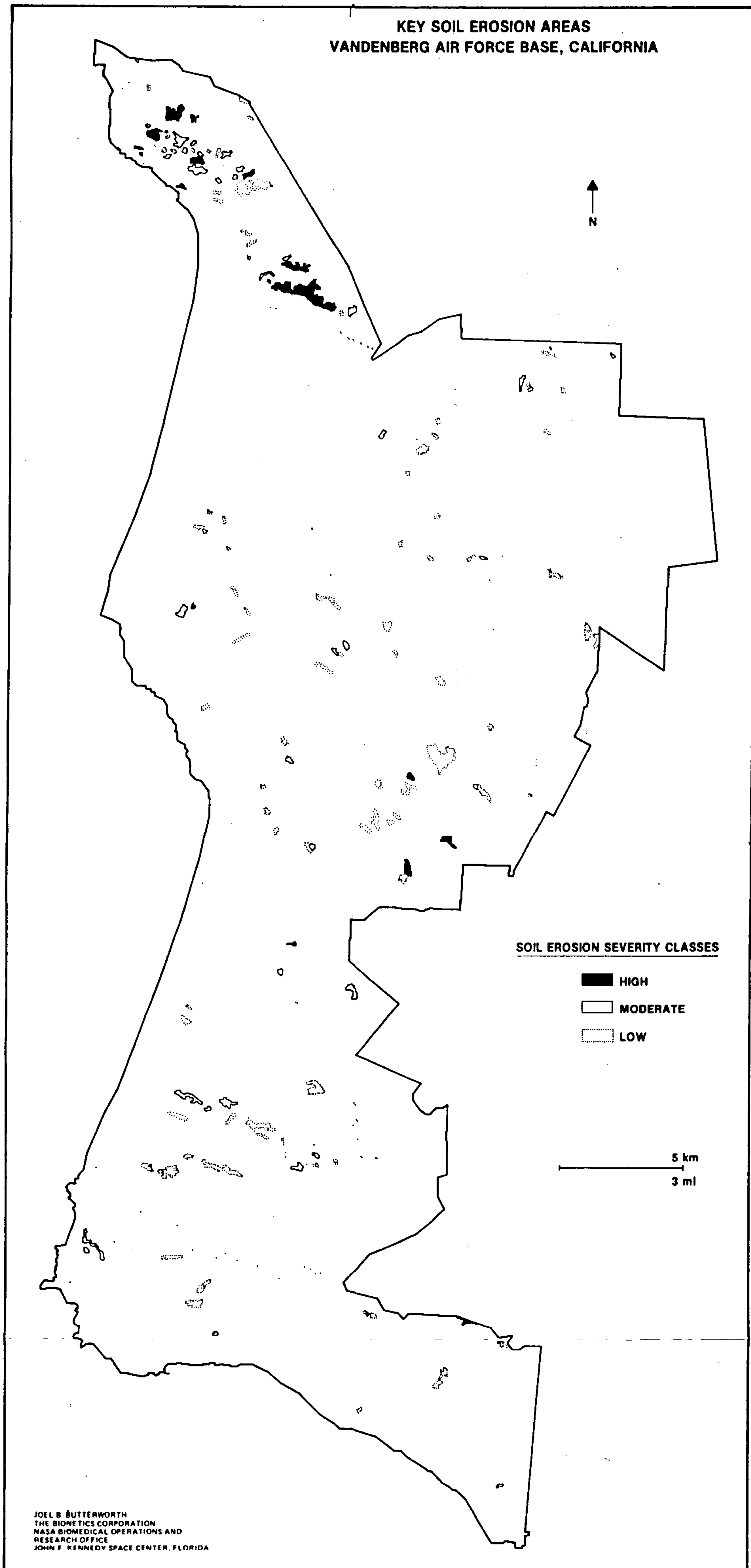
KEY SOIL EROSION AREAS
VANDENBERG AIR FORCE BASE, CALIFORNIA
N
SOIL EROSION SEVERITY CLASSES
HIGH
MODERATE
LOW
5 km
3 mi
JOEL B BUTTERWORTH
THE BIONETICS CORPORATION
NASA BIOMEDICAL OPERATIONS AND
RESEARCH OFFICE
JOHN F KENNEDY SPACE CENTER, FLORIDA

Table 2. Breakdown of erosion types by severity class.

Erosion Type	Severity Class Low	Moderate	High	Total
Gully	15	25	9	49
Excavation	32	10	3	45
Sheet	36	2	0	38
Mass movement	3	1	0	4
Gully/sheet	1	2	0	3
Gully/mass movement	0	0	1	1
Rill	0	0	1	1
Wind	1	0	0	1
Roadcut	15	21	15	51
Total	103	61	29	193

Printouts of the 44 Master Planning maps on which the erosion sites were located (Butterworth 1987) and GIS files are on deposit with the Vandenberg Environmental Task Force Office.

DISCUSSION

Based on evidence from historical aerial photography, most erosion on Vandenberg had taken place prior to 1928. Nearly all the erosion or disturbance that has taken place since then occurred before 1967, as indicated by aerial photography.

The two most conspicuously eroded locales are at the extreme northern part of the base. The first is a 2.5 mi^2 (6.5 km^2) area of severe gully, sheet, and mass movement erosion located in the drainages south of Mt. Lospe. Delineation numbers 2, 6, 7, 13, and 194 are the most eroded sites at this locale. The area of gully and sheet erosion occurs in the vicinity of Combar Road, where the substrate is comprised of the Point Sal formation (interbedded mudstone, siltstone, and thin-bedded sandstone), the upper member of the Lospe formation (interbedded greenish sandstone, siltstone, and gypsiferous mudstone), and Quaternary marine terrace deposits (weakly consolidated sandstones and shales) (Woodring and Bramlette 1950). Chamise and Shedd series soils, and Gullied land, Rough broken land, and Sedimentary rock land comprise the soils and land types in this area (Shipman 1972). Both the Chamise and Shedd soils have moderate- to high-erodibility (K= 0.24 and 0.37, respectively) and steep slopes (30 to 75%). Gullied land is found in areas that were probably previously occupied by Shedd and Chamise soils. Slopes are steep and runoff is rapid. Sedimentary rock land and Rough broken land occupy steep slopes (6 to 75+%) where runoff is very rapid, owing to a shallow to nonexistent soil cover (Shipman 1972). Sedimentary rock land and Rough broken land areas may have resulted from a previous erosion cycle, or may occur from geologic erosion due to steep slopes.

The exact cause of erosion of the Shedd and Chamise soil areas and Gullied land is uncertain, although steep slopes and erodible soils were probably contributing factors. Some of the gentler slopes were probably dryland farmed in the late 1800's (the 1943 aerial photographs show evidence of farming in parts of this area). The Chamise soils have a claypan that was ripped[b] by farmers in the early 1900's (Larry Spanne, pers. comm.). Subsoiling and plowing may have degraded soil structure and induced accelerated erosion or may have compounded existing erosion problems, as may have improper grazing.

Soil piping (subsurface drainage channels) was observed in the area of Shedd and Chamise soils, and in their substrates. Various studies (Jones 1971, Harvey 1982, Brumbaugh 1983) indicate that soils and rock materials may be prone to the formation of soil pipes when, among other factors, they: 1) are susceptible to cracking during dry periods, and 2) have a relatively impermeable layer beneath an erodible layer. The Mediterranean climate at Vandenberg is conducive to the formation of cracks in soils during the summer, especially in those having a high percentage of silt and clay. The claypan in the Chamise soils and the varying texture in some of the underlying rocks in this area would undoubtedly cause differences in permeability with depth. The soil pipes on Vandenberg may have enlarged to such a degree that their roofs eventually collapsed to form gullies (Harvey 1982, Crozier 1986).

Severe gully erosion, and several earthflows and soil slips have occurred 1.5 mi (2.4 km) southeast of the Combar Road area. Delineation

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[b]Ripping (also known as subsoiling) is the tillage of soil below normal depth to shatter a claypan or hardpan to improve root penetration and drainage.

numbers 5, 17, 18, 19, and 20 are the most eroded sites in this locale. The substrate there consists primarily of the upper member of the Lospe formation (Woodring and Bramlette 1950). Soils and the land type in this area are Shedd and Salinas series soils and Sedimentary rockland. Salinas soils are highly erodible (K= 0.37) and runoff is moderate (Shipman 1972).

As with the area to the north, the cause(s) of the gully erosion here is uncertain. Part of this area was mined for gypsum in the 1880's (Woodring and Bramlette 1950). Mining may have changed hydrologic conditions at adjacent areas sufficient to cause accelerated erosion. Except for the gentler slopes above the areas of mass movement, it is unlikely that these sites were ever farmed. Past grazing practices may have caused increased runoff, and this may have been a contributing factor.

The mass movements may have occurred entirely as natural phenomena, due to the effects of high pore water pressures caused by unusually heavy rainfall (Rice et al. 1969, Selby 1976). However, vegetation conversion (whether by mechanical means or by burning) from brush to grassland may have caused a reduction in both transpiration and shear strength (from root decay) to give rise to mass movements, particularly if conversion was followed by prolonged heavy precipitation (Brumbaugh et al. 1982).

The second locality of severe gully and sheet erosion is found immediately north of Point Sal Road at Shuman Canyon; it occurs in an area of 0.5 mi^2 (1.2 km^2). Erosion there is on the sideslopes of a terrace. The terrace is comprised of Quaternary marine deposits, and the sideslopes are underlain by generally fine-grained consolidated sedimentary rocks (Muir 1964). Tierra and Narlon soils are on the terrace; they are moderately erodible (K= 0.24 and 0.32, respectively) and slopes are 2 to 30%. Both soils have claypans. The sideslopes of the terrace are occupied by Crow Hill and Tierra soils; they are highly erodible (K= 0.43 and 0.37, respectively) and slopes are steep (15 to 75%) (Shipman 1972). Delineation numbers 23 and 25 are the most eroded sites in the area.

As with the locale to the north, the cause(s) of erosion here are uncertain, although steep slopes and erodible soils certainly made the area prone to accelerated erosion.

It is likely that the soils of the terrace were previously farmed, owing to favorable slopes and accessibility. Gully erosion may have been initiated by increased runoff as a result of cultivation, or may have been induced by concentration of runoff along livestock trails (Gerald Czarnecki, pers. comm.). The side slopes may have been excessively grazed, causing sheet and/or gully erosion.

Using historical aerial photography as a basis for comparison, there has been no significant gully headward erosion or sidewall collapse, or increase in sheet-eroded area at the North Base locales since 1928. Similarly, no further downslope movement of soil slips or earthflows was detected. Some areas of sheet erosion appear to have revegetated to a small degree.

Two qualifications should be made as to the determinations based on aerial photography. First, the fact that no significant enlargement of gully dimensions was detected in no way indicates that accelerated erosion has ceased at these areas. Because most of the eroded soils are underlain by weakly-consolidated rocks, both soil and rock materials can be eroded vertically from within the present confines of gullies, without horizontal enlargement of the gully system. This condition is particularly notable for the gullied land at the north end of Combar Road. Therefore, these sites may be sources of significant sediment production. Second, because the photography used varies according to film type, scale, distortion, resolution, and season of year, precise comparisons between photography of different dates are not possible. Therefore, only gross changes in soil and vegetative conditions can be detected with any degree of certainty.

Other sites throughout the remainder of the base are slightly to severely eroded, but the severely eroded sites occupy relatively small areas. A large percentage of these were identified as borrow or gravel pits; they represent most of the sites determined to have eroded within the past 50 to 60 years. Gully erosion has followed excavation at some sites, and several borrow pits are presently eroding along their outer margins due to concentration of runoff and/or vegetation removal.

Because of its proximity to Space Launch Complex 6, a large gully (delineation number 56) along the northwest edge of the complex is of special concern. The valley in which the gully is found was previously cultivated, as indicated by the 1938 photographs. The gully probably formed by concentrated runoff from agricultural fields. No appreciable expansion of its sidewalls since that date was detected; however, some sloughing probably does occur, especially during particularly wet winters. The headcut of the gully appears to be well stabilized, but the slope between the gully and the north access road needs further stabilization.

Disking of brush to create firebreaks (sometimes on steep slopes and/or erodible soils) was determined to be the cause of erosion in four instances. Only one of these appears to be currently eroding at accelerated rates. Erosion from the concentration of runoff from firebreaks is probably not common for two reasons: 1) because many firebreaks are located along ridgetops, there is little source area from which water can collect for runoff to concentrate, and 2) disking of fuels and soils tends to incorporate into the soil large amounts of coarse fragments from parent rocks located at shallow depths. Disking thus gives rise to high infiltration rates, and creates an irregular surface where runoff is retained for subsequent infiltration. In some places, disking has formed a berm at the edges of firebreaks, preventing runoff from reaching sideslopes.

Geologic erosion was determined to be the cause of almost all sheet-eroded areas on South Base. These sites are on steep slopes and have resistant parent materials that result in slow rates of soil formation. The chaparral or coastal sage scrub vegetation on these sites is commonly sparse and provides little protection from raindrop impact and runoff. Because these conditions probably occur naturally and because the soils and rock are generally permeable, these sites were usually assigned a low severity rating. However, because the majority of the sites have vegetation adapted to periodic burning, the soils may be prone to increased erosion following fire, due to the formation of less permeable hydrophobic layers. Soils with loam or coarser A horizon textures are particularly susceptible to coating by hydrophobic substances due to the low surface area of sands, compared to silts and clays (DeBano et al. 1979). Appendix 3 shows the soil and land types most sensitive to erosion following the formation of hydrophobic layers (under chaparral and coastal sage scrub vegetation), based on A horizon texture and slope.

Of the 51 road cuts mapped, 15 were assigned a severe rating; approximately half of these occur along the easternmost 2.5 mi (4.0 km) of Honda Ridge Road. The remainder are distributed throughout the base. The greatest problem associated with unvegetated or eroding road cuts is that they produce gravel and sediment that washes into culverts and onto roadways, thereby causing maintenance problems.

RECOMMENDATIONS FOR MANAGEMENT AND FURTHER STUDY

Future erosion-related work at Vandenberg should pertain to: 1) identification of key sediment-producing areas, watersheds, and road cuts, and 2) implementation of stabilization and conservation measures to these sites. The sites should be prioritized according to on- and off-site impacts, including erosion and sediment production rates and hazards to facilities and vehicles.

To determine sediment production rates, sediment collection pans can be installed at outlets of sub-watersheds identified to contain areas of significant accelerated erosion. These sub-watersheds are those in which a large proportion is occupied by large areas of gully erosion of moderate or high severity. Sediment production will probably have to be monitored over a period of several years to account for yearly variability of precipitation, and to account for the periodic flushing of sediments stored in gully bottoms.

For more precise determinations of the rate at which the larger gully and sheet-eroded areas are eroding or healing, conditions should be monitored at ground level. Erosion pins can be installed at various points at gully headcuts to serve as benchmarks for measuring headward erosion. Ground level photographs taken periodically from the same location and view angle may provide an indication as to the reestablishment or loss of vegetation within gullies and areas of sheet erosion.

Because grazing operations are of secondary importance at Vandenberg, it is probably not cost effective to institute elaborate soil conservation measures in eroded areas that are presently grazed. With an acre of rangeland presently worth approximately $10.00/year in forage value (Chuck Jachens, pers. comm.), conservation measures (in the form of check dams in major gullies) applied to only the most unstable sites would be appropriate.

However, certain off-site effects of sedimentation may warrant more extensive erosion control efforts in selected areas.

Regarding the establishment of new borrow pits, provisions should be made so that runoff is not concentrated in draining the area. Where practicable, a berm of soil and rock material should be formed along the perimeter of the downslope part of the pit so that runoff can percolate over a larger area.

Existing borrow pits rated as high severity (delineation numbers 14, 50, 54) should receive similar measures. Those in which suitable soil material is available would benefit from vegetative stabilization along their margins, after berms are constructed.

It was beyond the scope of this study to determine the degree to which each mapped area is in need of rehabilitation. However, one area in particular is obviously in need of immediate stabilization: rill and sheet erosion at map delineation number 38 will eventually undermine the roadway there. Erosion control fabrics should be applied, and the area should be seeded to provide a protective cover of grass.

With regard to road cuts, those identified in the remarks column of Appendix 1 as contributing sediment to culverts and roadways (and rated as high severity) should receive priority for stabilization; there are nine that meet these criteria. Efforts to control loose sediment and gravel should be tailored to particular site conditions of geology, soil, slope, and hydrology (Kennedy et al. 1979). Some road cuts, due to rockiness or steep slopes, are amenable to mechanical stabilization only; others need both mechanical and vegetative stabilization.

Sediment and rockfall control measures should be integral parts of road cut construction in the future. These should be in the form of wire netting, erosion control fabrics, water diversion dikes, and/or vegetative stabilization.

Stabilization of road cuts constructed through sand dunes should be accomplished primarily with erosion control fabrics and vegetative controls.

CONCLUSIONS

1) Areas of eroded soils on Vandenberg vary widely according to type, severity, and cause(s) of erosion. Most mapped eroded areas occurred prior to 1928, and perhaps much earlier, due to the combined effects of sensitive soils, steep slopes, and farming and grazing practices. Although these areas are apparently not increasing in lateral dimension, they are probably significant sources of sediment. Sediment production is probably punctuated following heavy and/or prolonged rainstorms, particularly from gullied sites.

2) Extensive areas, particularly on South Base, appear to have sparse vegetation cover and shallow soils due to geologic erosion, and some due to the effects of wildfire.

3) Most areas eroded since ca 1943 have occurred due to concentration of runoff following extraction of soil and rock materials at borrow and gravel pits.

4) Unstable road cuts represent the areas of most immediate concern. Sediment accumulation from road cuts increases maintenance costs and may pose a hazard to vehicles. Unvegetated road cuts are usually lacking in aesthetic appeal.

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Appendix 1. Key erosion areas on Vandenberg Air Force Base.

Delineation Number	Planning Sheet Number	Erosion Type(s)	Severity	Cause(s)	Areal Extent (Acres)	Remarks
2	5	Gully	High	Past farming practices	8.9	
3	5	Gully	Moderate	Improper grazing Steep slopes and/or high erodibility	5.1	
4	5	Gully	High	Improper grazing Steep slopes and/or high erodibility	20.0	
5	5	Gully	Moderate	Improper grazing Steep slopes and/or high erodibility	22.3	
6	5	Gully	Moderate	Improper grazing Steep slopes and/or high erodibility	22.5	
7	5	Gully	Moderate	Improper grazing Steep slopes and/or high erodibility	5.8	
8	5	Gully	Low	Improper grazing Steep slopes and/or high erodibility	4.0	
9	5	Mass movement	Moderate	Gravel or borrow pit, mining activity	4.9	
10	5	Excavation	Moderate	Gravel or borrow pit, mining activity	2.3	
11C	5	*	Moderate	Road cut	–	
12	5	Excavation	Low	Gravel or borrow pit, or mining activity	2.9	
13	5	Gully	High	Improper grazing Steep slopes and/or high erodibility	26.5	
14	7	Excavation	High	Gravel or borrow pit, or mining activity	7.1	
15	5	Gully	Moderate	Improper grazing Steep slopes and/or high erodibility	1.4	

Appendix 1. (continued).

Delineation Number	Planning Sheet Number	Erosion Type(s)	Severity	Cause(s)	Areal Extent (Acres)	Remarks
16	7	Sheet	Low	Improper grazing Steep slopes and/or high erodibility	5.8	
17	7	Gully	Moderate	Improper grazing Steep slopes and/or high erodibility	5.6	
18	8	Gully	Moderate	Improper grazing Steep slopes and/or high erodibility	4.2	
19	8	Gully	Moderate	Improper grazing Steep slopes and/or high erodibility	6.9	
20	8	Gully	High	Improper grazing Steep slopes and/or high erodibility	11.6	
21	19	Excavation	Moderate	Gravel or borrow pit, or mining activity	8.7	
22	19	Sheet	Low	Steep slopes and/or high erodibility	18.7	
23	10	Gully	High	Improper grazing Steep slopes and/or high erodibility	134.8	Sediment on road
24	10	Gully	Moderate	Improper grazing Steep slopes and/or high erodibility	5.6	
25	10	Gully	High	Improper grazing Steep slopes and/or high erodibility	37.6	
26	28	Excavation	Moderate	Gravel or borrow pit, or mining activity	8.2	Also ORV area
27	63	Gully	Low	Steep slopes and/or high erodibility	22.2	
28	28	Excavation	Low	Gravel or borrow pit, or mining activity	5.6	
29	24	Excavation	Low	Gravel or borrow pit, or mining activity	3.8	

Appendix 1. (continued).

Delineation Number	Planning Sheet Number	Erosion Type(s)	Severity	Cause(s)	Areal Extent (Acres)	Remarks
30	19	Excavation	Low	Gravel or borrow pit, or mining activity	3.1	
31	28	Excavation	Low	Gravel or borrow pit, or mining activity	7.1	
32	28	Excavation	Low	Gravel or borrow pit, or mining activity	4.7	
33	29	Excavation	Low	Gravel or borrow pit, or mining activity	14.0	
34	28	Excavation	Low	Gravel or borrow pit, or mining activity	4.9	
35	27	Excavation	Moderate	Gravel or borrow pit, or mining activity	7.1	
36	24	Sheet	Low	Steep slopes and/or high erodibility	4.2	
37	28	Excavation	Low	Gravel or borrow pit, or mining activity	8.9	
38	27	Rill	High	Road or facility construction	3.8	Needs stabilization
39	23	Excavation	Low	Gravel or borrow pit, or mining activity	2.3	
40	28	Sheet	Low	Steep slopes and/or high erodibility	18.9	
41C	51	*	Moderate	Road cut	–	
42	29	Excavation	Low	Road or facility construction	6.0	
43	7	Sheet	Low	Improper grazing	6.9	

Appendix 1. (continued).

Delineation Number	Planning Sheet Number	Erosion Type(s)	Severity	Cause(s)	Areal Extent (Acres)	Remarks
44	63	Gully Mass movement	High	Improper grazing Steep slopes and/or high erodibility	5.6	Mass movement hazard on south side
45	37	Excavation	Moderate	Gravel or borrow pit, or mining activity	7.3	
46	33	Excavation	Low	Gravel or borrow pit, or mining activity	7.3	
47	32	Excavation	Low	Gravel or borrow pit, or mining activity	7.8	
48	41	Excavation	Moderate	Gravel or borrow pit, or mining activity	6.5	
49	15	Gully	Low	Steep slopes and/or high erodibility	9.3	
50	42	Excavation	High	Gravel or borrow pit, or high erodibility	19.4	
51	66	Sheet	Low	Steep slopes and/or high erodibility	4.2	
52	38	Excavation	Low	Gravel or borrow pit, or mining activity	102.5	Base land fill
53	34	Excavation	Low	Gravel or borrow pit, or mining activity	13.1	
54	38	Excavation	High	Gravel or borrow pit, or mining activity	8.0	Actively eroding
55	37	Excavation	Low	Gravel or borrow pit, or mining activity	7.3	
56	57	Gully	Moderate	Past farming practices	21.8	
57C	59	*	High	Road cut	–	Gravel on road

Appendix 1. (continued).

Delineation Number	Planning Sheet Number	Erosion Type(s)	Severity	Cause(s)	Areal Extent (Acres)	Remarks
58C	24	*	Low	Road cut	–	
59	41	Gully	Low	Road or facility construction	7.3	
60	38	Excavation	Low	Gravel or borrow pit, or mining activity	6.0	
61	38	Excavation	Low	Gravel or borrow pit, or mining activity	3.6	
62	37	Sheet	Low	Steep slopes and/or high erodibility	11.3	
63	50	Gully	Moderate	Steep slopes and/or high erodibility	21.1	
64	50	Gully	Moderate	Steep slopes and/or high erodibility	26.5	
65	50	Gully	Moderate	Steep slopes and/or high erodibility	4.5	
66	48	Gully	Moderate	Steep slopes and/or high erodibility	18.0	
67	44	Excavation	Moderate	Gravel or borrow pit, or mining activity	5.8	
68	47	Wind	Low	Unknown	12.7	Bear Creek blowout
69C	51	*	Moderate	Road cut	–	
70C	58	*	High	Road cut	–	Gravel on road
71C	58	*	Low	Road cut	–	

Appendix 1. (continued).

Delineation Number	Planning Sheet Number	Erosion Type(s)	Severity	Cause(s)	Areal Extent (Acres)	Remarks
72	44	Gully	High	Improper grazing	5.8	
73	58	Sheet	Low	Steep slopes and/or high erodibility	22.7	
74C	58	*	Low	Road cut	–	
75C	53	*	High	Road cut	–	Sand on road; needs stabilization
76	53	Sheet	Low	Steep slopes and/or high erodibility	14.0	
77	54	Sheet	Low	Steep slopes and/or high erodibility	20.9	
78	54	Sheet	Low	Steep slopes and/or high erodibility	34.5	
79	50	Sheet	Low	Steep slopes and/or high erodibility	15.8	
80	50	Sheet	Low	Steep slopes and/or high erodibility	9.8	
81	55	Gully	Moderate	Runoff from firebreaks Steep slopes and/or high erodibility	12.5	
82	58	Sheet	Low	Steep slopes and/or high erodibility	14.9	
83	58	Sheet	Low	Steep slopes and/or high erodibility	15.8	
84C	58	*	Low	Road cut	–	
85	50	Sheet	Low	Steep slopes and/or high erodibility	–	

Appendix 1. (continued).

Delineation Number	Planning Sheet Number	Erosion Type(s)	Severity	Cause(s)	Areal Extent (Acres)	Remarks
86C	59	*	Moderate	Road cut	–	Gravel in culvert
87	50	Sheet	Low	Steep slopes and/or high erodibility	7.8	
88	55	Excavation	Low	Gravel or borrow pit, or mining activity	3.8	
89	61	Gully/ Sheet	Moderate	Improper grazing Steep slopes and/or high erodibility	3.8	
90C	64	*	Moderate	Road cut	–	
91	64	Excavation	Low	Demolition	3.8	
92C	55	*	Moderate	Road cut	–	
93	55	Excavation	Moderate	Gravel or borrow pit, or mining activity	4.9	
94	50	Gully	Low	Concentration of runoff from roads or facilities	2.2	
95C	54	*	Low	Road cut	–	
96C	48	*	Moderate	Road cut	–	
97C	41	*	Low	Road cut	–	
98C	14	*	Moderate	Road cut	–	
99C	14	*	Moderate	Road cut	–	

Appendix 1. (continued).

Delineation Number	Planning Sheet Number	Erosion Type(s)	Severity	Cause(s)	Areal Extent (Acres)	Remarks
100C	14	*	Moderate	Road cut	–	
101	63	Sheet	Low	Steep slopes and/or high erodibility	8.2	
102	62	Sheet	Low	Steep slopes and/or high erodibility	11.1	
103	5	Gully	Moderate	Improper grazing Steep slopes and/or high erodibility	10.7	
104	5	Gully	Low	Improper grazing Steep slopes and/or high erodibility	3.3	
105	5	Gully	Moderate	Improper grazing Steep slopes and/or high erodibility	4.2	
106C	13	*	Moderate	Road cut	–	
107C	13	*	Moderate	Road cut	–	
108	37	Excavation	Low	Gravel or borrow pit, or mining activity	3.6	
109	38	Excavation	Low	Gravel or borrow pit, or mining activity	22.5	
110	38	Sheet	Low	Steep slopes and/or high erodibility	6.5	
111C	13	*	Moderate	Road cut	–	
112C	13	*	Moderate	Road cut	–	
113C	10	*	Low	Road cut	–	

Appendix 1. (continued).

Delineation Number	Planning Sheet Number	Erosion Type(s)	Severity	Cause(s)	Areal Extent (Acres)	Remarks
114C	10	*	High	Road cut	–	
115C	10	*	Low	Road cut	–	
116C	4	*	Low	Road cut	–	
117C	5	*	Low	Road cut	–	
118	5	Gully	Low	Improper grazing Steep slopes and/or high erodibility	2.7	
119	5	Gully	Low	Improper grazing Steep slopes and/or high erodibility	6.5	
120	5	Excavation	Low	Gravel or borrow pit, or mining activity	5.1	
121	6	Sheet	Low	Improper grazing	10.2	
122	6	Sheet	Low	Improper grazing	4.2	
123	38	Excavation	Moderate	Improper grazing	3.6	
124	42	Sheet	Low	Burning	13.1	
125	38	Excavation	Low	Gravel or borrow pit, or mining activity	7.3	
126C	39	*	Low	Road cut	–	
127	39	Gully	Low	Steep slopes and/or high erodibility	2.5	

Appendix 1. (continued).

Delineation Number	Planning Sheet Number	Erosion Type(s)	Severity	Cause(s)	Areal Extent (Acres)	Remarks
128C	5	*	Moderate	Road cut	–	Gravel in culvert
129C	59	*	Moderate	Road cut	–	Gravel in culvert
130C	59	*	High	Road cut	–	Gravel on road
131C	58	*	High	Road cut	–	Gravel in culvert/on road
132C	25	*	Low	Road cut	–	
133C	25	*	Low	Road cut	–	
134	30	Gully	Low	Steep slopes and/or high erodibility	17.8	
135	8	Mass movement	Low	Unknown	36.3	
136	8	Mass movement	Low	Unknown	24.0	
137	8	Mass movement	Low	Unknown	8.5	
138	30	Gully	Low	Steep slopes and/or high erodibility	11.6	
139C	19	*	Moderate	Road cut	–	Sediment in culvert
140	4	Gully	Moderate	Steep slopes and/or high erodibility	3.3	
141	15	Sheet	Low	Steep slopes and/or high erodibility	5.1	

Appendix 1. (continued).

Delineation Number	Planning Sheet Number	Erosion Type(s)	Severity	Cause(s)	Areal Extent (Acres)	Remarks
142C	58	*	High	Road cut	–	Gravel in culvert
143	25	Sheet	Low	Steep slopes and/or high erodibility	13.3	
144	51	Sheet	Low	Steep slopes and/or high erodibility	35.6	
145C	24	*	Moderate	Road cut	–	
146C	24	*	High	Road cut	–	Sediment on shoulder
147C	40	*	High	Road cut	–	Sediment on shoulder
148	15	Sheet	Moderate	Road or facility construction	3.1	
149	37	Excavation	Low	Gravel or borrow pit, or mining activity	6.0	
150	5	Sheet	Low	Steep slopes and/or high erodibility	3.6	
151	19	Sheet	Low	Steep slopes and/or high erodibility	5.6	
152	5	Gully	Low	Improper grazing Steep slopes and/or high erodibility	3.1	
153	10	Sheet	Moderate	Steep slopes and/or high erodibility	12.9	
154	22	Excavation	Low	Gravel or borrow pit, or mining activity	4.5	
155	22	Excavation	Low	Gravel or borrow pit, or mining activity	2.9	

Appendix 1. (continued).

Delineation Number	Planning Sheet Number	Erosion Type(s)	Severity	Cause(s)	Areal Extent (Acres)	Remarks
156	22	Sheet	Low	Steep slopes and/or high erodibility	9.6	
157	28	Sheet/ gully	Low	Steep slopes and/or high erodibility	13.8	
158	57	Excavation	Moderate	Gravel or borrow pit, or mining activity	5.8	
159	10	Gully	Low	Improper grazing Steep slopes and/or high erodibility	3.3	Sediment on road
160	47	Excavation	Low	Gravel or borrow pit, or mining activity	3.1	
161C	55	*	Moderate	Road cut	–	Sediment in culvert
162	54	Sheet	Low	Steep slopes and/or high erodibility	20.5	
163C	53	*	High	Road cut	–	
164C	54	*	High	Road cut	–	
165	24	Gully	Low	Runoff from firebreaks Steep slopes and/or high erodibility	5.1	
166	24	Gully	Moderate	Runoff from firebreaks Steep slopes and/or high erodibility	4.5	
167	19	Excavation	Low	Gravel or borrow pit, or mining activity	5.1	
168C	24	*	Low	Road cut	–	
169	38	Sheet	Low	Burning	17.8	

Appendix 1. (continued).

Delineation Number	Planning Sheet Number	Erosion Type(s)	Severity	Cause(s)	Areal Extent (Acres)	Remarks
170	42	Gully	High	Runoff from firebreaks	16.0	Actively eroding
171	38	Sheet	Low	Steep slopes and/or high erodibility	6.5	
172	20	Gully	Low	Improper grazing Steep slopes and/or high erodibility	4.5	
173	15	Gully	Moderate	Improper grazing	4.2	
174	15	Gully	Moderate	Improper grazing	3.1	
175	15	Gully	Moderate	Improper grazing	8.7	
176	38	Excavation	Low	Gravel or borrow pit, or mining activity	10.7	
177	55	Excavation	Low	Gravel or borrow pit, or mining activity	4.2	
178C	54	*	High	Road cut	–	
179C	51	*	High	Road cut	–	
180C	51	*	High	Road cut	–	
181	54	Sheet	Low	Steep slopes and/or high erodibility	8.0	
182	10	Gully	Moderate	Steep slopes and/or high erodibility Improper grazing	2.0	
183	10	Gully	Moderate	Steep slopes and/or high erodibility Improper grazing	6.5	

Appendix 1. (continued).

Delineation Number	Planning Sheet Number	Erosion Type(s)	Severity	Cause(s)	Areal Extent (Acres)	Remarks
184	10	Sheet	Low	Road or facility construction	2.2	
185	8	Sheet	Low	Steep slopes and/or high erodibility	6.0	
186	8	Sheet	Low	Steep slopes and/or high erodibility	7.1	
187C	7	*	Moderate	Road cut	–	
188	5	Gully	Moderate	Steep slopes and/or high erodibility Improper grazing	3.8	
189	28	Gully/ sheet	Moderate	Steep slopes and/or high erodibility Off road vehicle activity	4.9	
190C	8	*	Low	Road cut	–	
191C	25	*	Low	Road cut	–	
192	34	Excavation	Low	Gravel or borrow pit, or mining activity	4.5	
193C	55	*	High	Road cut	–	Sediment on road
194	5	Gully	High	Past farming practices Steep slopes and/or high erodibility	43.6	

*Erosion type was not identified for road cuts because they are not eroding in a conventional sense.

Appendix 2. GIS filenames for soil erosion data, with descriptions.

Filename	Description
SOILAREA.GIS	Polygons (eroded areas) only- data values indicate delineation number.
ROADCUT.GIS	Points (roadcuts) only- data values indicate delineation number.
SOILCUT.GIS	Polygons (eroded areas) and points (roadcuts)- data values indicate delineation number.
SOILSSEV.GIS	Polygons (eroded areas) and points (roadcuts)- data values and color-codes indicate severity class. Codes: 2=high; 3=moderate; 4=low.

Appendix 3. Soil and land types with high susceptibility to hydrophobic layer formation following fire1.

North and Central Vandenberg2:

Map Symbol	Soil and Land Type
ArF	Arnold sand, 15-45% slopes
ArF3	Arnold sand, 9-45% slopes, severely eroded
ChF	Chamise shaly loam, 15-45% slopes
ChG2	Chamise shaly loam, 30-75% slopes, eroded
CwF	Crow Hill loam, 30-45% slopes
CwG	Crow Hill loam, 45-75% slopes
CwG3	Crow Hill loam, 15-75% slopes, severely eroded
GmG	Gaviota sandy loam, 30-75% slopes
GuE	Gullied land
RuG	Rough broken land
SfF3	San Andreas-Tierra complex, 9-45% slopes, severely eroded
SfG	San Andreas-Tierra complex, 30-75% slopes
TcG	Terrace escarpments, sandy
TdF	Terrace escarpments, loamy

South Vandenberg3:

Map Symbol	Soil and Land Type
Cv	Crow Hill loam, steep and very steep (31% + slopes)
Gd	Gaviota fine sandy loam, steep (31-45% slopes)
Gk	Gaviota stony soils, undifferentiated, steep and very steep (31% + slopes)
Jc	Jalama stony soils, undifferentiated, hilly and steep (16-45% slopes)
Lp	Los Osos stony soils, undifferentiated, steep and very steep (31% + slopes)
Lr	Los Trancos stony loam, hilly and steep (16-45% slopes)
MM	Montara stony soils, undifferentiated, hilly and steep (16-45% slopes)
Nl	Nacimiento stony soils, undifferentiated, very steep (46% + slopes)
Rd	Rough broken and stony land, Montara soil material
Rf	Rough broken and stony land, Los Trancos soil material
Sb	San Andreas fine sandy loam, steep, moderately eroded (31-45% slopes)

Appendix 3 (continued).

Sr	Santa Lucia shaly loam, steep (31-45% slopes)
Ss	Santa Lucia shaly loam, very steep (46% + slopes)
Su	Santa Lucia stony soils, undifferentiated, steep and very steep (31% + slopes)
Tk	Terrace breaks
Wt	Watsonville soils, undifferentiated, steep (31-45% slopes)
Zv	Zaca stony soils, undifferentiated, steep and very steep (31% + slopes)

[1]Defined by the co-occurrence of loam or coarser surface horizon textures and slopes greater than 30%.

[2]Shipman, G.E. 1972. Soil survey of the northern Santa Barbara area, California. USDA Soil Conservation Service, Washington, D.C. 182pp. and maps.

[3]Cole, R.C., R.A. Gardner, K.D. Gowans, E.L. Begg, G.L. Huntington, and L.C. Leifer. 1958. Soil Survey of the Santa Barbara area, California. USDA Soil Conservation Service, Washington, D.C. 177pp. and maps.

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15. Supplementary Notes

16. Abstract

In this study, areas of significant soil erosion and unvegetated road cuts were identified and mapped for Vandenberg Air Force Base, California. One hundred forty-two eroded areas (most greater than 3 ac [1.2 ha]) and 51 road cuts were identified from recent color infrared aerial photography and ground truthed to determine the severity and cause(s) of erosion.

Comparison of the present eroded condition of soils (as shown in the 1986 photography) with that in historical aerial photography indicates that most erosion on the base took place prior to 1928. However, at several sites accelerated rates of erosion and sedimentation may be occurring as soils and parent materials are eroded vertically.

The most conspicuous erosion is in the northern part of the base, where severe gully, sheet, and mass movement erosion have occurred in soils and in various sedimentary rocks. Past cultivation practices, compounded by highly erodible soils prone to subsurface piping are probably the main causes of erosion in this area. Improper range management practices following cultivation may have also increased runoff and erosion. The 1986 aerial photography shows that no appreciable headward erosion or gully sidewall collapse have occurred in this area since 1928.

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Extensive areas of South Base have partly vegetated soils, probably due to the natural consequences of steep slopes, resistant parent materials, erodible soils, and fire. Other mapped areas of the base are moderately to severely eroded; conditions that are due to a variety of causes, including (but not limited to) past cultivation and grazing practices, steep slopes, and borrow pit construction. Some areas are in need of immediate rehabilitation, particularly several road cuts that supply sediment to drainage or may present a hazard to vehicles.