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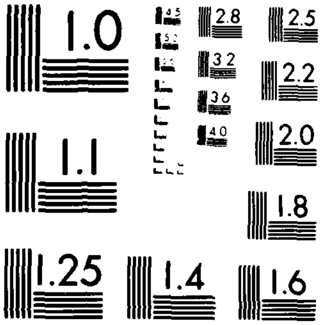

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M-X/MPS

ENVIRONMENTAL
TECHNICAL REPORT

ETR 34
WIND EROSION

DEPLOYMENT AREA SELECTION
AND LAND WITHDRAWAL/
ACQUISITION

DEPARTMENT OF THE AIR FORCE

M-X ETR-34

ENVIRONMENTAL CHARACTERISTICS OF ALTERNATIVE DESIGNATED DEPLOYMENT AREAS: WIND EROSION

Prepared for

United States Air Force
Ballistic Missile Office
Norton Air Force Base, California

By

Henningson, Durham & Richardson, Inc.
Santa Barbara, California

REVIEW COPY OF WORK IN PROGRESS

2 October 1981

DEPARTMENT OF THE AIR FORCE
WASHINGTON 20330

OFFICE OF THE ASSISTANT SECRETARY

Federal, State and Local Agencies

On October 2, 1981, the President announced his decision to complete production of the M-X missile, but cancelled the M-X Multiple Protective Shelter (MPS) basing system. The Air Force was, at the time of these decisions, working to prepare a Final Environmental Impact Statement (FEIS) for the MPS site selection process. These efforts have been terminated and the Air Force no longer intends to file a FEIS for the MPS system. However, the attached preliminary FEIS captures the environmental data and analysis in the document that was nearing completion when the President decided to deploy the system in a different manner.

The preliminary FEIS and associated technical reports represent an intensive effort at resource planning and development that may be of significant value to state and local agencies involved in future planning efforts in the study area. Therefore, in response to requests for environmental technical data from the Congress, federal agencies and the states involved, we have published limited copies of the document for their use. Other interested parties may obtain copies by contacting:

National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
Telephone: (703) 487-4650

Sincerely,

JAMES F. BOATRIGHT
Deputy Assistant Secretary
of the Air Force (Installations)

1 Attachment
Preliminary FEIS

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1.0 INTRODUCTION AND OVERVIEW

A frequently raised issue in both comment letters and public meetings was the increased potential for wind erosion due to construction of roads, shelters, operating bases, operational activities, and ORV use. The majority of these comments centered on the Texas/New Mexico study area. They were primarily concerned with the lack of technical quantitative analysis, the feared loss of agricultural productivity, the adverse effects on native vegetation, the incomplete presentation of detailed mitigation measures, and the return of "Dust Bowl" conditions.

The purpose of this report is to provide a comprehensive discussion of the potential for M-X-related activities to accelerate wind erosion of soils. Discussions of the soils and their general characteristics are presented for the Texas/New Mexico and Nevada/Utah study areas and the specific M-X OBs in ETR-11. Additionally, ETR-11 examines potential soil erosion due to surface runoff. ETR-13 identified wind erosion due to M-X construction and operation as a potential source of considerable quantities of suspended particulates in the atmosphere. Soil erosion involves the entrainment and transport of soil particulates in the atmosphere. Soil erosion involves the entrainment and transport of soil particles by wind or water. Because all eroded material is eventually deposited, erosion is generally considered as a three phase process: entrainment, transport, and deposition. The wind erosion process is discussed in Appendix A.

The major factors affecting wind erosion rates are: soil characteristics (primarily texture, chemical composition, and moisture), wind velocity, surface conditions including surface roughness, vegetative cover, and unsheltered distance that wind travels across an area. The wind erosion equation which incorporates these factors is discussed in Appendix B. Soil and climatic conditions in both the Nevada/Utah and Texas/New Mexico areas are highly conducive to wind erosion. The hazards of wind erosion in these areas are among the highest in the U.S., particularly in western Texas and eastern New Mexico. The sparse natural vegetation of the areas provides some degree of stability to soils. However, removal of the vegetative cover, such as for agriculture or construction, can have serious consequences. Much of the research on control of wind erosion conducted in the United States is carried out in these areas.

Impacts that can be anticipated due to wind erosion during M-X construction include:

1. Loss of productive surface soils at construction sites, hindering revegetation
2. Release of high levels of suspended atmospheric particulates, covering vegetation, presenting potential health hazards to workers and residents, and reducing visibility
3. Accelerated wind erosion in offsite areas due to soil avalanching initiated at construction sites
4. Mobilization of currently stabilized dunal areas due to increased recreational activity

5. Burial of transportation routes, drainageways, crops, and other features

6. Degradation or destruction of vegetation, including crops, in the vicinity of construction sites due to abrasion by windborne particles

These potential impacts would be most severe for the Texas/New Mexico study area.

Considerable research has been conducted on development of effective wind erosion control techniques. Strict adherence to well-planned mitigation measures will significantly reduce the severity of impacts. Implementation of mitigation measures may prove costly, particularly due to the magnitude of the project, but failure to implement and strictly adhere to effective wind erosion controls could have serious implications for the environment, residents, and agricultural productivity of the study area.

2.0 WIND EROSION IN M-X STUDY AREAS

The exact dimensions of areas to be devegetated and subjected to accelerated wind erosion during construction and operation of M-X are not available at this time. However, estimates are available for certain facilities. During construction, approximately 10 acres will be cleared for installation of each of the 4,600 missile shelters. Approximately 1,260 to 1,460 mi of paved Designated Transportation Network (DTN) roadway will be constructed. Width of the DTN disturbance corridor is anticipated to be 100 ft. The 24-ft wide paved road surface will not contribute additional soil particles to saltation or suspension. However, until revegetated, the entire 100 ft disturbance corridor, including pavement, will offer no barriers to reduce wind velocity. Approximately 5,940 to 6,200 mi of unpaved cluster roads with 100 ft disturbance corridors are anticipated and approximately 1,320 mi of support roads will be required. Support roads will have 50-ft disturbance corridors. During construction, approximately 900-1,300 mi of unpaved roads with 30-ft disturbance corridors will be required for movement of construction materials.

Construction at the operating base (OB) will include operational facilities and housing and support facilities for employees. Construction is expected to devegetate 6,140 acres at the first OB site, and 4,240 acres at the second OB sites. Installation of well sites along the DTN, surveillance equipment security buildings, and maintenance buildings will disturb many small areas (several acres) scattered throughout the project region. Estimated soil losses due to wind erosion during construction of M-X facilities (see Table 2-1) were calculated using the wind erosion equation. Wind erosion factors (I', K', C', L', and V') are assumed to be representative of the study areas and construction ocnditions. Detailed discussion of applications of the equation is presented in Appendix B. Large facilities associated with M-X construction such as construction camps, an Operational Base Test Site, cement plants, quarries, and borrow pit areas could result in disturbance of several acres to several hundred acres each (Table 2-1).

Additional disturbance of the vegetative cover can be expected to result from activities indirectly associated with the M-X project. For example, intensive recreational use of open land by workers with off-road vehicles (ORVs), especially in sand dune areas, could severely damage vegetation cover over vast areas that are highly susceptible to wind erosion.

2.1 NEVADA/UTAH STUDY AREA

Soils in the Nevada/Utah study area generally have developed under low precipitation regimes and sparse vegetation. Humus content is typically low except in the mountains where greater vegetative cover occurs due to higher precipitation and cooler temperatures. Many soils of the area contain calcium carbonate horizons, often cemented into caliche. Duripans (indurated silica horizons) also occur. Sodium and other salt contents are often high in soils of low lying areas, such as playas, due to evaporation.

The surface of some areas is covered with pebbles or cobbles called desert pavement. Desert pavement protects underlying finer particles, thereby reducing susceptibility to wind erosion.

Table 2-1. Estimated soil loss for selected areas disturbed during M-X construction (tons/acre/year) (Page 1 of 2).

Width (in ft)	C'	I'=235	I'=134	I'=86	I'=56	I'=48
30[1]	200	315	163	80	43	30
	150	265	112	56	25	17
	100	165	72	31	13	8
	50	78	27	10	3	2
50[2]	200	353	184	94	52	39
	150	290	134	68	34	24
	100	188	84	39	18	14
	50	91	36	14	6	3
100[3]	200	395	210	112	65	51
	150	320	150	80	38	35
	100	210	100	50	25	20
	50	103	45	20	10	6
125[4]	200	400	220	116	70	55
	150	328	159	85	46	37
	100	215	104	54	27	22
	50	105	48	22	12	7
200[5]	200	422	236	132	80	63
	150	342	174	97	56	44
	100	225	114	62	34	27
	50	112	55	27	14	11
660[6]	200	440*	262	158	99	80
	150	353	195	117	72	58
	100	235	130	78	47	38
	50	118	65	37	22	17
1,045[7]	200	440*	268	163	104	87
	150	353	200	125	76	63
	100	235	134	82	52	42
	50	118	67	40	24	19

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Table 2-1. Estimated soil loss for selected areas disturbed during M-X construction (tons/acre/year) (Page 2 of 2).

Width (in ft)	C'	I'=235	I'=134	I'=86	I'=56	I'=48
1,548[8]	200	440*	268	168	107	92
	150	353	201	128	79	66
	100	235	134	84	55	44
	50	118	67	42	26	21
3,300[9]	200	440*	268	172	112	95
	150	353	201	129	84	70
	100	235	134	86	56	48
	50	118	67	43	28	23
5,321[10]	200	440*	268	172	112	96
	150	353	201	129	84	72
	100	235	134	86	56	48
	50	118	67	43	28	24
16,354[11]	200	440*	268	172	112	96
	150	353	201	129	84	72
	100	235	134	86	56	48
	50	118	67	43	28	24
13,590[12]	200	440*	268	172	112	96
	150	353	201	129	84	72
	100	235	134	86	56	48
	50	118	67	43	28	24

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*Greater than 440 which was the highest value that could be calculated using Figure B.6-1.

[1] Construction roads.

[2] Support roads.

[3] DTN and cluster roads.

[4] Remote surveillance sites (RSSs) (.35 acres).

[5] Wells along DTN (1 acre).

[6] Missile shelters, concrete plants, and material source points (10 acres).

[7] Construction camps (25 acres).

[8] Area support centers (55 acres).

[9] Operational base test site/training site (OBTS) (250 acres).

[10] Marshalling yards (650 acres).

[11] First operating base (OB) (6,140 acres).

[12] Second operating base (OB) (4,240 acres).

Soil formation throughout the area reflects four distinct landscape situations (Figure 2.1-1).

1. Soils formed on the flat playa beds areas (A) reflect pedogenesis marked by repeated flooding and evaporation. When groundwater is near the surface, playa soils may be soft and "puffy." Often however, the playa surface is smooth and crusted. Playa soils can be expected to be high in clays and silt (WEG groups 4-7) that have been transported from surrounding areas while coarser sediments have been retained on alluvial fans. Additionally, most playa beds are high in sodium and other salts due to the repeated flooding and evaporation. Undisturbed playa sediments can be quite resistant to wind erosion because crusting occurs after drying and few sands are present to initiate saltation. However, if pulverization of the crust occurs, such as from vehicles, the fine clays and silts could be readily transported, primarily in suspension.

2. Soils that have formed on valley floors and floodplains (B) are generally higher in sand than are playa soils but also contain considerable clay and silt. Surface textures are commonly silty clay loams to loams (WEG groups 4-7). These soils are slightly to moderately susceptible to wind erosion.

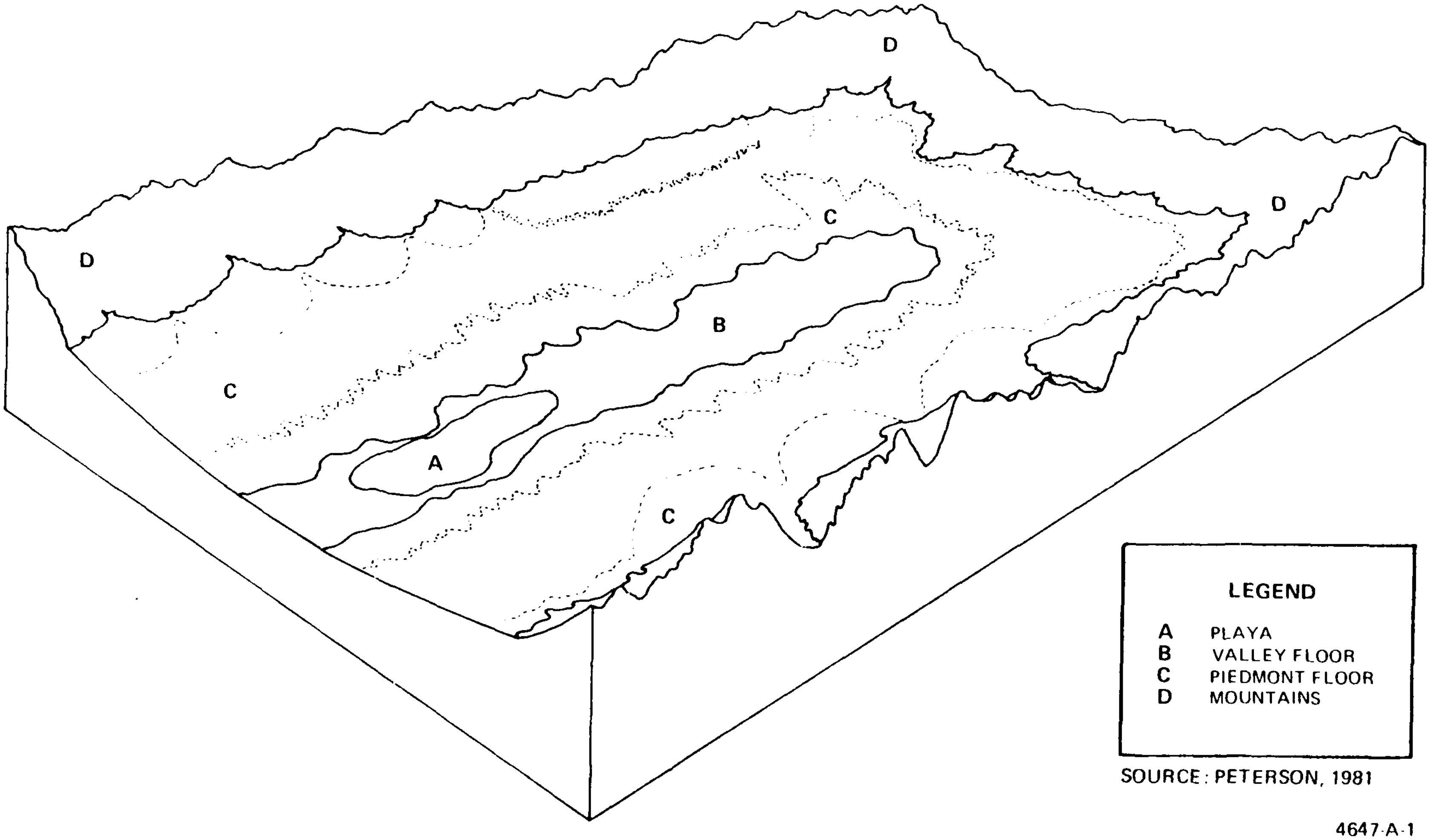
3. Piedmont slopes (C), consisting of alluvial fans and terraces, occupy much of the landscape in the Nevada/Utah study area. Soil textures vary considerably, ranging from silty clay loams to sands and gravelly sandy loams. Soils in all WEG groups can occur on the piedmont slope. In general, coarse soil separates such as gravel increase upslope toward the adjoining mountains. Calcium carbonate horizons and duripans occur in many of these soils. Susceptibility of alluvial fan and terrace soils to wind erosion ranges from extremely erodible for sands to moderately erodible. The presence of gravels on upper fan soils greatly reduces their susceptibility to wind erosion by increasing surface roughness.

4. Mountain soils (D) have formed under quite different climatic and vegetative regimes than the soils discussed above. Somewhat higher precipitation, cooler temperatures and denser vegetation have resulted in accumulations of humus in certain mountain soils. Pedogenesis have often taken place on materials that have formed in situ from weathered bedrock rather than from transported and sorted sediments. Often this results in mixtures of coarse resistant fragments and humus with very little mineral fines. Soils forming in the mountain environment are generally only slightly susceptible to wind erosion with WEG groups 5-8 dominating.

2.2 NEVADA/UTAH OPERATING BASE SITES

Beryl, Utah (2.2.1)

The soils of the proposed Beryl OB site have formed primarily on very gently sloping to sloping (up to approximately 7 percent slope) older alluvial fans and terraces. The Dixie-Neola association predominates in the site area. Dixie soils in the site area have a loam or gravelly loam surface texture over a clay loam horizon and a weakly to strongly cemented caliche layer at 15 to 36 in. (38 to 91 cm). Neola soils in the area have a sandy loam surface texture over a stongly cemented caliche



SOURCE: PETERSON, 1981

4647-A-1

Figure 2.1-1. Typical landscape zonation in Nevada/Utah study area.

layer at 12 to 24 in (30 to 61 cm). Zane coils are also common in the OB site area and have a clay loam surface underlain by horizons of heavy clay loam, silt loam, and fine sandy loam to over 60 in.(1.52 m) deep. Other important soils in the OB site area include Beryl very fine sandy loam, Antelope Springs and Tomas silt loams, Crestline and Escalante fine sandy loam, and Uvada loam and silt loam. Major soils in the OB site area are highly susceptible to moderately susceptible to wind erosion (WEG = 3-6). Neola, Beryl, Crestline, and Escalante soils are the most susceptible major soils in the area. Additionally, small areas of sand dunes occur in the area, particularly in association with Escalante fine sandy loam (U.S.D.A., 1960a). These areas are extremely susceptible to wind erosion.

COYOTE SPRING VALLEY, NEVADA (2.2.2)

The soils of the Coyote Spring Valley OB area have formed primarily on terraces and alluvial fans with 2 to 15 percent slopes. The dominant soils in the area are Bard, Colorock, and Tonopah. Bard and Tonopah soils occupy old terraces and alluvial fans and have gravelly sandy loam or gravelly fine sandy loam-textured surfaces. Colorock soils occur on broad alluvial fans and have very gravelly clay loam surfaces. The gravel pavements of undisturbed Bard, Tonopah, and Colorock soils tend to protect the soils from wind erosion. However, removal or disruption of the shallow Bard surface layer (5 in.) will expose the more wind erodible underlying fine sandy loam (WEG=3). Areas of highly wind erodible Arizo fine sands (WEG=1) also occur in the Coyote Spring Valley OB area.

DELTA, UTAH (2.2.3)

The soils of the Delta OB site have developed on lake plains and terraces with slopes generally zero to two percent. Three soil associations dominate this area; Abrahams-Anco-Abbott in the northeast, Yuba-Uffens-Uvada in the central portion, and Uvada-Playas-Goshute in the southwest portion. All major soils within the OB site area have silty clay, silt loam, silty clay loam, or loam horizons and generally are in WEG groups of 4 to 4L. Goshute gravelly silt loam typically has between 20 and 30 percent nonerodible grains, which is insufficient to reduce wind erosion below other silt loams (WEG=4L). Thus for major soils, the Delta OB site area has a relatively uniform moderate susceptibility to wind erosion, with an average soil erodibility factor of 86 tons/acre/year (U.S.D.A., 1977a).

ELY, NEVADA (2.2.4)

Detailed mapping by soil series is not available for the Ely OB site at this time. The soils of the proposed Ely OB site are primarily Durorthids that have formed on gently sloping (generally three to five percent) alluvial fans. They are calcareous and have loamy skeletal textures (I' = approximately 86 tons/acre/year). The duripan may be found about 20 in. (50 cm) below the surface (ETR-11, Geology and Mining).

MILFORD, UTAH (2.2.5)

Detailed soil mapping of the proposed Milford OB site is not available at this time. Soils occuring southwest of Milford in the area of the OB site are predominantly Aridisols (Natragids and Calciorthids) that have formed on valley bottoms and flood plains and Aridisols (Calciorthids) and Entisols (Torriofluvents and

Torriorthents) on the piedmont slopes. Valley bottom and floodplain soils consist primarily of deep, level to gently undulating (less than one percent to three percent slopes) soils that are moderately to very stongly alkaline. Surface textures are loam, silt loam, or silty clay loam (WEG = 4-7) over fine and fine loamy subsurface horizons. Piedmont slope soils are deep, mildly to strongly alkaline soils on slopes ranging from less than 1 percent to nearly 30 percent slopes. Surface layers are loam, silt loam, or sandy loam (WEG = 3-4L) while subsoils are loamy skeletal, fine loamy, fine silty, and sandy.

2.3 TEXAS/NEW MEXICO STUDY AREA

The Texas/New Mexico study area consists largely of broad, level to nearly level uplands. The major exception to this level upland is the highly dissected Canadian River Breaks that form an east-west zone across Oldham County, Texas and Quay County, New Mexico. Soils in the study area generally have formed on previously transported and sorted sediments. Surface texture of major soils in the area are fine sandy loams, loamy fine sands, loams and clay loams. The clay content of soils throughout the area is generally high. Reworked clays have accumulated and formed almost impermeable liners in shallow upland depressions. Argillic horizons (illuviated clay layers) are common to most of the upland soils, with calcium carbonate accumulations often occuring at or directly below the argillic horizon. The $CaCO_3$ accumulations of certain soils in the area have become indurated to form petrocalcic horizons. Although such soils are generally of limited extent, their relative importance increases from east to west.

The broad flat landscape of the Texas/New Mexico study area provides little resistance to winds. High wind velocities are common, especially in late winter and spring. The average annual afternoon windspeed at Amarillo, Texas, just east of the study area, is 8.4m/second (19 mph). Kimberlin, Hidlebaugh, and Grunewald (1977) examined potential wind erosion problems for the U.S. By combining climatic factors and highly erodible soil acreages for nonfederal rural land they formulated an index of wind erosion hazards. Index numbers were standardized to Kansas, which was assigned a value of 100 percent. Four states west of the Mississippi River: Arizona, California, Nevada, and Utah were not included due to insufficient data. Texas and New Mexico were found to have the greatest state wind erosion hazards in the U.S., with values of 869 and 666, respectively. Although the study was conducted at state level, the Texas wind erosion hazard value is assumed to reflect in large part conditions in the more arid and windier western portion of the state. Similar soil and climatic conditions exist in eastern New Mexico. Wilson et al. (1975) estimated that soil loss due to wind erosion varied from 5 to 50 tons per acre annually for typical rangeland, the predominant agricultural land use, in New Mexico. Similar or slightly higher soil losses are assumed to occur in western Texas due to similar soil and climatic conditions.

The southern portion of the Texas/New Mexico study area is dominated by soils with fine sandy loam and loamy fine sand surface textures. The Amarillo Series, in both the fine sandy loam and loamy fine sand phases, is a principal soil throughout this portion of the study area. Other important upland soils include Clovis, Springer, Portales, and Arvana Series. Fine sand such as the brownfield and Tivoli Series are abundant, but generally to a lesser degree than either the loamy fine sands or fine sandy loams. The loam phases of several series, most notably Amarillo, Clovis, and Portales, are also important. Because most upland soils in the area have formed on eolian deposits, fine sands dominate the coarse fraction of the soil separates. In general, the fine sand fraction decreases northward. In Curry and southwest Quay counties, New Mexico, for example, the loam phase dominates the Amarillo Series. However, Pullman loam is the principal upland soil throughout much of this area. Clay content increases eastward so that throughout Parmer, Castro, Swisher, Deaf Smith, Randall counties and southern Oldham County, Texas, clay loams, primarily of the Pullman and Olton series, dominate (soil surveys listed in References). Unlike the situation in counties to the south and west where several phases occupy a major portion of the upland landscape, clay loams overwhelmingly dominate the uplands in these central counties occupying 60 to over 85 percent of county areas. Most of these soils formed from eolian deposits.

Soils development in the Canadian River Breaks has created highly complex soil distributions patterns. Soils in the Breaks have generally formed on alluvial deposits of the Canadian River and its tributaries or on colluvium from badlands dissection, often of recent origin. Soil textures range from clays to gravelly loams. Due to the rugged terrain and resulting intricate soil patterns, soil mapping for much of the Breaks area has been done at the association or soil complex level of generalization. The Canadian River Breaks are not included in the DDA suitability areas.

The fine sand content is generally higher in soils north of the Canadian River than in soils of the counties in the central portion of the study area. Loams, fine sandy loams and loamy fine sands dominate the northern portion of the study area, except in Sherman County where clay loams dominate (U.S.D.A., 1975b). In Sherman County, Sherm, Sunray, and Gruver clay loams are the principal upland soils. Major upland soils in most of the northern portion of the Texas/New Mexico area include Dallam fine sandy loam and loamy fine sand, Perico and Dalhart fine sandy loams, and Dumas, Gruver, and Conlen loams (soil survey listed in References).

2.4 TEXAS/NEW MEXICO OPERATING BASE SITES

CLOVIS, NEW MEXICO (2.4.1)

The principal soils of the proposed Clovis OB site are Amarillo loamy fine sand (WEG=2) and fine sandy loam (WEG=3). Small areas of Clovis loamy fine sandy (WEG=2) and fine sandy loam (WEG=3), and Mansker fine sandy loam (WEG=3) also occur. However, Amarillo soils overwhelmingly dominate the site (U.S.D.A., 1958).

DALHART, TEXAS (2.4.2)

The major soils within the proposed Dalhart OB site are Dallam fine sandy loam (WEG=3) and loamy fine sand (WEG=2) and Vingo loamy fine sand (WEG=2). The Dallam soils occur in extensive, nearly level (0-3 percent slope) tracts within the OB area as well as in association with Vingo soils. Where the two series occur in association, vingo loamy fine sand occupies the broad low (approximately 10 ft high) ridges and Dallam loamy fine sands occur in the lower areas. Other soils occupying smaller but significant tracts within the proposed site include: Perico fine sandy loam (WEG=3) and loamy fine sand (WEG=2), Rickmore fine sandy loam (WEG=3) and loamy fine sand (WEG=2), Spurlock fine sandy loam (WEG=3), and Valentine fine sand (WEG=2) (U.S.D.A., 1977b).

3.0 M-X IMPACTS

Wind erosion impacts will occur to both onsite and offsite areas. Without proper mitigating measures, direct onsite impacts will include soil losses which make it difficult to revegetate and stabilize the site, and the release of high levels of suspended particulates. Offsite impacts that can be anticipated if proper mitigating measures are not taken include: 1) accelerated wind erosion due to soil avalanching, 2) abrasion from windborne particles, and 3) burial of objects, ranging from crops to roadways.

Potential wind erosion impacts were ranked as low, moderate, or high to very high for the DDA subunits in each study area. Nevada/Utah subunit impact rankings were based on the ration of hydrologic subunit area to wind erosion area equivalents (WEAE). WEAEs were calculated as follows:

a) Wind erosion sensitive areas (lower Piedmont slopes and valley floors) are assumed to have soil erodibility factors (I') one factor higher than middle and upper Piedmont slopes. Due to the lack of detailed soil information for hydrologic subunits, wind erosion sensitive area was defined as acreage in Alkali sink shrub and shadscale native vegetation. These plant communities generally occupy the lower Piedmont slope and valley floors. These areas typically have soils that are among the most erodible in the hydrologic subunit.

b) For missile shelters and climatic factors (C') 100-200, raising the I' one factor value, e.g., from 86 to 134 tons/acre/year, increases the annual soil loss approximately 66 percent (Table 2-1) therefore,

c) Sensitive disturbed areas are multiplied by 1.66 and the remaining (nonsensitive) disturbed areas by 1.0.

d) The sum of the values obtained in C is the WEAE for that hydrologic subunit.

Country wind impact rankings for Texas/New Mexico were based on the projected proportion of each county to be disturbed and the estimated average soil loss (tons per acre per year) for construction areas in that county. The estimated average soil loss was based on solution of the wind erosion equation for a 10 acre disturbed area and representative climate (C') and soil erodibility (I') factors for each county.

3.1 NEVADA/UTAH

Soil and climate information is incomplete for the Nevada/Utah study area. Site specific analysis is, therefore, impossible at this time but will be undertaken in a later tier. However, certain generalizations regarding the impacts of M-X on wind erosion can be made. Activities related directly to M-X construction and operation are expected to be confined largely to piedmont slopes, valley bottoms, and floodplains. Many of the piedmont slope soils are in WEG groups 3, 4, and 4L, which have average erodibility factors of about 86 tons/acre/year. The climatic factor for these sites can be expected to be high, probably ranging between 100 and 200. Table 2-1 presents values for the anticipated disturbance areas for selected facility construction sites.

For comparison, an acre foot of surface mineral soil is commonly assumed to weigh between 1,500 tons and 2,000 tons or approximately 125 to 170 tons per acre inch (Brady, 1970). Although actual values will vary considerably with composition and compaction, this general value suggests that for piedmont slope soils in the Nevada/Utah study area, approximately 0.25 to 0.50 in. of soil per acre per year (39 to 94 tons per acre annually) can be expected to be removed during support road construction. The values for large areas (such as OB sites) can be expected to be between 0.5 and 1.0 in. per acre per year (86 to 172 tons per acre annually).

Only the Steptoe hydrologic subunit is expected to have low short-term wind erosion impacts. Sevier Desert, Government Creek, Big Smoky-Tonapah Flat, Monitor-North and South, Newark, Long, Butte-South, Spring, Patterson, White River, Pahroc, and Pahranagat subunits are expected to have moderate short-term impacts. All remaining units are anticipated to experience high short-term wind erosion impacts without proper mitigation measures. Long-term impacts should be low following revegetation.

Short-term potential wind erosion impacts are expected to be high for both the Coyote Spring Valley and Milford OB sites if proper mitigation measures are not taken. Long-term impacts shall be low if the sites are revegetated.

Although soils with erodibility factors averaging approximately 86 tons per acre per year predominate on the piedmont slopes, sandy soils also exist. Placing facilities on these soils would result in much higher erosion rates (Table 2-1). For example, if a segment of support road is constructed through a sand dune area over 350 tons per acre can be expected to be mobilized annually. Maximum soil movement is achieved over narrower open areas for highly erodible soils than for less erodible soils. Estimated potential wind erosion impacts in the Nevada/Utah DDA are given by hydrologic subunits in Table 3.1-1.

Figure 3.1-1 shows the distribution of critical areas for wind erosion in Utah. Critical areas were defined as those areas with sandy soils or dunes or playas. Extensive critical area is present in Delta OB area of east central Millard County. (Similar data for Nevada are currently not available at state level but are being sought for continued analysis of the potential wind erosion impacts in the Nevada/Utah study area.)

Disturbance and destabilization of dune areas by recreational ORVs could mobilize thousands of tons of sands. Traffic on playa beds could mobilize considerable quantities of alkaline suspendable particulates. Eroded playa material would be less effective in accelerating erosion in surrounding areas and would be unlikely to cause significant burial. However, dust from eroded playa beds could reduce plant photosynthesis if accumulated in sufficient quantities. Additionally, high levels of airborne particulates would present a health hazard.

Potential impacts from wind erosion in most hydrologic subunits in the Nevada/Utah area would be high to very high without strict adherence to mitigations (Table 3.1-1). Disruption of the fragile playa surface and destabilization of dunes that could result in interference with or burial of transportation and drainage routes and soil avalanching, represent very real threats to the environment and residents. Economic impacts could be most severe for the Delta OB site due to the considerable amount of irrigated agriculture in the vicinity that would be

Table 3.1-1. Estimated potential wind erosion impacts in Nevada/Utah DDA.

Hydrologic Subunit		Total Hydrologic Subunit Area (acres)	Potential Area[1] Disturbed During Construction (acres)	Estimated Wind[2] Erosion Sensitive Area Disturbed During Construction (acres)	Wind Erosion[3] Area Equivalents (acres)	Relative[4] Impact Rating
No.	Name					
4	Snake, Nev/Utah	1,728,000	10,495	4,485	13,455	*****
5	Pine, Utah	467,200	3,998	2,901	5,913	*****
6	White, Utah	601,600	4,746	3,155	6,828	*****
7	Fish Springs, Utah	256,000	2,061	1,920	3,328	*****
8	Dugway, Utah	207,200	1,936	797	2,462	*****
9	Government Creek, Utah	362,400	562	88	620	***
46	Sevier Desert, Utah	1,920,000	5,662	914	6,265	***
46A	Sevier Desert-Dry Lake, Utah	620,800	7,934	7,579	12,936	*****
54	Wah Wah, Utah	384,000	5,662	4,492	8,627	*****
137A	Big Smoky-Tonopah Flat, Nev.	1,025,900	3,247	2,831	5,115	***
139	Kobeh, Nev.	555,500	4,886	54	4,922	*****
140	Monitor, Nev.	664,300	3,934	322	4,147	***
141	Ralston, Nev.	586,900	6,247	4,939	9,507	*****
142	Alkali Spring, Nev.	200,300	3,248	2,795	5,093	*****
148	Cactus Flat, Nev.	See Stone Cabin				
149	Stone Cabin, Nev.	630,400	4,529	1,843	5,745	*****
151	Antelope, Nev.	284,200	4,311	330	4,529	*****
154	Newark, Nev.	512,600	2,373	1,722	3,510	***
155	Little Smoky, Nev.	714,100	4,873	3,382	7,105	*****
156	Hot Creek, Nev.	663,000	4,623	3,054	6,639	*****
170	Penoyer, Nev.	448,000	3,810	1,292	4,663	*****
171	Coal, Nev.	294,400	3,683	467	3,991	*****
172	Garden, Nev.	315,500	3,301	3,255	5,449	*****
173	Railroad, Nev.	1,716,300	10,787	5,776	14,599	*****
174	Jakes, Nev.	270,100	3,060	627	3,474	*****
175	Long, Nev.	416,600	1,315	358	1,551	***
178B	Butte-South, Nev.	646,400	3,310	421	3,588	***
179	Steptoe, Nev.	1,242,900	445	00	445	*
180	Cave, Nev.	231,700	1,999	333	2,219	*****
181	Dry Lake, Nev.	564,500	6,683	3,797	9,189	*****
182	Delamar, Nev.	245,100	1,935	492	2,260	*****
183	Lake, Nev.	369,300	2,998	28	3,016	*****
184	Spring, Nev.	1,063,000	1,374	180	1,493	***
196	Hamlin, Nev./Utah	264,300	3,998	1,380	4,909	*****
202	Patterson, Nev.	266,200	591	00	591	***
207	White River, Nev.	1,036,800	4,123	432	4,408	***
208	Pahroc, Nev.	305,900	250	00	250	***
209	Pahranagat, Nev.	503,000	624	379	874	***

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[1] Includes area for DTN, cluster roads shelters, construction ramps and concrete plants. OBs, OBTs and airfields are not included.

[2] Due to the lack of detailed soil information for hydrologic subunits, wind erosion sensitive area was defined as acreage in alkali sink shrub and shadscale native vegetation, these plant communities generally occupy the lower piedmont slope and valley floors. These areas typically have soils that are among the most erodible in the hydrologic subunit.

[3] The Wind Erosion Area Equivalents (WEAEs) are calculated as follows:

a) Wind erosion sensitive areas (defined above) are assumed to have soil erodibility factors (I') one factor higher than mid and upper piedmont slopes.

b) For missile shelters and climatic factors (C') 100-200, raising the I' one factor value, e.g., from 86 to 134 tons/acre/year, increases the annual soil loss approximately 66% (Table 4-1) therefore,

c) Sensitive disturbed areas are multiplied by 1.66 and the remaining (nonsensitive) disturbed areas by 1.0.

d) *The sum of the values obtained in (c) is the WEAE for that hydrologic subunit.*

[4] - = No impact.

* = Low impact.

*** = Moderate impact.

***** = High to very high impact.

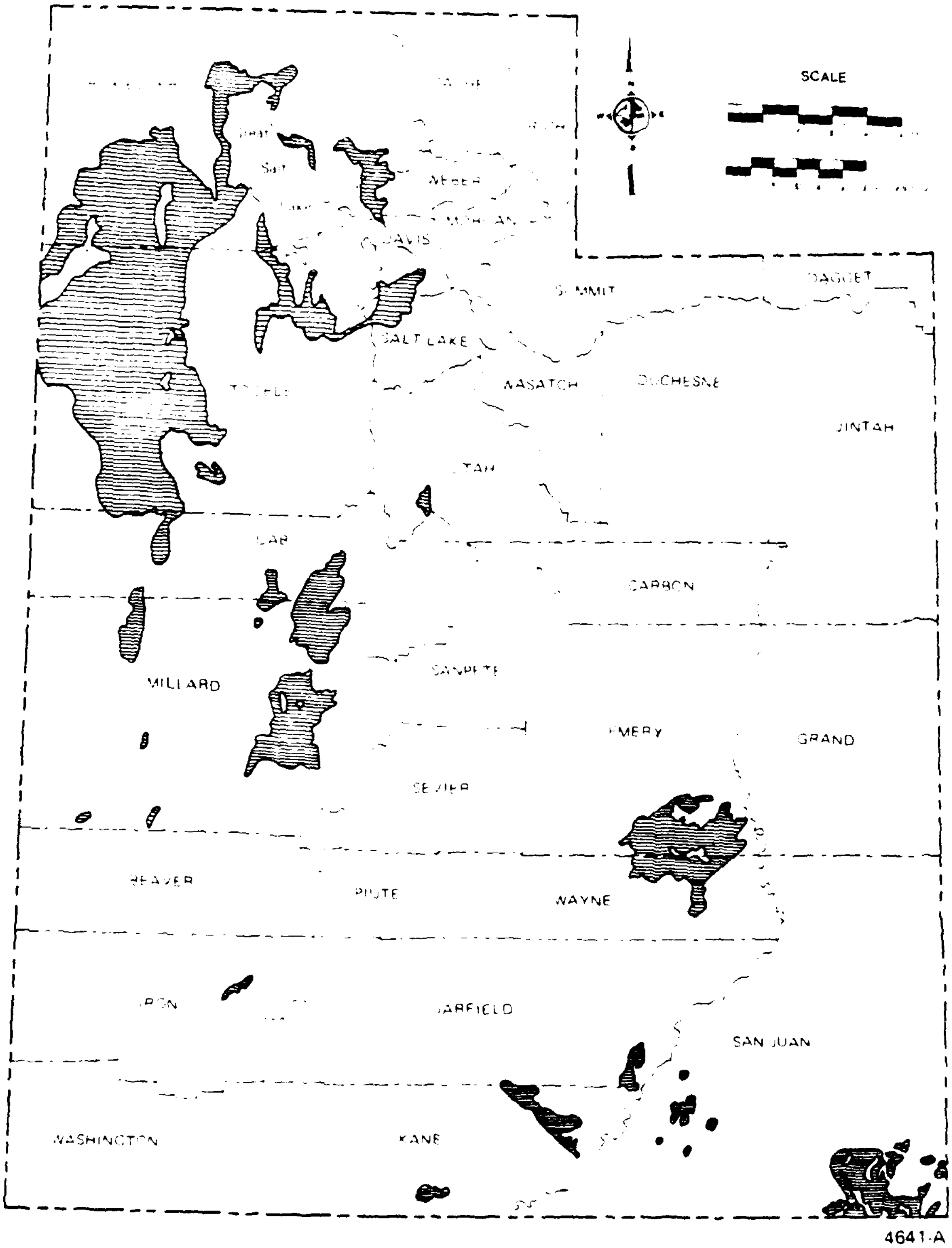

Figure 3.1-1. Critical areas for wind erosion in Utah.

susceptible to decreased crop yields or crop failures due to abrasion by windborne soil particles.

3.2 TEXAS/NEW MEXICO

Although climate and soils vary considerably within the Texas/New Mexico study area, more detailed information is available for this area than for the Nevada/Utah area. Annual C' values for the study area range from about 100 in the south to somewhat over 150 in the north (Kimberlin et al., 1977). Although certain sites might have C' values outside this range, it is assumed that typical annual values for the study area will be between 100 and 150. C' values in the area are highly seasonal. The lowest C' values occur in August, September, and October. Maximum C' values occur in the spring (March through May) when they exceed 200 in the north (Woodruff and Armbrust, 1968). Therefore, maximum wind erosion will occur in the spring. Soils in all WEG groups occur in the study area. However, all major upland soils are in groups 2 (average I' = approximately 134 tons/year/acre) through 6 (average I' = approximately 48 tons/year/acre). Loamy fine sands and fine sandy loams, with average I' values of approximately 134 and 86 respectively, dominate the uplands in the southern portion of the study area. Loams (average I' = approximately 48 - 56 tons/acre/year) are somewhat more common in the northern and west central portions of the study area than in the south. However, general wind erosion hazards may be greatest in the north due to higher C' values. Clay loam soils predominate in the central portion and have WEG values of 5 to 6 (average I' = approximately 48 and 56 tons/acre/year, respectively) depending upon clay content. Estimated potential wind erosion impacts for the Texas/New Mexico DDA are given by county in Table 3.2-1.

Removal of the vegetative cover at construction sites will expose the soil surface to accelerated erosion. The amount of soil lost will depend upon the I' and C' values at the site and the size of the area exposed. For narrow, unsheltered areas such as support roads, soil losses could range from 14 tons per acre annually for clay loams where C'=100, to about 134 tons per year for fine loamy sands and C'=150, if proper mitigating measures are not taken (Table 2-1). If dunal areas were traversed, losses over 290 tons per acre could be expected annually. Soil loss values calculated using C'=150 and I'=86 are representative of typical soil losses that can be expected in the Texas/New Mexico area during M-X construction. These values range from 56 tons/acre/year (approximately 0.33 to 0.50 in.) for construction road, to 129 tons/acre/year (approximately 0.75 to 1.0 in.) for larger areas.

Wilson et al. (1975) estimated that typical rangeland in New Mexico lost between 5 and 50 tons of soil per acre per year due to wind erosion. Texas rangeland losses are assumed to be similar due to similar soil and climatic conditions. Thus, typical soil losses at M-X construction (C'=150, I'=86) would be two to five times greater than the mean value for Wilson's estimate.

Total soil loss is expected to be less at sites with clay loam soils but relative proportions of suspended particulates emission will be greater than at sites with coarser soils. During construction, particulate concentrations within the immediate vicinity of sites are expected to exceed established air quality standards. Airborne suspended particulate emissions could be sufficiently high to cause health problems and reduced visibility for workers. All workers should be equipped with dust filters for health protection.

Table 3.2-1. Estimated potential wind erosion impacts in Texas/New Mexico.

County	County Area (acres)	Estimated Average Soil Loss[1] (tons/acre/year)	Area to be Disturbed (acres)	Impact Ranking[5]
Bailey, Tex.	534,400	104[2]	3,396	*****
Castro, Tex.	563,200	47[3]	3,784	***
Cochran, Tex.	500,800	104	2,329	***
Dallam, Tex.	945,200	117[4]	19,406	*****
Deaf Smith, Tex.	966,400	47	15,913	*****
Hartley, Tex.	952,300	117	10,382	*****
Hockley, Tex.	See Lamb County			
Lamb, Tex.	654,100	104	2,135	***
Oldham, Tex.	945,300	104	1,748	***
Parmer, Tex.	549,800	47	6,972	***
Randall, Tex.	584,000	47	1,261	*
Sherman, Tex.	586,200	47	679	*
Swisher, Tex.	See Castro County			
Chaves, N. Mex.	389,400	117	13,293	*****
Curry, N. Mex.	897,900	117	7,568	*****
DeBaca, N. Mex.	1,507,800	117	1,261	*
Guadalupe, N. Mex.	See Quay County			
Harding, N. Mex.	1,365,400	117	4,754	***
Lea, N. Mex.	2,811,200	117	873	*
Quay, N. Mex.	1,840,000	117	14,069	*****
Roosevelt, N. Mex.	1,570,800	117	17,950	*****
Union, N. Mex.	2,442,200	104	6,307	***

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[1] Average soil loss per county was based on missile shelter area and estimated average erodibility factor (I') and climatic factor (C') for county.

[2] For counties in the southern portion of DDA, average C' was assumed to be 100 and average I' was assumed to be I'=134+86/2 thus, 130+78=208/2=104 (Table 2-1).

[3] For counties in the central portion of the DDA, average C' was assumed to be 100 and average I' was assumed to be 56 due to prevalence of clay loam.

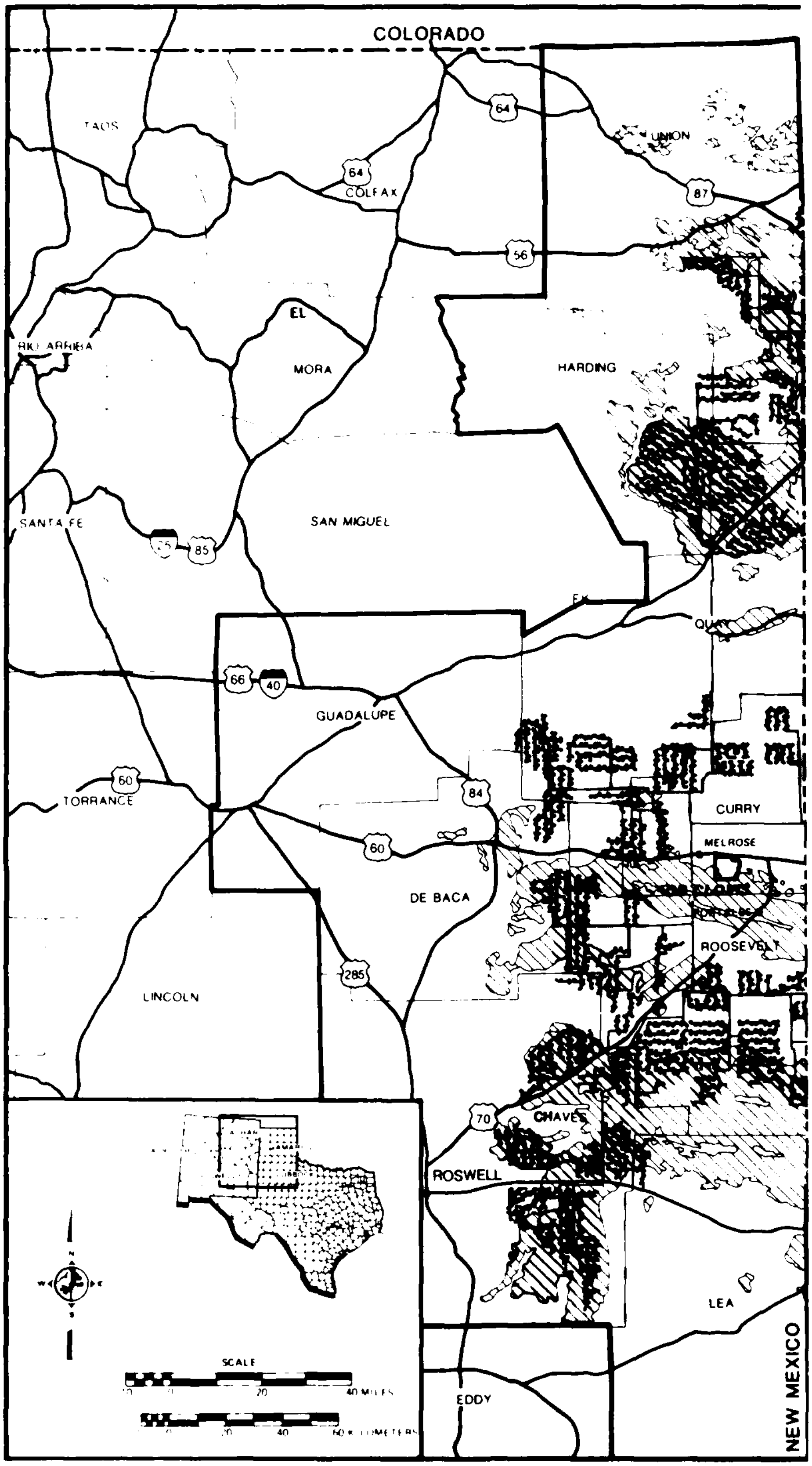
[4] For western and northern counties, average C' was assumed to be 150 and average I' was assumed to be 86 due to the prevalence of loams and sandy loams.

[5] - = No impact.
* = Low impact.
*** = Moderate impact.
***** = High to very high impact.

Accelerated soil loss at construction sites would have adverse impacts on areas downwind of the site. Dust accumulations on crops could reduce yields. However, because deposition of suspended particulates is generally distriubted over considerable distances, accumulations should not be sufficient to severely impact crop yields. Texas and New Mexico have been identified as states in which air quality standards for certain major cities cannot be met because of uncontrollable sources of particulates. Hagen and Woodruff (1973) estimated that during the 1960s an average of 77 million tons of dust were suspended annually over the Great Plains states. If 1,500 mi of DTN (24 of the 100-ft wide disturbance corridor paved), 6,200 mi of cluster roads, 1,500 mi of support roads, and 4,600 missile shelters are constructeud, total suspended particulates emitted from these facility sites could be as high as 800,000 tons annually. This reasonable worst case assumes that all sites are located on loamy fine sands and that suspended particulates are 3.8 percent of the total soil loss for each site (as suggested by Office of Air Quality Planning and Standards Guidelines) (ETR-13, Atmospheric Resources, 1981). Thus, up to 1 percent of the estimated total annual Great Plain's suspended particulates observed during the 1960s could be generated by M-X construction sites if proper mitigating meaures were not employed. Wilson et al. (1975) estimated that wind erosion in Luna County, New Mexico contributed 225,000 tons of suspended particulates to the atmosphere annually. This represents approximately 76 tons per square mile annually. The estimated annual suspended particulate emissions for construction (approximately 800,000 tons of suspended particulates annually) without mitigating measures represents approximately 3,560 tons per sq mi of construction area annually or 50 times greater than Wilson's estimate for a non-M-X New Mexico landscape. As certain cities in Texas and New Mexico are currently classified as nonattainment areas for air quality particulate standards, wind erosion controls at M-X construction sites should be strictly adhered to so as not to aggravate the situation.

The impacts on surrounding areas caused by accelerated erosion at construction sites would be greatest where soils with high sand content exist. Not only would sandy (e.g., fine loamy sands or find sands) soils mobilize more readily than loamy or clay loam soils (as shown in Table 2-1), but proportions transported by saltation and surface creep would be greater. Soil mobilized at unprotected construction sites would provide materials that could cause accelerated soil removal on otherwise stable agricultural land on the leeward side of the site. Additionally, soil-laden winds are highly abrasive and can be highly detrimental to vegetative cover. For example, even short periods of exposure to sand blasting by high winds can reduce crop yields. Reduction in vegetative cover by windborne soil will increase field susceptibility to wind erosion. Without proper mitigation measures, abrasion and burial by windborne soil particles would reduce crop yields downwind of construction sites. Yield reductions could range from negligible to total crop failure. Fields near large construction areas with medium, or coarse textured soils, for example, the Clovis and Dalhart OBs, would be most susceptible to severe impacts. Thus, soil avalanching initiated by saltation at M-X construction sites could greatly accelerate soil erosion on productive agricultural land in the area and could damage or destroy crops by abrasion. The potential for damage to agricultural land will be greatest during the spring when wind velocities are high and field cover is low.

Figure 3.2-1 shows critical areas for wind erosion in the Texas/New Mexico area. Figure 3.2-1 is based on data from appropriate soil surveys and Soil



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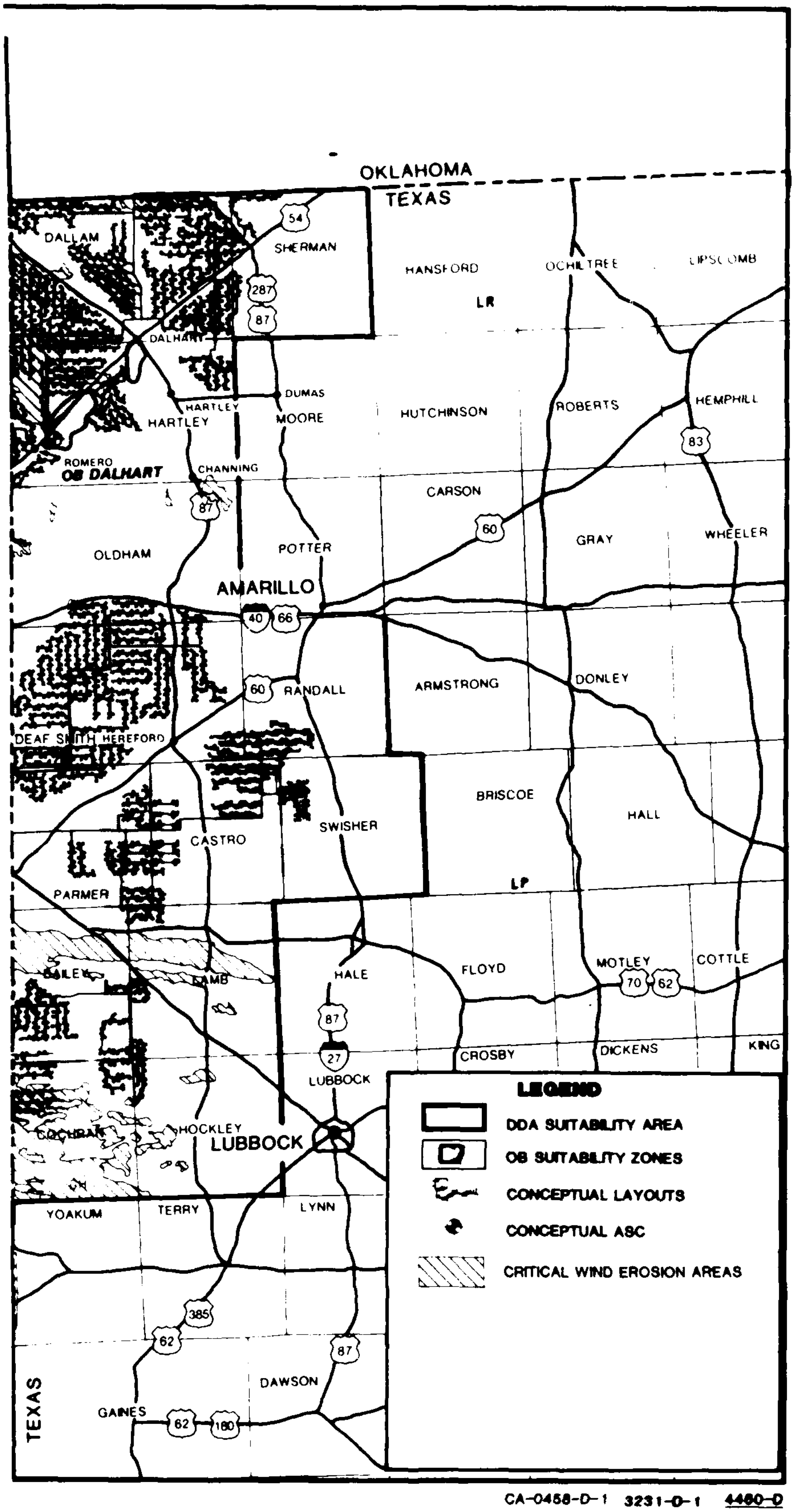

Figure 3.2-1. Critical areas for wind erosion in Texas/New Mexico area.

Association and Land Classification for Irrigation Reports listed in References. Critical areas were defined as areas in which more than 50 percent of the soils are extremely susceptible to wind erosion (WEG = 1 or 2). Critical areas for wind erosion are extensive throughout the southern, western, and northern portions of the Texas/New Mexico DDA.

The study area would also experience removal of vegetative cover due to activities indirectly related to M-X such as recreation and non-M-X construction that would occur in the study area. Because much of the land in the Texas/New Mexico DDA is agricultural, access for ORVs would be reduced. However, if stabilized dune areas were devegetated by intensive recreational activity, dune migration could result in burial of crops and blockage of transportation routes.

Potential impacts from wind erosion in Texas/New Mexico would be high to severe in the northern, southern, and western portions of the DDA without strict adherence to mitigation techniques. Soil and climatic conditons are conducive to extensive mobilization of soil from bare areas throughout much of the area. Potential problems include destabilization of dunal areas or creation of new dunal areas, increase in already excessively high atmospheric particulates, damage to or destruction of vegetation, including crops, and accelerated erosion of productive soils by soil avalanching initiated at construction sites.

4.0 FUTURE WIND EROSION IMPACTS WITHOUT M-X

Soil and climatic conditions in both the Nevada/Utah and Texas/New Mexico areas are highly conducive to wind erosion. The hazards of wind erosion in these areas are among the highest in the U.S., particularly in western Texas and eastern New Mexico. The sparse natural vegetation of the areas provides some degree of stability to soils. However, removal of the vegetative cover, such as for agriculture or construction, can have serious consequences. Much of the research on control of wind erosion conducted in the United Staes is carried out in these areas.

Implementation of improved wind erosion control techniques can be expected to reduce the impacts of wind erosion relative to given levels of disturbance. Expansion of irrigated agriculture will tend to reduce local wind erosion by increasing vegetative cover and surface moisture. However, increased recreational use of ORVs can be expected to devegetate considerable areas highly susceptible to wind erosion. Dunal areas and playas are favored areas for recreational ORV activity. Although both study areas will become increasingly subject to these activities, the Texas/New Mexico area should be less affected due to the higher proportion of private land ownership and new crop agriculture.

5.0 MITIGATIONS

5.1 AIR FORCE PROGRAMS

The Air Force will establish an erosion control program including: selecting appropriate sites where drainage, topography, and soils are favorable for planned use; minimizing disturbed areas and the mixing of soils; revegetating disturbed areas; paving roads as early in the project life as practicable; applying dust palliatives on roads and restricting off-road travel.

5.2 OTHER MITIGATION MEASURES UNDER CONSIDERATION

Numerous control measures are available for wind erosion. Fortunately, with proper controls, potentially severe impacts can be mitigated. However, because of the extent of the project and associated total mitigation costs, high susceptibility of the soils to wind erosion, and the time that may be required for revegetation, careful planning will be necessary to maximize the effectiveness of mitigations in reducing the impacts of wind erosion. The site selection process could take soil suspectibility to wind erosion into consideration. Whenever possible, sites with less erodible soils could be selected. Dunal or sand hill areas could be avoided to the extent possible.

Areas disturbed during construction could be minimized and vegetative cover maintained as long as possible prior to construction. Vehicles routes at sites could be selected to minimize distance across the more erodible soils. All construction activities could include implementation of appropriate wind erosion control techniques and construction work could be minimized during periods of high winds.

Considerable research in wind erosion control has been conducted and numerous effective techniques have been developed. Much of the research has focused on control of wind erosion for agricultural land. However, the experience gained from this work and from research focused on wind erosion control for construction sites, particularly for highway disturbance corridors, has direct application to M-X.

Revegetation of disturbed areas will be slow, and the period during which construction sites must be artificially protected may be prolonged. Revegetation procedures could begin as soon as possible. Best procedures for rapid stabilization and revegetation could be used. Topsoil from disturbed areas could be stockpiled and redistributed prior to revegetation in order to facilitate plant growth.

The construction of barriers is one means of wind erosion control applicable to M-X sites. The most effective barriers have porosities of approximately 40 percent and can effectively reduce erosion over an area approximately 30 times as wide as the barrier height. (Nonporous barriers reduce windspeeds abruptly, but the effective distance is considerably less.) The barriers would have to be movable to account for shifting wind directions. Soil susceptibility to wind ersoion will be most intense during actual construction due to repeated disruption of the surface by vehicles. Portable wind fences could be used during this time to reduce suspended particulate emissions and grain saltation. Additionally, strategic placement of vehicles when not in use could help reduce soil movement and could be used in conjunction with, but not as substitutes for, wind fences.

Suppression of suspended particulates with water such as by sprays, foggers, or by soil saturation may be used as an emergency response but could be avoided to the extent possible due to excessive water requirements and limited supply. Strategic placement and alignment of the structures could significantly reduce wind erosion. For example, the layout of OB buildings could be planned so as to function as wind barriers.

Artificial mulching with shredded wood, paper, or plastic has proven effective for erosion control. The artificial mulch is taked down with wire mesh and seeds placed directly into the mulch. This technique would be appropriate for protecting bare soil surfaces within the OB and in road disturbance corridors and would expedite revegetation. Spreading nonerodible materials such as very coarse gravel or cobbles over the bare surface would also reduce erosion by increasing surface roughness and would be appropriate on less erodible soils such as clay loams. The election of a suitable surface covering material may be largely an economic decision.

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APPENDIX A THE WIND EROSION PROCESS

In order to appreciate the potential adverse impacts that could result from wind erosion of soils in the fragile arid and semiarid Southwest due to M-X-related activities, it is necessary to understand the processes by which wind erosion occurs. The following discussion provides a brief overview of the processes involved in wind erosion.

A.1 SOIL ENTRAINMENT AND TRANSPORTATION

The entrainment and transport of soil particles by wind occurs on a grain-by-grain basis. Entrainment of individual particles is highly selective. Certain particles within the soil matrix have much higher potentials for entrainment than others. Factors which affect the wind's ability to entrain and transport soil particles include:

1. wind velocity,
2. soil texture,
3. degree and stability of soil aggregates, and
4. soil surface roughness and vegetative cover.

For winds passing over soil surfaces, the velocity of the wind increases rapidly with height above the soil surface. The change in wind velocity with height above the soil surface is called the wind's velocity gradient. The velocity gradient is a function of friction caused by soil surface roughness, with rough surfaces having steeper velocity gradients than smooth surfaces. Due to sharp velocity gradients near the soil surface, individual grains protruding higher are subject to stronger winds. Moving air exerts three pressures on soil grains (see Figure A.1-1) (Chepil and Woodruff, 1963):

1. Velocity pressure - positive pressure against the windward side of a grain that creates form drag on the soil grain.
2. Viscosity pressure - negative pressure on the leeward side of a grain that creates skin friction drag.
3. Static pressure - negative pressure on the top of a grain relative to pressure at the bottom of a grain exerted tangential to wind flow creates lift.

The threshold total drag (form drag and skin friction drag) and lift required to mobilize surface grains is influenced by the diameter, density, and shape of the grains, angle of repose of the grains relative to mean drag level of the wind, degree of packing of top grains, and impulses of turbulence associated with drag and lift (winds capable of entraining soil grains are always turbulent). Drag and lift per unit of horizontal area occupied by top grains is much higher than for the netire bed because top grains take most of the drag and lift but occupy only a portion of bed area. The mean aerodynamic surface (effective roughness height) remains constant

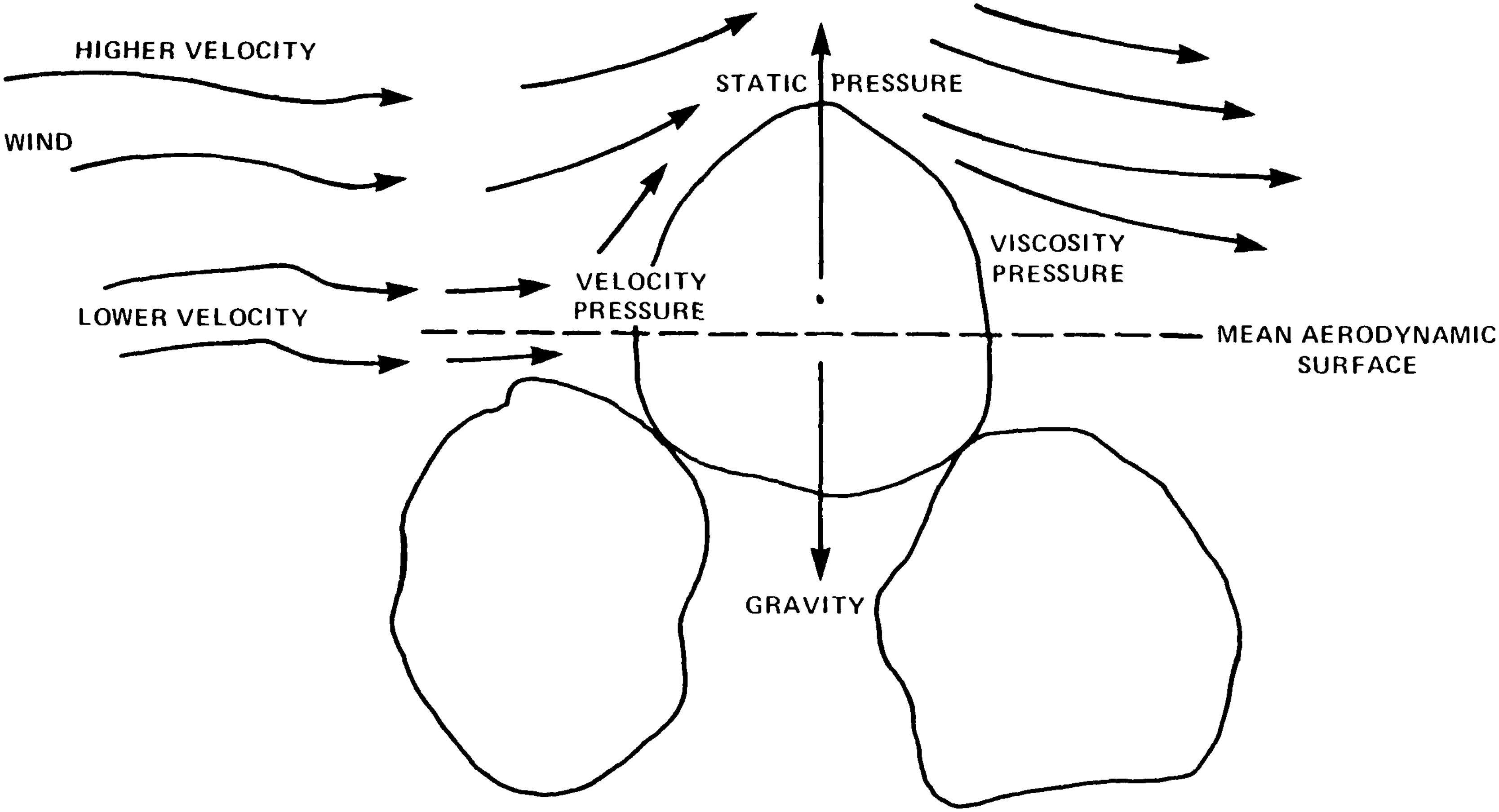

Figure A.1-1. Velocity, viscosity, and static pressures exerted on soil particles. (Source: Chepil and Woodruff, 1963).

for a surface regardless of windspeed. Therefore, higher wind velocities create steeper velocity gradients and exert greater drag and lift on protruding grains. Prior to lift into the windstream soil particles may spin or vibrate due to the reduced pressure above the particle (Troeh et al., 1980) (Figure A.1-2).

The most readily erodible soil particles are approximately 0.1 mm in diameter (fine to very fine sands) (Table A.1-1). As lighter grains of a given diameter are more erodible than heavier grains of the same diameter, it is convenient to express diameter and density in a single term called the equivalent diameter. Equivalent diameters are calculated by the equation:

$$D_e = P_e D/2.65$$

Where:

D_e = Equivalent diameter
P_e = Bulk density (grams/cubic centimeter)
D = Actual grain diameter (determined by dry sieving)
2.65 = Average particle density of arable surface soil (grams/cubic centimeter)

Grains larger than D_e = 0.5 mm (approximately 0.84 mm actual diameter) are generally not erodible by winds of common velocities (Chepil and Woodruff, 1963). Therefore, the 0.84 mm grain diameter (coarse sand) is commonly accepted as the boundary between wind erodible and nonerodible particles, although violent winds can move soil particles larger than coarse sand. Throughout this ETR, the term nonerodible material will be used to include all soil separates larger than 0.84 mm in diameter.

While coarse sands and gravels resist wind erosion due to size, undisturbed silts and clays resist erosion due to particle cohesion. However, if dry clays and silts which commonly occur in playas in the M-X study areas are mechanically disrupted, they are readily transported by even mild winds. Vehicle traffic across playas provides sufficient surface disruption to initiate considerable entrainment of silt and clay particles. Approximately 50-70 percent of soil movement is by saltation (Brady, 1974). Saltation begins when winds attain the threshold velocity necessary to detach soil grains. Individual particles are then lifted almost vertically (75°-90°) from the soil surface. Saltating grains generally rise less than 5-10 cm and rarely rise more than 30 cm. The grains return to the surface at an accelerating velocity due to gravity. Under the combined influences of drag and gravity, the grains impact the surface at a much lower angle than their detachment angle, typically 6°-12° (Troeh et al., 1980). Their impact therefore has a detaching effect on other particles.

Very small soil grains such as clays may be dislodged by saltating particles, or other mechanical means, and transported in suspension for great distances. Suspended transport can account for as much as 40 percent of soil movement but rarely exceeds 15 percent. Particles too large to saltate may roll along the surface (surface creep). Surface creep can account for up to 25 percent of soil movement (Brady, 1974).

Saltating grains that originate from soils that are highly susceptible to wind erosion such as bare sands can be transported to areas of more resistant soils. These

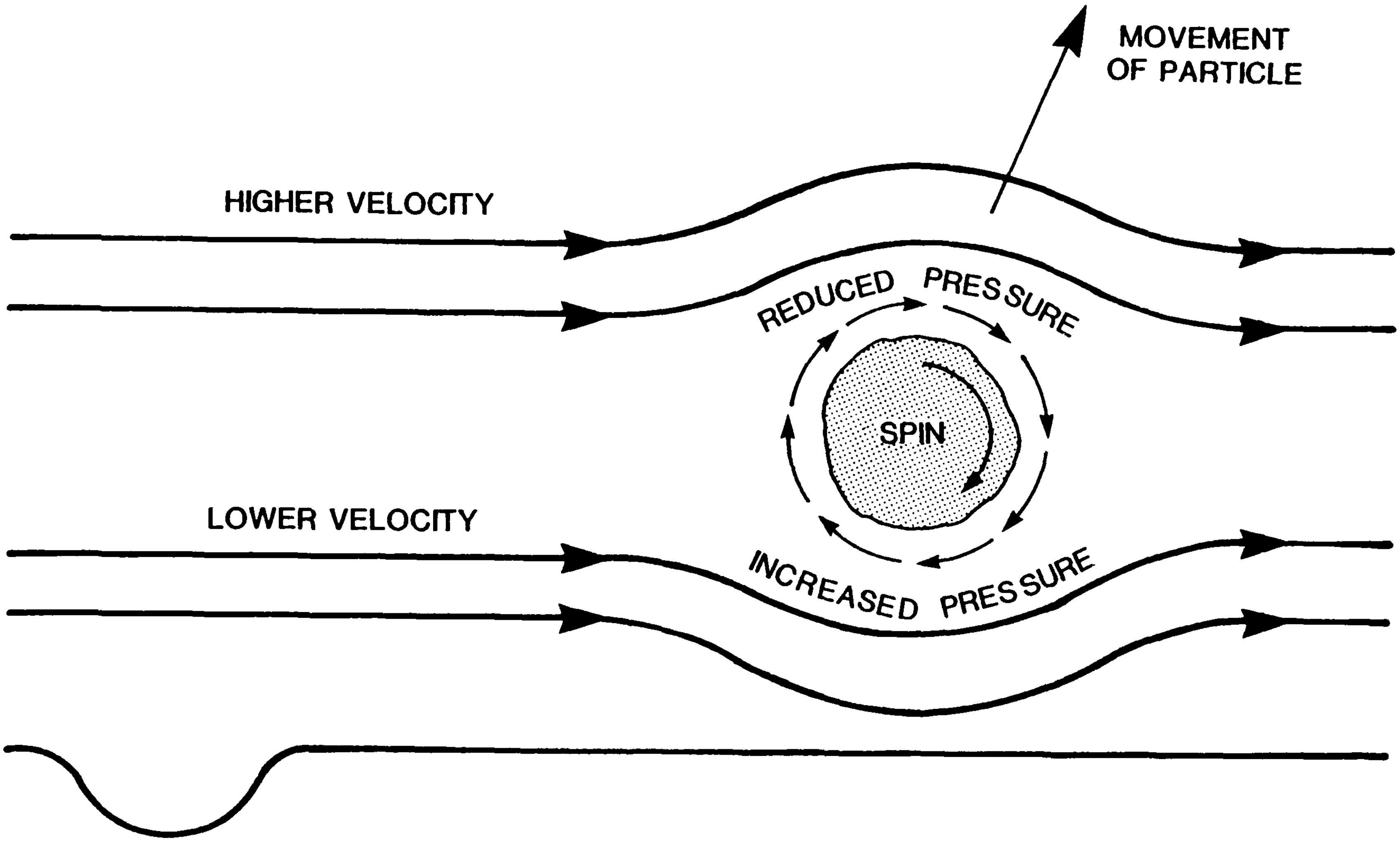

Figure A.1-2. The roll of spin in soil particle entrainment. (Source: Troeh, et al, 1980).

Table A.1-1. U.S. Department of Agriculture soil separates classification system.

Separate	Diameter (mm)
Very coarse sand	2.00-1.00
Coarse sand	1.00-0.50
Medium sand	0.50-0.25
Fine sand	0.25-0.10
Very fine sand	0.10-0.05
Silt	0.05-0.002
Clay	Less than 0.002

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Source: USDA.

saltating particles can provide sufficient impact to initiate entrainment of the more resistant soils at lower wind velocities than would otherwise be required. Thus, initial saltation sets in motion a cascading effect, commonly called soil avalanching, in which the rate of soil movement increases with the distance that wind travels across the eroding surface.

A.2 FACTORS AFFECTING WIND EROSION OF SOIL

Soil characteristics, wind conditions, and physical configuration of the soil surface are the principal factors that influence the amount of wind erosion.

SOIL CHARACTERISTICS (A.2.1)

The primary soil characteristics affecting susceptibility to wind erosion are texture, the degree and stability of soil aggregation, and surface moisture. Soil texture refers to the relative proportions of sand, silt, and clay separates. Soils with high contents of fine to very fine sand separates are highly susceptible to wind erosion. In general, soil resistance to wind erosion increases with clay and silt content. A study conducted in western Texas revealed that soils containing 10 percent clay eroded 30-40 times more readily than soils with 25 percent clay content (Foth, 1980). However, aggregates composed entirely of clay are readily broken down by drying, freezing or mechnical means. Soils with mixtures of 20-30 percent clay, 40-50 percent silt, and 20-40 percent sand (loam-clay loam) tend to be most resistant to wind erosion (Ritter, 1978). Soil aggregates larger than 0.84 mm in diameter are generally nonerodible and if they protrude above the soil surface, they protect smaller, otherwise erodible particles, from wind.

Calcium carbonate ($CaCO_3$) tends to decrease the cohesiveness of clays. The presences of free $CaCO_3$ in the soil decreases soil aggregate stability and can increase susceptibility to wind erosion. Accumulations of $CaCO_3$ are common in soils in the M-X study areas. On the other hand, accumulations of sodium increase soil aggregate stability and can thereby increase resistance to wind erosion (Chepil and Woodruff, 1963).

Water in the soil increases resistance to wind erosion by forming a film around individual soil particles. This film greatly increases soil cohesion. Soils with 15 bars or greater surface moisture (the approximate wilting point of most plants) are nonerodible to all but very strong winds (Troeh et al., 1980). However, dry winds moving across bare soil can rapidly desiccate the surface and thereby increase erodibility. Fine separates such as clays retain moisture more tenaciously than coarser grains.

WIND (A.2.2)

The velocity and turbulence of the wind, and particulate content carried by the wind, all contribute to the potential for soil movement. The ability of the wind to detach and transport soil particles is a function of velocity. The wind's ability to detach soil particles is proportional to the square of drag velocity, and its carrying capacity is proportional to the cube of drag velocity. Although estimates of the exact value vary, the threshold wind velocity required to initiate soil movement is approximately 5 m/sec (10-12 mph). For a bare soil, drag (or friction) velocity is directly proportional to the wind velocity up to the point at which erosion occurs.

When soil movement occurs, energy is used to transport particles and forward velocity decreases within the zone of transport. However, the entrained soil particles increase the winds erosive power by abrasion. Sand blasting by wind-borne particles can break down soil aggregates, surface crusts, and can reduce or even totally destroy the vegetative cover.

All winds capable of causing soil movement are turbulent (Chepil and Woodruff, 1963). Although turbulence may contribute to grain entrainment and saltation, its most significant role appears to be in keeping detached soil particles in suspension.

SOIL SURFACE CONDITIONS (A.2.3)

The physical nature or configuration of the soil surface is a primary factor affecting wind erosion. Drag increase with surface roughness. Because the wind's ability to entrain soil is a function of drag, the positive relationship between drag and roughness would seem to imply that rough surfaces are more erodible than smooth surfaces. However, surface roughness is a result of residual, nonerodible particles or objects protruding above the mean aerodynamic surface (Z_o). The mean aerodynamic surface is below the tops of the highest protrusions, but above the mean roughness surface. These highest protrustions absorb much of the drag and shelter smaller particles. For impervious irregular surfaces such as bare soil with clods and soil aggregates forming the surface irregularities, the mean forward velocity slightly above A_o is zero. Because A_o is a function of surface roughness rather than wind velocity, it remains constant regardless of wind speed. Therefore, increased wind velocity must increase the velocity gradient and hence the drag velocity. Soil particles that protrude above Z_o are subject to a disproportionately large fraction of the wind's erosive force. If these grains are sufficiently large (e.g., cobbles) and sufficiently abundant they can signficantly reduce wind erodibility. For example, stoney or gravelly soils are very resistant to wind erosion. If protruding grains are within the size range for entrainment (e.g., sand grains) saltation will occur. Hence, bare sandy soils are highly erodible (Chepil and Woodruff, 1963 and Troeh et al., 1980).

The mean aerodynamic surface for vegetated surfaces approximates the boundary between free flow and restricted flow and is constant for a particular vegetative cover provided the plants do not bend. Forward velocity approaches zero slightly above A_o and then rises rapidly, creating a high velocity gradient. However, as the mean aerodynamic surface for vegetated surfaces is defined by plant roughness and is somewhat above the soil surface, the plant tops are subject to steep velocity gradients and absorb most of the drag. Unlike conditions associated with impervious surfaces irregularities, the forward velocity below the A_o may be somewhat greater than zero due to air movement among plants, but will always be less than the free flow wind velocity above (Chepil and Woodruff, 1963 and Troeh et al., 1980). Therefore, even sparse vegetation such as is typical of both the Nevada/Utah and Texas/New Mexico study areas is effective in reducing wind erosion of soil.

Crusting of the soil surface can be a temporary inhibitor of soil erosion. However, surface crusts are generally not considered a factor in reducing wind erosion because most crusts are susceptible to the impact of saltating grains and tend to break down rapidly. Highly resistant crusts such as commonly occur on playas could significantly retard wind erosion unless mechanically disturbed or subjected to excessive abrasion and impact by saltating grains originating from sandier soils.

APPENDIX B THE WIND EROSION EQUATION

An equation for predicting potential soil loss due to wind erosion has been developed (Agricultural Research Service, 1961). The equation is E=f(I'K'C'L'V')

Where:

E = Predicted annual soil loss (tons/acre or tonnes/hectare/year)
I' = Soil erodibility factor (tons/acre or tonnes/hectare/year)
K' = Soil ridge roughness factor (dimensionless)
C' = Climatic factor (diimensionless)
L' = Width of field factor (dimensionless)
V' = Vegetative cover factor (dimensionless)

B.1 SOIL ERODABILITY FACTOR (I')

Soil erodibility values have been determined for various soil textures based on wind tunnel tests and measured soil losses near Garden City, Kansas. Estimated I' values for level to nearly level topography are presented in Figure B.1-1.

Soil textures have been grouped into Wind Erosion Groups (WEG) according to their susceptibility to wind erosion (Table B.1-1). WEG values are now being assigned to each soil phase in county soil surveys. Table B.1-1 lists the WEG groups, corresponding soil textures, and the average I' factor for each group.

B.2 SOIL SURFACE ROUGHNESS FACTOR (K')

Soil surface roughness can be an expression of cloddiness, vegetation cover, or microlandforms such as field furrows and ridges. Cloddiness is included in factor I' and vegetative cover is expressed in factor V'. The K' factor is an index of the surface roughness due to nonerodible ridges such as those produced by tillage practices. To determine the K' factor, a K_r equivalent is calculated as follows (Troeh, et al., 1980):

$$K_r = \frac{\text{Measured ridge height to spacing ratio (1:x)}}{\text{Standardized ridge height to spacing ratio (1:4)}} \text{ X measured ridge height}$$

K_r is then converted to K' using Figure B.2-1. K' is a dimensionless value that can range from 1.0 for a smooth surface, to approximately 0.5 for a field with an optimum ridge height to spacing ratio. K' for construction sites is assumed to be 1.0 due to leveling during site preparation.

B.3 CLIMATIC FACTOR (C')

C' is an expression of the combined influence of wind velocity and moisture of surface soil. When seasonal erosion is to be predicted, monthly or seasonal figures should be used. However, if predictions are made for annual erosion potential, annual average velocity for a standard height should be used. Wind velocity data can be obtained from weather station records. Potential evapotransporation indexes

Figure B.1-1. Soil erodibility (I') for soils with different percentages of nonerodible fractions as determined by standard dry sieving.

Dry Soil Fractions Greater Than 0.84 mm (%)	Units									
	0	1	2	3	4	5	6	7	8	9
0	--	310	250	220	195	180	170	160	150	140
10	134	131	128	125	121	117	113	109	106	102
20	98	95	92	90	88	86	83	81	79	76
30	74	72	71	69	67	65	63	62	60	58
40	56	54	52	51	50	48	47	45	43	41
50	38	36	33	31	29	27	25	24	23	22
60	21	20	19	18	17	16	16	15	14	13
70	12	11	10	8	7	6	4	3	3	2
80	2	--	--	--	--	--	--	--	--	--

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Source: Skidmore and Woodruff, 1968.

Note: Figure B.1-1 is a matrix graph. To determine the I' value for a specific soil, find the percent soil fraction greater than 0.84mm on the vertical column. Then find the unit value on the horizontal scale. For example, for 58 percent soil fraction greater than 0.84 mm, find 50 in the column, then move across to below 8 and read the I' value as 23 tons per acre.

Table B.1-1. Wind erodibility group (WEG) characteristics.

WEG No.	Texture Class of Surface Layer	Dry Soil Aggregates More than 0.84 mm (Percent)	Soil Erodibility Factor (I') (tons/acre/year)
1.	Very fine, fine, and medium sands; dune sands	1-7	310-160
2.	Loamy sands; loamy fine sands, or sapric organic material	10	134
3.	Very fine sandy loams; fine sandy loams; sandy loams	25	86
4.	Clays; silty clays; noncalcareous clay loams, silty clay loams with more than 35 percent clay	25	86
4L.	Calcareous loams, silt loams; noncalcareous clay loams and silty clay loams with less than 35 percent clay	25	86
5.	Noncalcareous loams and silt loams with less than 20 percent clay; sandy clay loams; sandy clays; or hemic organic material	40	56
6.	Noncalcareous loams and silt loams with more than 20 percent clay; noncalcareous clay loams with less than [illegible] percent clay	45	48
7.	Silts; noncalcareous silty clay loams with less than 25 percent clay	50	38
8.	Very wet or stony soils, usually not erodible	N/A	N/A

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Source: USDA Soil Conservation Service.

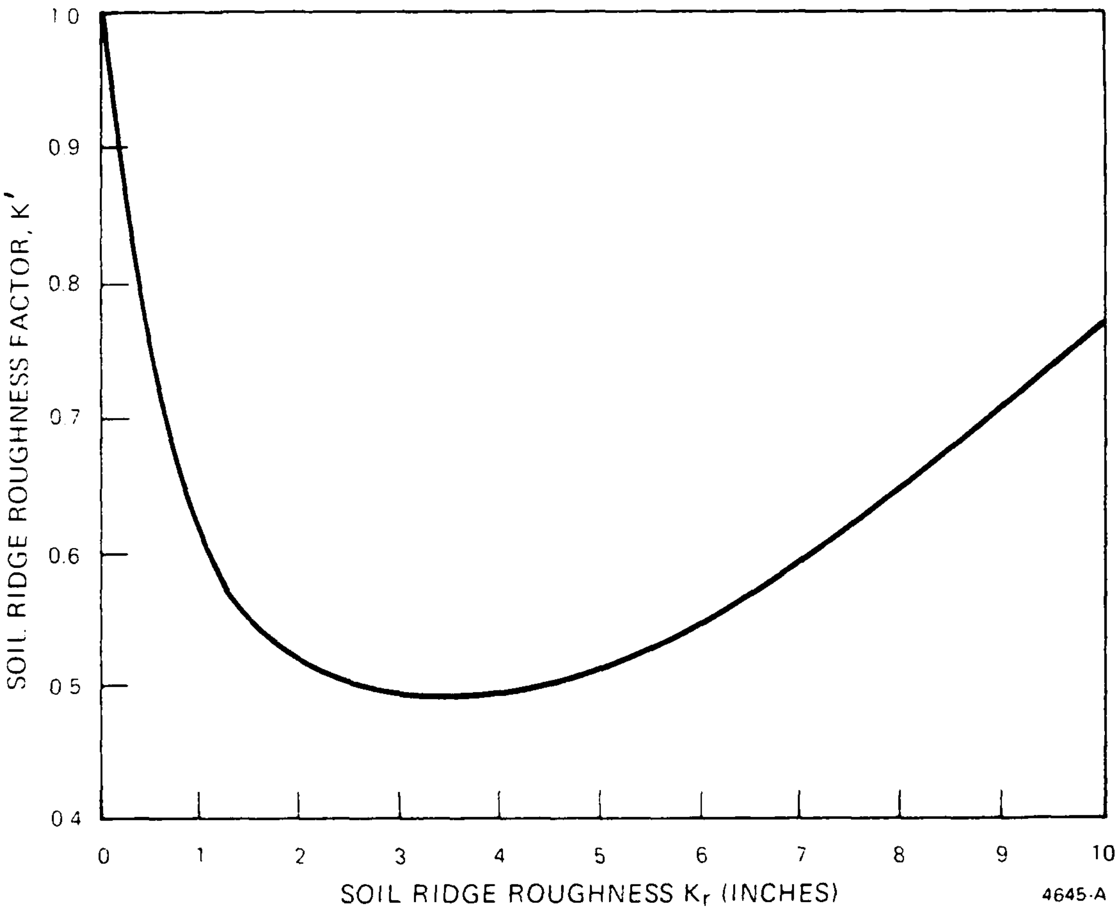

Figure B.2-1. Graph for determining soil ridge roughness factor (K') from soil ridge roughness (K_r).

developed by Thornthwaite are used as an expression of surface soil moisture. The rate of soil movement varies directly with the cube of wind velocity and inversely with the square of surface soil moisture.

Thus:

$$C = \frac{V^3}{(P-E)^2}$$

Where:

V = Wind velocity at 30 ft
(P-E) = yearly sum of monthly Thornthwaite values

Soil near Garden City, Kansas, was found to have a C value of 2.9. Wind tunnel and field erodibility research that led to the development of the equation was conducted there. Because I' values are based on conditions at Garden City, C values for other locations must be adjusted relative to this value. Therefore, Garden City was designated 100 percent and adjusted C' values are calculated by (Troeh, et al., 1980):

$$C' = \frac{100}{2.9} \cdot \frac{V^3}{(P-E)^2}$$

or

$$C' = 34.48 \cdot \frac{V^3}{(P.E)^2}$$

Annual average C' values for western Texas and eastern New Mexico range from approximately 200 in the extreme south to between 50 and 80 southeast of the M-X study area. C' values between 100 and 150 represent a reasonable range of values typical to the study area (Kimberlin, et al., 1977). Due to the climatic diversities of the Utah/Nevada study area, C' values are highly variable. Mountain soils tend to retain higher moisture due to cool temperatures, low evaporation, and more dense vegetative cover than occurs in the valleys. Although C' values range from over 20 to 300, values between 50 and 200 are more typical (ETR-13, Atmospheric Resources, 1981). However, C' values in the Nevda/Utah study area are subject to much more pronounced local variations than are values for the Texas/New Mexico area.

C' values calculated in the above fashion are commonly presented as percentages of the Garden City value. Therefore, C'=50 indicates a wind erosion climatic factor that is 50 percent of the Garden City value. This system is suitable for interpretation of C' distributions; however, for calculations of the wind erosion equation, C' must be expressed in its decimal form, i.e., C' = 50 percent = 0.50.

B.4 WIDTH OF FIELD FACTOR (L')

The unsheltered field width (L') is unsheltered distance across a field or strip in the direction of prevailing erosive winds. The rage of soil movement across an eroding field is directly related to the width of the unprotected area. Soil movement increases across the field in the direction of the wind. Variables for calculating L' for a specific area include angle (A) that prevailing winds cross the area and the preponderance of those winds (R_m). Wind preponderance indicates the prevalence of the prevailing wind erosion direction. If there is no prevailing wind erosion direction, there can be no preponderance and R_m = 1.0 and A = 1.9. For calculations involving areas of unknown orientation to prevailing winds and for multiple areas with differing orientations to prevailing wind, no prevailing wind direction is assumed, hence, R_m = 1.0 (Troeh, et al., 1980). R_m and A are then used to calculate the multiplier K_{50}, the median travel distance of erosive forces across an area. However, if there is no prevailing wind, then R_m = 1.0 and A = 1.9 so that K_{50} is always 1.9 (Table B.4-1).

The unsheltered distance L' = (L) (K_{50})
where

L = actual field width
K_{50} = median travel distance multiplier

Because K_{50} is always 1.9 for areas with no prevailing wind or with no specified orientation to a prevailing wind, L' = (L)(1.9) where these situations exist such as for generalization of M-X construction.

B.5 VEGETATIVE COVER FACTOR (V')

Because of the effectiveness of vegetation in reducing wind erosion, the nature of the vegetative cover is a significant factor in estimating soil loss due to wind. The vegetative cover factor (V') is a dimensionless value that integrates vegetation characteristics such as plant type, spacing, height, and weight per unit area. Determination of the V' for specific vegetated areas such as cropland requires utilization of graphs prepared by the Soil Conservation Service for particular crops and crop conditions. For bare soils the value of V' is 1.0.

B.6 PREDICTED ANNUAL SOIL LOSS (E)

The estimated potential annual loss of soil due to wind erosion from an area is determined in the following manner:

(1) Determine the average soil erodibility factor (I') for the site; as an example, a sandy loam I' = 86 tons/acre/year.

(2) Determine the soil ridge roughness factor (K'); for construction sites this value is assumed to be 1.0.

(3) Determine the climatic factor (C'); as an example, a site in Texas with a C' value of 200.

(4) Determine prevailing wind and preponderance of that wind to determine K_{50}; for M-X construction K_{50} = 1.9.

(5) Determine unsheltered field width (L'); as an example, for an M-X construction site 100-ft wide, L' = (100) (1.9) = 190 ft.

Table B.4-1. Chart to determine the multiplier K_{50} used to calculate the median travel distance of erosive forces across a field.

R_m	A (degrees)										
	0	5	10	15	20	25	30	35	40	45	50
1.0	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
1.1	1.69	1.71	1.74	1.76	1.79	1.81	1.84	1.85	1.87	1.89	1.92
1.2	1.55	1.58	1.62	1.65	1.69	1.73	1.77	1.80	1.84	1.88	1.93
1.3	1.46	1.49	1.53	1.57	1.62	1.66	1.70	1.76	1.83	1.88	1.94
1.4	1.39	1.43	1.47	1.51	1.55	1.59	1.64	1.71	1.79	1.87	1.95
1.5	1.33	1.37	1.42	1.46	1.50	1.55	1.60	1.68	1.77	1.86	1.96
1.6	1.29	1.34	1.39	1.43	1.46	1.51	1.56	1.65	1.75	1.86	1.97
1.7	1.25	1.30	1.36	1.39	1.43	1.47	1.52	1.62	1.73	1.86	1.99
1.8	1.22	1.28	1.33	1.37	1.40	1.44	1.49	1.60	1.71	1.86	2.01
1.9	1.20	1.25	1.31	1.34	1.37	1.41	1.46	1.57	1.69	1.86	2.03
2.0	1.18	1.24	1.29	1.32	1.35	1.40	1.44	1.56	1.68	1.86	2.04
2.1	1.17	1.22	1.27	1.30	1.34	1.38	1.43	1.55	1.67	1.86	2.06
2.2	1.16	1.21	1.26	1.29	1.33	1.37	1.41	1.54	1.67	1.87	2.07
2.3	1.14	1.19	1.25	1.28	1.32	1.36	1.40	1.53	1.66	1.87	2.09
2.4	1.13	1.19	1.24	1.28	1.31	1.36	1.40	1.53	1.66	1.89	2.11
2.5	1.13	1.18	1.23	1.27	1.31	1.35	1.40	1.53	1.67	1.90	2.13
2.6	1.12	1.17	1.22	1.26	1.30	1.35	1.40	1.54	1.68	1.92	2.16
2.7	1.12	1.17	1.22	1.26	1.30	1.35	1.41	1.55	1.70	1.94	2.19
2.8	1.11	1.16	1.21	1.25	1.30	1.36	1.42	1.57	1.72	1.97	2.22
2.9	1.10	1.15	1.20	1.25	1.30	1.36	1.43	1.59	1.74	2.00	2.26
3.0	1.10	1.14	1.19	1.24	1.30	1.37	1.44	1.60	1.77	2.03	2.30
3.1	1.09	1.14	1.18	1.24	1.30	1.37	1.45	1.62	1.80	2.07	2.33
3.2	1.08	1.13	1.18	1.24	1.30	1.38	1.46	1.64	1.83	2.10	2.37
3.3	1.07	1.13	1.18	1.24	1.31	1.39	1.47	1.67	1.86	2.14	2.41
3.4	1.07	1.12	1.18	1.25	1.32	1.40	1.49	1.69	1.90	2.17	2.45
3.5	1.06	1.12	1.17	1.25	1.32	1.42	1.51	1.73	1.95	2.22	2.49
3.6	1.06	1.11	1.17	1.25	1.33	1.43	1.53	1.76	2.00	2.27	2.54
3.7	1.05	1.11	1.16	1.25	1.33	1.44	1.55	1.80	2.05	2.32	2.58
3.8	1.05	1.10	1.16	1.25	1.34	1.45	1.57	1.83	2.10	2.36	2.63
3.9	1.04	1.10	1.16	1.25	1.35	1.47	1.60	1.88	2.16	2.42	2.68
4.0	1.04	1.10	1.16	1.26	1.36	1.49	1.63	1.93	2.23	2.48	2.73

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Source: Troeh, et. al., 1980.

(6) Determine Y=f(I'K'C'L') using Figure B.6-1.

A. Calculated X=I'K'C' = (86 tons/acre/year)(1)(2) = 172 tons/acre/year and locate on movable bar (by interpolation).

B. Calculate E'=I'K' = (86 tons/acre/year)(1) = 86 tons/acre/year and locate on curved lines of nomogram (by interpolation).

C. Align movable bar so that X on bar is at E' on nomogram.

D. Locate intersection of interpolated curve with unsheltered distance L' (190 ft).

E. From perpendicular of intersection back to movable bar read Y = 112 tons per acre per year.

(7) Determine the vegetative cover factor (V'), for M-X construction site, use 1.0.

(8) Determine E=f(Y,V') = 112 tons/acre/year.

The SCS has constructed a graph of V' values for use with vegetated areas (see Agricultural Handbook No. 346, Wind Erosion Forces in the United States and Their Use in Predicting Soil Loss, for additional discussion of predicting soil loss on cropland due to wind erosion).

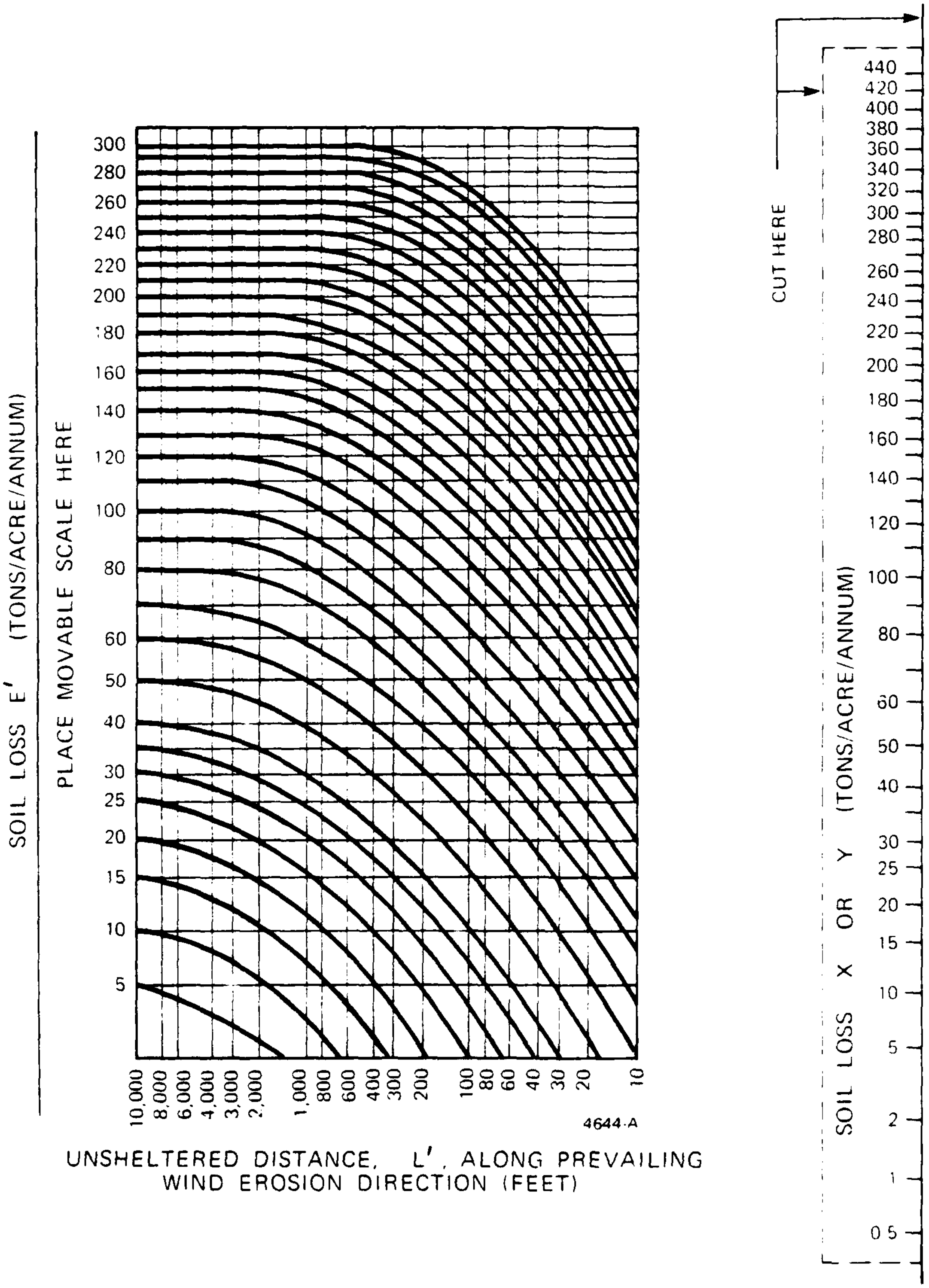

Figure B.6-1. Graph for determining predicted annual soil loss Y = f (I'K'C' L').

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