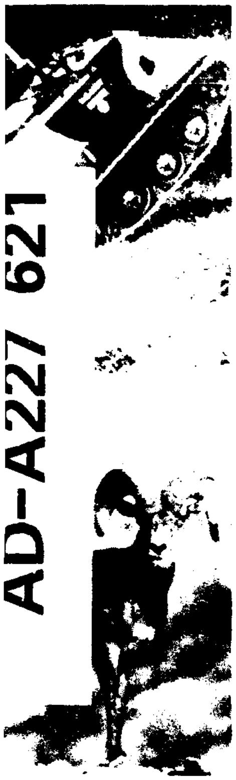

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PROPOSED 9TH INFANTRY DIVISION FORCE CONVERSION; MANEUVER DAMAGE, EROSION AND NATURAL RESOURCES ASSESSMENT FORT LEWIS, WASHINGTON

VOLUME I: MAIN TEXT

by

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This study was conducted to determine the impact of a proposed conversion from a motorized to a mechanized force structure by the 9th Infantry Division Motorized (9ID MTZ) I Corps on the Fort Lewis, WA, study area. The study provides (a) an assessment of vehicle off-road mobility and maneuver damage, (b) an assessment of future erosion effects, (c) an assessment of the natural resources impact of maneuver damage addressing four force structures related to the possible I Corps mechanization, and (d) recommendations for management and mitigation.

Volume I of this report contains the text analysis of this study, and Volume II contains oversized plates of maps describing vehicle mobility, maneuver damage disturbance levels, soil erosion, and environmental factors.

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EXECUTIVE SUMMARY

The US Army Engineer Waterways Experiment Station (WES) conducted a study to determine the impact of a conversion from a motorized to a mechanized force structure by the 9th Infantry Division Motorized (9ID MTZ) I Corps on the Fort Lewis, WA, study area. Specifically, WES provided (a) an assessment of vehicle mobility and maneuver damage, (b) an assessment of future erosion effects, (c) an assessment of the natural resource impact of maneuver damage addressing four force structures related to the possible I Corps mechanization, and (d) recommendations for management and mitigation.

The Army Mobility Model (AMM), which uses empirical mathematical algorithms to predict the performance of a vehicle on a terrain in terms of speed, and a digital terrain data base for the study area were used to predict maneuver damage based on the sinkage of the vehicles and the effect of soil disturbance due to tire and track slip and turning. These predictions were made for three vehicles representing the components of four vehicle force structures, made up of armored, mechanized, and motorized divisions, respectively. They were the M998 High Mobility Multi-Purpose Wheeled Vehicle (HMMWV) representing the 3-3-5,* and 4-3-3 force structures, an 8X8 wheeled combat vehicle also representing the 4-3-3 force structure, and the M60A3 Combat Tank representing the 5-5-0 force structure. Predictions were made for the dry normal and wet slippery surface conditions.

Rut Depth Relations

The fundamental relations of single tire sinkage on the first pass as a function of vehicle parameters such as the tire height, width, diameter, and deflection, and soil strength, wheel load, and slip were determined empirically from controlled laboratory tests in fine-grained soils and remoldable sands (Freitag 1965). These relations were modified based on several field test programs that required a detailed assessment and update of predictive relationships for vehicle traction, motion resistance, and sinkage. One-pass

* The 3-3-5 force structure designation refers to the number of armored, mechanized, and motorized battalions, respectively (i.e., 3 armored, 3 mechanized , and 5 motorized battalions). All other force structure designations follow the same convention.

wheeled vehicle rut depth versus soil strength (RCI) relations were obtained by substituting specific study vehicle parameters at a constant slip value of 20 percent. Studies have indicated that 20 percent wheel slip for most vehicles in fine-grained soils is the point of maximum drawbar horsepower efficiency (or vehicle work output index). The vehicle's ground clearance was used as the maximum wheel sinkage because a vehicle operating in soft soils will generally immobilize when its undercarriage drags on the soil surface. The relations were expanded to include a single track where first pass sinkage was a function of track width, length, and soil strength (Turnage 1973). The relations were further adjusted based on vehicle tests and VCI_1 data (see definitions, paragraph 5). This led to the development of the present first pass rut depth versus soil strength (RCI) relations for wheeled and tracked vehicles traveling in a straight path.

The first pass relations were used as a basis along with VCI_{50} data and some 50 and limited 500 pass test results to establish multi-pass (i.e., in the same rut) relations. Additional methodology was developed from limited field data for adjusting these relations to account for terrain, slope, and vehicle steering influences (turning for wheeled vehicles and pivoting for tracked vehicles). These data indicated that wheeled and tracked vehicles produced rut depths on slopes and when turning/pivoting which corresponded to those described for straight-line travel, but at RCI (see definitions, paragraph 5) values less than actual values used in the straight-line relationships (Willoughby and Turnage in preparation). Finally, the first pass relations, multi-pass relations, and adjustments to account for terrain, slope, and vehicle steering were used with the AMM to provide a model to predict soil disturbance due to vehicle traffic over an area. The model does not consider soil compaction below the soil disturbance depth nor does it consider the reduction of rock fragments by increased vehicle passes.

Maneuver Damage

It was determined that 10, 50, and 1,000 vehicle passes over the entire terrain of the potential traffic area presented the best estimate of the low, medium, and high tactical scenarios, respectively, in a training year for the study area. Five classes of disturbance were established corresponding to depths of rutting to evaluate the effects of vehicle traffic on the study area. They were minimal (0 to 0.5 in.), slight (>0.5 to 2 in.), moderate (>2 to 5 in.), high (>5 to 12 in.), and severe (>12 in.).

The following soil disturbance results were determined for the 3-3-5 and 4-3-3* force structures in the dry normal and wet slippery surface conditions:

	Percent of Total Area**					
	10 Passes		50 Passes		1,000 Passes	
	D-N†	W-S††	D-N	W-S	D-N	W-S
Minimal disturbance	46.4(65.9)	25.6(36.4)	0	0	0	0
Slight disturbance	0.2 (0.3)	19.4(27.6)	45.2(64.2)	34.5(49.0)	45.2(64.2)	0.1(0.1)
Moderate disturbance	0	0	0.2 (0.3)	9.2(13.1)	0.1 (0.1)	43.5(61.8)
High disturbance	0	0	0	0	0	0
Severe disturbance	0	0	0	0	0	0
NOGO	23.8(33.8)	25.4(36.0)	25.0(35.5)	26.6(37.8)	25.0(35.5)	26.5(37.6)
Urban/off-limits	28.3	28.3	28.3	28.3	28.3	28.3
Water	1.3	1.3	1.3	1.3	1.3	1.3
	100.0	100.0	100.0	100.0	100.0	100.0

* The principal vehicle for this force structure is the M998 (HMMWV).
** Values in parentheses indicate equivalent percents of the potential traffic area (all acres less urban/off-limits and water).
† D-N = dry normal surface condition.
†† W-S = wet slippery surface condition.

The following soil disturbance results were determined for the 4-3-3* force structure in the dry normal and wet slippery surface conditions:

	Percent of Total Area**					
	10 Passes		50 Passes		1,000 Passes	
	D-N†	W-S††	D-N	W-S	D-N	W-S
Minimal disturbance	47.9(68.0)	0.1 (0.1)	0	0	0	0
Slight disturbance	0	45.7(64.9)	47.9(68.1)	1.3(1.8)	47.9(68.1)	0.1 (0.1)
Moderate disturbance	0.2 (0.3)	0.5 (0.7)	0	44.5(63.2)	0	24.4(34.7)
High disturbance	0	0	0.1 (0.1)	0.2(0.3)	0.1(0.1)	21.5(30.5)
Severe disturbance	0	0	0.1 (0.1)	0.3(0.4)	0.1(0.1)	0.3(0.4)
NOGO	22.3(31.7)	24.1(34.3)	22.3(31.7)	24.1(34.3)	22.3(31.7)	24.1(34.3)
Urban/off-limits	28.3	28.3	28.3	28.3	28.3	28.3
Water	1.3	1.3	1.3	1.3	1.3	1.3
	100.0	100.0	100.0	100.0	100.0	100.0

* The principal vehicle for this force structure is the 8X8 wheeled vehicle.

** Values in parentheses indicate equivalent percents of the potential traffic area (all acres less urban/off-limits and water).

† D-N = dry normal surface condition.

†† W-S = wet slippery surface condition.

The following soil disturbance results were determined for the 5-5-0 force structure in the dry normal and wet slippery surface conditions:

	Percent of Total Area*					
	10 Passes		50 Passes		1,000 Passes	
	D-N†	W-S††	D-N	W-S	D-N	W-S
Minimal disturbance	0	0	0	0	0	0
Slight disturbance	43.4(61.7)	0.2(0.3)	0	0	0	0
Moderate disturbance	0.1 (0.1)	41.6(59.1)	42.2(60.0)	0.2 (0.3)	1.4(2.0)	0
High disturbance	0	0.3(0.4)	0	36.6(52.0)	40.8(58.0)	23.7(36.5)
Severe disturbance	0	0	0.1 (0.1)	4.2 (6.0)	0.1(0.1)	15.3(21.7)
NOGO	29.9(38.2)	28.3(40.2)	28.1(39.9)	29.4(41.7)	28.1(39.9)	29.4(41.8)
Urban/off-limits	28.3	28.3	28.3	28.3	28.3	28.3
Water	1.3	1.3	1.3	1.3	1.3	1.3
	100.0	100.0	100.0	100.0	100.0	100.0

* Values in parentheses indicate equivalent percents of the potential traffic area (all acres less urban/off-limits and water).

† D-N = dry normal surface condition.

†† W-S = wet slippery surface condition.

Effects of Vehicle Traffic on Soil Erosion

The processes of wind and water erosion in a temperate environment were examined and used in an analysis of the erosional impact of possible military activity in the Fort Lewis study area. The analysis included the factors of soil, grain size, cohesion, crust formation, surface slope, climate, roughness, and organic content. Wind and water erosion algorithms were developed to include depth of soil disturbance by vehicles and factors for the number of vehicle passes for the study area. The wind and water erosion algorithms represent the dominant modes of erosion for the dry normal and wet slippery surface conditions, respectively.

The impact of soil erosion during both the dry and wet cycle is presented as a function of allowable soil loss (soil erosion severity); soil loss rate equal to the soil regeneration rate is a severity of one. Maintaining a realistic battlefield environment for training requires appropriate vegetation and terrain conditions that remain relatively unchanged after battlefield training. A soil system that regenerates itself at the same rate as it is consumed or destroyed, undergoes no effective change. Soil erosion estimates for each force structure and climatic condition are presented in map format. Soil erosion severity is presented as the maximum possible erosion for each 164- by 164-ft (50- by 50-m) parcel of the study area. The assumption is that every parcel gets the maximum vehicle traffic considered in the analyses. The eroded soil may be transported to and deposited in an adjacent parcel with less than 10 percent of all the soil eroded from the parcels actually leaving the area. Erosion during the wet slippery condition is considerably more than erosion during the dry condition.

Recommended methods of reducing soil erosion are given. Soil erosion can be minimized by restricting vehicle traffic to arteries between activity centers, avoiding areas underlain by silty or clayey soils, and scheduling vehicular activity to seasons (months) with the least wind and water erosion potential. Optimum planning of maneuvers to reduce soil erosion would incorporate all of these considerations.

Effects on Natural Resources

Basis for predicting impacts on natural resources

The primary natural resource impacts addressed in this study relate to the alteration or destruction of soil structure and vegetation and subsequent effects on fish and wildlife caused by the different vehicle force structures. The disturbances from traffic represent the worst case scenario; i.e., all but the obvious exclusions (e.g., impact areas, Weir Prairie) are assumed to be affected. Because of practical constraints such as the narrow access point to Training Area 16 (Ranier Training Area) and the difficulty of maneuvering in wetland soils, the actual impact may occur on a much smaller percentage of the area. However, cumulative impacts on soils and vegetation from repeated use could bring the total impact on a localized area to 100 percent. Because of these ambiguities, specific acreages and locations are not reported; indices and percentages are used to show relative impacts among the various force structures.

The model used to predict soil disturbance from vehicles does not consider compaction, so this impact cannot be quantified. Compaction from any source (wildlife or hiking trails, vehicles) negatively affects plants by reducing soil aeration and moisture-holding capacity so that plant growth is reduced or eliminated. Effects on animals that live below the surface include death or displacement, depending on the severity of compaction.

Prediction of vegetation impacts

Soil disturbance may result in loss of surface vegetation, break down of organic matter, and removal of the top layers of soil. With increased soil disturbance, sensitive plant species are destroyed, and vegetation composition shifts to those species that are tolerant of disturbance.

One way to estimate the effects of traffic on vegetation associations is to examine their structural complexity. This complexity can be described by the number of soil/vegetation layers present. Studies have shown that a higher number of layers allows more habitat complexity, and that basically "more is better".

Eight layers have been identified on Fort Lewis that contribute to habitat quality by increasing complexity when they are present and functioning. The soil and vegetation layers and identifying numbers are:

1 subsurface	5 midstory
2 surface	6 subcanopy
3 litter	7 canopy
4 understory (herbaceous)	8 tree bole

In addition to their ecological significance, these layers can be used to quantify and understand impacts. The number of layers potentially present in each cover type and thought to be affected by disturbance are:

Disturbance Level	Grasses (4)	Shrubs (5)	Trees (8)
Minimal*	3,4	3,4,5	3,4,5
Slight*	2,3,4	2,3,4,5	2,3,4,5
Moderate	1-4	1-5	1,2,3,4,5,8
High	1-4	1-5	1-8
Severe	1-4	1-5	1-8

* Data were not available to determine if Layer 1 is affected by these levels of disturbance; excluding it may be a conservative decision.

Based on personal observations and existing literature, the percent of vegetation that should be lost for each disturbance level and layer is as follows:

Disturbance	Dry-Normal		Wet-Slippery	
Level	Layers 1-4	Layers 5-8	Layers 1-4	Layers 5-8
Minimal	10	5	25	10
Slight	25	15	50	30
Moderate	50	30	100	75
High	100	75	100	100
Severe	100	100	100	100

For each disturbance level, the magnitude of the impact on each cover type was obtained by applying the percent loss of vegetation to each affected layer within each cover type. The percentages for all layers within a disturbance level were added and then divided by the total percentage available (number of vegetation layers × 100) to obtain a weighting factor. For example, the impact of minimal disturbance to shrubs in dry weather would be:

Layer 3 = 10 percent	Total layers available = 5
Layer 4 = 10 percent	Total percentage available = 500
Layer 5 = 5 percent	

TOTAL = 25 percent
Therefore, the weighing factor = 25/500 = 0.05.

These weighing factors were then used to establish an index of disturbance for each force structure and cover type under both wet and dry conditions. The 3-3-5 force structure was used as the baseline for comparing relative impacts.

Relative impacts

Under dry conditions, within each scenario and for all three cover types, the amount of impact increases only slightly from the 3-3-5 force structure to the 4-3-3 force structure, which seems to indicate the HMMWV and 8x8 wheeled vehicle will impact all three cover types similarly. However, impact increases to a greater degree for the 5-5-0 force structure, in which tracked vehicles are dominant.

Under wet conditions, the analysis is more complicated. In a low-use scenario, the relative impacts increase in the same manner for all three cover types as they do for dry conditions, although the magnitude is larger. This same pattern is also seen in Fort Lewis forests for medium-use and high-use scenarios. However, for grasslands and shrublands under medium-use and high-use scenarios, the impacts increase with the 4-3-3 force structure and then decrease slightly for the 5-5-0 force structure. We feel this may be explained by one or more factors. First, there may be some threshold values being met, resulting, for example, in no difference in disturbance levels between the medium- and high-use scenarios in the north half of Thirteenth Division Prairie. Second, since the amount of NOGO acreage increases under wet conditions, the acreage to which the index applies decreases. Third, as mentioned previously, soils compact more easily under wet conditions than under dry conditions. Thus, the absolute damage is greater under wet conditions than dry conditions. The index used is relative to "baseline" conditions, the baseline being the 3-3-5 force structure. Under wet conditions and at high use (1,000 passes), the damage from each force structure is so great that there is little difference in relative impact values. This same situation holds true for the medium use scenario (50 passes) although the 4-3-3 (8X8) force structure, possibly due to greater weight per contact area (psi), shows greater relative impacts than either the 3-3-5 or 5-5-0 force structures.

Effects on specific plants and animals

A total of 12 plant and 21 animal (including birds, mammals, and fish) species and communities were identified as being of special interest at Fort

Lewis. Many of the plant species/communities should receive little or no impact because of their location in either current off-limits areas (such as Weir and Johnson Prairies) or the fact that they occur in predicted NOGO areas. Three other species/communities (the Douglas fir, red alder and lodgepole pine) may receive some disturbance but because of their abundance these are not considered to be serious impacts. However, the oak shrub community on Monette Hill will receive some disturbance from all force structures. Some stands of quaking aspen may also receive impacts ranging from minimal to severe, depending upon location and force structure. The Douglas fir/snowberry oceanspray community requires field verification.

Of the bird species, only the streaked horned lark, ruffed grouse, and Oregon vesper sparrow are expected to be impacted. Impacts to the osprey, bald eagle, and great blue heron are highly dependent upon season and location. The Pacific water shrew and western gray squirrel are not expected to be impacted. The black-tailed deer may be displaced slightly in response to vehicles, but should benefit from those disturbances that result in earlier successional stages of plant communities (for browse).

Any training activity that would cause increased stream and lake turbidity could impact the sea-run populations of these fish during spawning and other life stages spent within Fort Lewis waters. Disturbance of water during stream crossings under uncontrolled conditions would increase turbidity levels immediately downstream of the crossing and add to general turbidity further downstream. The improved crossing system already in place may be adequate to prevent this from happening, but should be evaluated in light of potential new traffic.

Natural resource recommendations

Because of the apparent existence of disturbance thresholds in the force structures evaluated, and also because of the time, expense, and unpredictability of restoration efforts, vehicle use should be concentrated on resistant areas and areas that are already impacted. Location and timing of new activities should be planned in light of soil, water, and biotic resources as well as training needs. Proper timing of training exercises is critical because it reduces damage and prolongs the life of the facility, as well as reducing vehicle wear and tear and increasing safety.

Major recommendations include:

a. Traffic in the wet season (October through March) should be minimized.

b. Restrict activities to the poorer quality prairies, thereby protecting the white-topped aster which occurs in the higher quality prairies.

c. The off-limits designation of Weir and Johnson Prairies protects prime white-topped aster habitat and should be maintained, and the borders of those designated areas checked against the current extent of grassland.

d. The lodgepole pine community at Spurgeon Creek is in the extreme corner of the installation and is largely surrounded by terrain that makes it part of the disturbance NOGO condition. Posting that area off-limits would be beneficial to the pine community and would not significantly affect maneuvers.

e. All wetlands and open water should be considered for an off-limits designation by all vehicles.

f. Each designated crossing should be evaluated to be sure it has a concrete or gravel/cobble ford in place prior to equipment changes. Upgrades in existing crossings and establishment of additional crossings that are constructed to lessen turbidity and to discourage unofficial crossings may be necessary, under the proposed force structure changes.

g. Quantification of the amount of sediment that could be added to the streams is not possible at this time. We recommend monitoring the sediment load during a small number of training exercises under a variety of conditions (number and type of vehicles, wet versus dry weather). The results would help determine the need for management actions such as sediment traps.

h. The osprey and eagle areas should be reevaluated for adequacy of a buffer zone related to changes in vehicle access from the potential change in force structure.

i. A conservation education program is highly recommended to introduce soldiers to the resources at Fort Lewis and to stress the importance of good environmental sense and stewardship in training exercises.

PREFACE

Personnel of the US Army Engineer Waterways Experiment Station (WES) conducted the study described herein from February 1989 to September 1989 for the US Army Corps of Engineers, Seattle District, Washington, under Project No. E87-893153.

The study was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, Geotechnical Laboratory (GL); Dr. J. Harrison, Chief, Environmental Laboratory (EL); MAJ Monte L. Pearson, Ph.D, Assistant to Chief, GL; Mr. N. R. Murphy, Chief, Mobility Systems Division (MSD), GL; Dr. A. G. Franklin, Chief, Earthquake, Engineering, and Geosciences Division (EEGD), GL; and Dr. C. J. Kirby, Chief, Environmental Resources Division (ERD), EL. The study was conducted under the direct supervision of Mr. R. P. Smith, Chief, Terrain Evaluation Branch (TEB), MSD; Dr. L. M. Smith, Chief, Engineering Geology Branch (EGB), EEGD; Mr. E. C. Brown, Chief, Wetlands and Terrestrial Habitat Group (WTHG), ERD; and Mr. H. R. Hamilton, Chief, Resource Analysis Group (RAG), ERD.

MAJ Pearson coordinated the overall study. Field data collection was conducted by Ms. R. M. Drinkard and Messrs. G. B. McKinley and C. P. Rabalais, TEB, MSD, and T. C. Dean, Modeling Branch, MSD. Ms. S. J. Price and Ms. P. A. Morris, TEB, MSD, prepared the mobility and maneuver damage predictions. Ms. M. Sabol, Hilton Systems, Inc., prepared the maps. Ms. Morris, TEB, MSD, and MAJ Pearson, GL, prepared Parts I through IV of this report. Mr. R. J. Larson, Chief, Geologic Environments Analysis Section, EGB, EEGD, prepared Part V. Ms. L. J. O'Neil, RAG, ERD, Dr. M. C. Landin, WTHG, ERD, Mr. M. R. Waring, RAG, ERD, and Dr. H. G. Hughes prepared Part VI. Dr. Hughes is under an Interpersonnel Act Agreement between Pennsylvania State University, DuBois, PA, and RAG.

COL Larry B. Fulton, EN, was the Commander and Director of WES during the conduct of this study and preparation of this report. Dr. Robert W. Whalin was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI* (metric) units as follows:

Multiply	By	To Obtain
acres	0.404686	hectares
acres	4,046.873	square metres
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins**
feet	0.3048	metres
inches	2.54	centimetres
knots (international)	0.514444	metres per second
miles (US statute)	1.609347	kilometres
miles (US statute) per hour	0.44704	metres per second
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
square inches	6.4516	square centimetres
tons (force)	8.896444	kilonewtons

* SI refers to the international system of units which is the metric system being adopted in the United States. Conversion factors are taken from ASTM Designation: E380-1185, Standard for Metric Practice, issued in October 1985. SI literally stands for *Systeme International*.

** To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

PROPOSED 9TH INFANTRY DIVISION FORCE CONVERSION; MANEUVER DAMAGE, EROSION, AND NATURAL RESOURCES ASSESSMENT FORT LEWIS, WASHINGTON

VOLUME I: MAIN TEXT

PART I: INTRODUCTION

Background

1. Personnel at the US Army Corps of Engineers, Seattle District (CENPS) asked the US Army Engineer Waterways Experiment Station (WES) to determine the impact of a conversion from a motorized to a mechanized force structure on Fort Lewis, WA. Specifically, WES was asked to (a) provide an assessment of vehicle mobility and maneuver damage, (b) determine soil disturbance effects, (c) provide an assessment of the natural resources impact of maneuver damage, and (d) make recommendations for management and mitigation. These would address four force structures related to the possible 9th Infantry Division Motorized (9ID MTZ), I Corps mechanization.

Objective

2. The objective of this study was to provide mobility, maneuver damage, and natural resources analyses to determine the impact of the current and/or alternative force structures on the present land (86,759 acres*, Department of the Army 1978) owned by the Army at Fort Lewis. Note that the area of potential traffic for the Fort Lewis study area is equal to the total study area acreage (86,759 acres) minus the acreage consisting of urban, off-limits, and water areas (25,681 acres) leaving an area of 61,078 acres.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 19.

Scope

3. The principal activities necessary to achieve the objective of this study were as follows:

   a. The Army Mobility Model (AMM), as described in the High Mobility (HIMO) study (Nuttall and Randolph 1976), and a digital terrain data base for the study area were used to predict maneuver damage based on the sinkage of the vehicles and the effect of soil disturbance due to tire and track slip and turning. Relationships were developed to predict soil disturbance levels as a function of the soil strength and the number of vehicle passes for the study vehicles and surface conditions in the study area.

   b. Climatological, soil, geologic, topographic, hydrologic, and vehicular damage data were used to interpret soil erosion effects.

   c. Soil, slope, erosion, vegetation, hydrologic, and wildlife data were used to produce a natural resource assessment of maneuver damage addressing the four proposed force structures.

4. This report describes the methodology, discusses the various predictive models, presents mobility and natural resources data, and discusses impacts on the study area. Figures located in this volume are referred to in the text as such. Oversized maps are located in Volume II and are referred to in the text as plates. The study area is located in Pierce and Thurston Counties, approximately 15 miles south of Tacoma, WA (Figure 1). It is the major military reservation in the Pacific Northwest and currently serves as the Headquarters of I Corps.

Definitions

5. The following are definitions of terms:

   a. Cone index (CI). An index of the shearing resistance of a medium obtained with a standard cone penetrometer.

   b. Remolding index (RI). A ratio in terms of CI that expresses the proportion of the original strength of a soil that will be retained after being altered by the traffic of a moving vehicle.

   c. Rating cone index (RCI). The product of the RI and the average of the measured in situ CI for a specific layer of soil (usually 0 to 6 in.).

   d. Vehicle cone index (VCI). The minimum RCI that will permit a vehicle to complete a specified number of passes. For example, VCI_{50} means the minimum RCI needed to complete 50 passes, and VCI_1 means the minimum RCI needed to complete one pass.

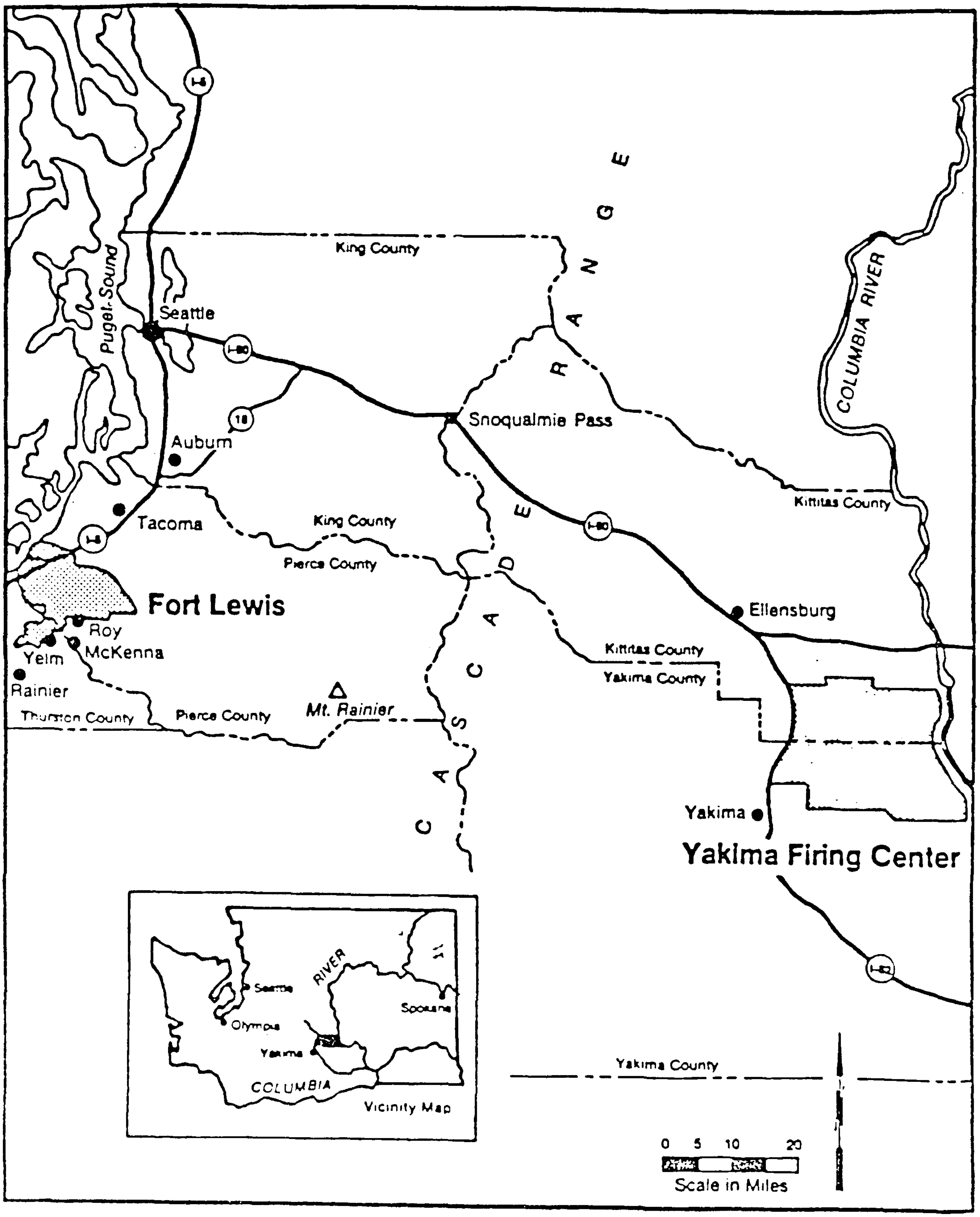

Figure 1. Location of Fort Lewis, Washington study area

e. Off-road. The vehicle is off-road when it is operating cross-country or is not negotiating a specific path.

f. Areal terrain. Terrain features (usually off-road) that are depicted as polygons on a map as opposed to features such as roads that are depicted as lines.

g. Soil disturbance level. The soil surface surrounding a track or rut that has been displaced, compacted, or has lost strength due to remolding.

h. Liquid limit. The moisture content at which a pat of soil in a standard brass cup and cut by a groove of standard dimensions will flow together so as to close the groove 1/2 in. along its bottom under the impact of 25 blows in a standard liquid limit apparatus.

i. Deflation. The sorting out, lifting, and removal of loose dry fine-grained particles (usually clay and silt sizes) by the turbulent eddy action of the wind.

j. Abrasion. The mechanical wearing, grinding, scraping, or rubbing away of rock surfaces by friction and impact, in which the solid rock particles transported by wind are the tools of abrasion. The term corrasion is essentially synonymous.

k. Transport. A phase of sedimentation that includes the movement by natural agents (wind) of sediment or of any loose material, either as solid particles or in solution, from one place to another on or near the earth surface.

l. Erosion. The general process or the group of processes whereby the materials of the earth's crust are loosened, dissolved, or worn away by natural agencies, which include weathering, solution, corrasion, and transportation (exclusive of mass wasting such as landslides, slump, etc.).

m. Soil disturbance NOGO. A soil disturbance NOGO situation is predicted when a vehicle is immobilized by sinkage to its ground clearance by multiple passes in the same rut. A soil disturbance NOGO may be caused by insufficient soil strength, insufficient traction, soil and slope resistances, and a combination of obstacles, soil, slope, and vegetation acting jointing.

n. Environmental NOGO. Areas recommended to be placed off-limits to vehicles by administrative order, based on the special or sensitive nature of the area.

o. Wetness index. The influence of the water table on the wetness of the soil and its duration of wetness is measured in terms of a wetness index. The wetness index ranges from 0 (arid) to 5 (saturated, perennially waterlogged).

p. Compaction. Any process by which a soil mass loses pore space and becomes more dense, thereby increasing its bearing capacity and general stability in construction.

PART II: STUDY VEHICLES, TERRAIN DATA, AND SURFACE CONDITIONS

Study Vehicles

6. Representative vehicles for the armored, mechanized, and motorized divisions were chosen for evaluation. They were the M60A3/M1, M113A1/M2, and the M998 (HMMWV) and 8X8 wheeled combat vehicle, respectively. Additionally, other types of vehicles will also be maneuvering the study area. Two factors considered in the determination of the principal vehicle for each vehicle force structure were a statistical analysis of the number of vehicles and the total number of miles that the vehicles would travel during a training exercise. In general, wheeled vehicles travel a greater number of miles during a training exercise than tracked vehicles. Soil disturbance (i.e., rut depth) maps for the representative vehicles and surface conditions were prepared for each force structure for a varied number of vehicle passes. In most cases, the wheeled or tracked vehicle which exhibited the greatest level of disturbance for each force structure was chosen as the principal vehicle to represent maneuver damage. However, in some cases, the respective wheeled vehicle was chosen as the principal vehicle in spite of the fact that it may not have caused as much damage to the study area as the tracked vehicle does per unit of movement, but would have a greater maneuver impact simply because it traveled more miles in a training exercise. The principal maneuver vehicles selected for evaluation purposes from each vehicle force structure were:

		Principal Vehicle Characteristics for Force Structure	
Force Structure*	Representative Vehicle	Principal Vehicle	Contact** Pressure psi
3 Armored	M60A3/M1	M998, High Mobility	27.1
3 Mechanized	M113A1/M2	Multi-purpose Wheeled	
5 Motorized	HMMWV	Vehicle (HMMWV), 8,860 lb	

(Continued)

* These data were provided by I Corps personnel and refer to the number and type of maneuver battalions.

** As a comparison, an average 6 ft tall human male exerts approximately 2 psi.

Force Structure	Representative Vehicle	Principal Vehicle Characteristics for Force Structure: Principal Vehicle	Contact Pressure psi
4 Armored 3 Mechanized 3 Motorized	M60A3/M1 M113A1/M2 HMMWV	M998, High Mobility Multi-purpose Wheeled Vehicle (HMMWV),† 8,860 lb	27.1
4 Armored 3 Mechanized 3 Motorized	M60A3/M1 M113A1/M2 8X8 Wheeled	8X8 Wheeled Combat Vehicle†† 27,660 lb	45.4
5 Armored 5 Mechanized 0 Motorized	M60A31/M1 M113A1/M2 HMMWV	M60A3, Combat Tank 127,000 lb	13.3

† Future direction from I Corps personnel may direct WES to analyze this force structure with the M113A1 tank as the principal vehicle.

†† The 8X8 wheeled combat vehicle required as principal vehicle under guidance of FORCOM personnel.

Terrain Data

7. Personnel from the WES collected ground measured data at the study area. An extremely important aspect of any field data collection program is the selection of sites to be studied and documented. Preliminary site selections were made using aerial photographs and standard class 1:50,000 scale topographic maps. Each site chosen was representative of the terrain surrounding it. Sites selected were finalized after the conduct of a thorough ground reconnaissance. Data were eventually collected from 118 ground sites throughout the study area. Observation sites were also established between ground sites so as to note any changes in terrain features and soil type. Many sections of the Fort Lewis study area are analogous with respect to terrain features and were classed as such. Factor maps were drawn from evaluation and analysis of the measured ground truth data. Factor maps for soils, obstacles, drainage, vegetation, and elevation contour (slope) data were prepared. Plate 1 shows the slope map for the Fort Lewis study area.

Soil types

8. The US Army Engineer Waterways Experiment Station (1960) describes and explains the use of the Unified Soil Classification System (USCS).

Descriptions of the surface soil types (classified by USCS) as found in the Fort Lewis study area are given below. Plate 2* is a map which provides the spatial distribution of soil types identified in the Fort Lewis study area. Bulk samples were taken and tested for moisture content and grain size distribution.

9. GM soil type. This group comprises gravel with fines (more than 12 percent passing the No. 200 sieve) having low or no plasticity. The gradation of the materials is not considered significant and both well graded and poorly graded materials are included. Some of the gravel in this group will have a binder composed of natural cementing agents so proportioned that the mixture shows negligible swelling or shrinkage. Thus, the dry strength of such materials is provided by a small amount of soil binder. The fine fraction of other materials in this group may be composed of silts or rock flour types having little or no plasticity, and the mixture will exhibit no dry strength. This group was found in 88.1 percent of the study area.

10. SM soil type. This group comprises sands with fines (more than 12 percent passing the No. 200 sieve) having low or no plasticity. This group was found in 3.2 percent of the study area.

11. GC soil type. This group comprises gravel soils with fines (more than 12 percent passing the No. 200 sieve) which may or may not exhibit plasticity. The gradation of the materials is not considered significant and both well graded and poorly graded materials are included. The plasticity of the binder fraction has more influence on the behavior of the soils than does the variation in gradation. The fine fraction is generally composed of clays. This group was found in 2.4 percent of the study area.

12. SP soil type. This group comprises poorly graded sands containing little or no nonplastic fines (less than 5 percent passing the No. 200 sieve). This group was found in 2.0 percent of the study area.

13. PT soil type. This group is comprised of the highly organic soils which are very compressible. Peat, humus, and swamp soils with a highly organic texture are typical soils of this group. Particles of leaves, grass, branches, or other fibrous vegetable matter are common components of these oils. This group was found in 1.4 percent of the study area.

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* All plates are found in Volume II.

14. CL soil type. In this group, the symbol C stands for clay with L denoting a low liquid limit (less than 50). The soils are primarily inorganic clays. Low plasticity clays are usually lean clays, sandy clays, or silty clays. This group was found in 1.2 percent of the study area.

15. SC soil type. This group comprises sandy soils with fines (more than 12 percent passing the No. 200 sieve) which have either low or high plasticity. The gradation of the materials is not considered significant and both well graded and poorly graded materials are included. The plasticity of the binder fraction has more influence on the behavior of the soils than does the variation in gradation. The fine fraction is generally composed of clays. This group was found in 0.8 percent of the study area.

16. CLML soil type. This is an example of a borderline soil which exhibits characteristics of both CL and ML soil groups. The CL soil group comprises clays with low plasticity (liquid limit less than 50). The ML group comprises silts with low plasticity. This group was found in 0.6 percent of the study area.

17. GP soil type. This group comprises poorly graded gravel containing little or no nonplastic fines (less than 5 percent passing the No. 200 sieve). This group was found in 0.4 percent of the study area.

Obstacles, vegetation, and elevation data

18. Obstacles. Obstacles observed during data collection consisted of escarpments, embankments, logs, and stumps.

19. Vegetation. Areas of vegetation observed during data collection consisted of logged areas (i.e., selected cuts and clear cut areas) open grassland, and forests. More specific vegetation information was collected for the natural resources evaluation (refer to Part VI).

20. Elevation data. A 1:50,000 scale map was prepared from elevation contour data obtained from a Fort Lewis Special Map prepared by the Defense Mapping Agency. These data were used for slope determination.

Surface Conditions

21. Two surface conditions were considered for analysis, dry normal and wet slippery.

a. Dry normal condition. The dry normal surface condition describes the lowest soil moisture condition for each soil type which in turn produces the highest soil strengths found during the driest 30-day period for an average rainfall year. It has been at least 6 hr since the last rainfall. This is typically the best surface condition.

b. Wet slippery condition. The wet slippery surface condition describes the soil moisture and associated low soil strength found during the wettest 30-day period for an average rainfall year. It has rained within the last 6 hr which produces a slippery effect that reduces vehicle traction. Some sinkage occurs because of softer soil conditions.

The following are the soil strength values corresponding to the dry normal and wet slippery surface conditions. These values are derived from the Soil Moisture-Strength Prediction (SMSP) model (Kennedy et al. 1988). The SMSP model uses precipitation data for an area to predict soil moisture content and soil strength values in terms of rating cone index (RCI) for each of the USCS soil type classes and for each wetness index. The wetness index for an area ranges from 0 (arid) to 5 (saturated, perennially waterlogged) and may be inferred from the slope and vegetation type. Lower slope values are assigned a higher wetness index. Additionally, vegetation types which indicate marsh, swamps, or wetlands are assigned a wetness index of five, while a wet crop is assigned a wetness index of four.

	Percent of Total Study Area	
RCI	Dry Normal	Wet Slippery
>280	97.9	29.6
>220-280	0.0	0.0
>160-220	0.0	0.0
>100-160	0.0	66.7
>60-100	0.2	1.5
>40-60	0.0	0.0
>33-40	0.0	0.0
>26-33	0.0	0.2
>17-26	1.0	0.0
>11-17	0.0	1.0
≤11	0.9	1.0
Total	100.0	100.0

The precipitation data for Fort Lewis used in the SMSP model is summarized as follows (average of a 12-year data base):

	Mean Monthly Precipitation	
	in.	mm
January	6.73	170.94
February	4.74	120.40
March	4.09	103.89
April	2.64	67.06
May	1.77	44.96
June	1.47	37.34
July	0.74	18.80
August	1.04	26.42
September	1.58	40.13
October	4.29	108.97
November	6.14	155.96
December	5.84	148.34
	41.07	1,043.21

PART III: MOBILITY PREDICTIONS

AMM Mobility Performance

22. The AMM was used to predict off-road performances for the study vehicles for the dry normal and wet slippery surface conditions in the study area. The AMM examines vehicle-driver-terrain interactions to determine the maximum feasible speed that a vehicle can achieve in a single areal terrain patch. The inputs to the AMM are vehicle characteristics and a quantitative terrain description of the study area.

AMM Vehicle Characteristics

23. The vehicle is specified in the data base in terms of geometric, inertial, and mechanical characteristics that determine its interactions with the terrain. The completed vehicle characterization as used by the model includes measures of dynamic response to ground roughness and to obstacle impact. The model structure permits use at these points of appropriate data derived either from actual field tests* or from supporting stand-alone computer simulation. The required steady-state tractive force-speed relation may also be input directly from field test data, when available, or computed using a power train submodule.*

AMM Terrain Descriptions

24. In the AMM, the basic approach to representing a complex terrain is to subdivide it into areal patches, generically referred to as terrain units, each of which can be considered uniform within its bounds. This concept is implemented by dividing the range of each individual terrain factor into a number of class intervals, based on consideration of vehicle response sensitivity, practical measurement accuracy and mapping resolution problems. A new terrain unit is defined whenever one or more factors fall into a new class interval. Each terrain unit is described by values for a series of 22 mathematically independent terrain factors for that unit.

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* Denotes use in this study.

Speed Performance

25. The output from the AMM is the maximum safe speed for a given study vehicle in each terrain unit examined. The output can be used to produce statistical analyses or can be displayed graphically as speed maps. The output selected for use in this study is the speed map.

26. The off-road speed map for a vehicle, terrain, and surface condition is a visual representation of the average speed the vehicle can sustain. The off-road speed map for the M998 (HMMWV) wheeled vehicle in the dry normal surface condition (see paragraph 21) is shown in Plate 3. The off-road speed map for the M998 (HMMWV) wheeled vehicle in the wet slippery surface condition is shown in Plate 4. The off-road speed map for the 8X8 wheeled combat vehicle in the dry normal surface condition is shown in Plate 5. The off-road speed map for the 8X8 wheeled combat vehicle in the wet slippery surface condition is shown in Plate 6. The off-road speed map for the M60A3 tank in the dry normal surface condition is shown in Plate 7. The off-road speed map for the M60A3 tank in the wet slippery surface condition is shown in Plate 8.

Factors Limiting Speed

27. Speed is limited by one or a combination of the following factors off-road:

- a. Traction available to overcome the combined resistances of soil, slope, obstacles, and vegetation.
- b. Driver discomfort in negotiating rough terrain (ride) and his tolerance to vegetation and obstacle impacts.
- c. Driver reluctance to proceed faster than the speed at which the vehicle could be braked to a stop within the visibility distance prevailing in the areal unit.
- d. Maneuvering to avoid trees and/or obstacles.
- e. Acceleration or deceleration between obstacles if they are to be overridden.

Plates 9 through 14 show the speed limiting reasons over the study area for each principal vehicle and surface condition.

PART IV: EFFECTS OF VEHICLE TRAFFIC ON STUDY AREA

Soil Disturbance Levels

28. Soil disturbance is defined as the soil surface surrounding a track or rut that has been displaced, compacted, or has lost strength due to remolding caused by vehicle traffic. For this study, the soil disturbance levels relate to rut depths resulting from vehicle traffic. Soil disturbance levels and corresponding rut depths for this study are:

Soil Disturbance Levels	Rut Depths
Minimal	0 to 0.5 in.
Slight	0.5 to 2 in.
Moderate	2 to 5 in.
High	5 to 12 in.
Severe	>12 in.

Soil disturbance levels were established from relations of rut depth as a function of vehicle passes, VCI, RCI, and vehicle characteristics. These soil disturbance level classes are arbitrary and are left to the discretion of the range conservation officer or appropriate land manager to modify as needed for a particular environment.

Rut Depth Relations

29. The fundamental relations of single tire sinkage on the first pass as a function of vehicle parameters such as the tire height, width, diameter, and deflection, and soil strength, wheel load, and slip were determined empirically from controlled laboratory tests in fine-grained soils and remoldable sands (Freitag 1965). These relations were modified based on several field test programs that required a detailed assessment and update of predictive relationships for vehicle traction, motion resistance, and sinkage. One-pass wheeled vehicle rut depth versus soil strength (RCI) relations were obtained by substituting specific study vehicle parameters at a constant slip value of 20 percent. Studies have indicated that 20 percent wheel slip for most vehicles in fine-grained soils is the point of maximum drawbar horsepower efficiency (or vehicle work output index). The vehicle's ground clearance was

used as the maximum wheel sinkage because a vehicle operating in soft soils will generally immobilize when its undercarriage drags on the soil surface. The relations were expanded to include a single track where first pass sinkage was a function of track width, length, and soil strength (Turnage 1973). The relations were further adjusted based on vehicle tests and VCI_1 data.* This led to the development of the present first pass rut depth versus soil strength (RCI) relations for wheeled and tracked vehicles traveling in a straight path.

30. These first pass relations were used as a basis along with VCI_{50} data** and some 50 and limited 500 pass test results to establish multi-pass (i.e., in the same rut) relations. Additional methodology was developed from limited field data for adjusting these relations to account for terrain, slope, and vehicle steering influences (turning for wheeled vehicles and pivoting for tracked vehicles). These data indicated that wheeled and tracked vehicles produce rut depths on slopes and when turning/pivoting which corresponded to those described for straight-line travel, but at RCI values less than actual values used in the straight-line relationships (Willoughby and Turnage in preparation). Finally, the first pass relations, multi-pass relations, and adjustments to account for terrain, slope, and vehicle steering were used with the AMM to provide a model to predict soil disturbance due to vehicle traffic over an area. The model does not consider soil compaction below the soil disturbance depth nor does it consider the reduction of rock fragments by increased vehicle passes.

Maneuver Areas

31. No distinguishable maneuver corridors were established for the study area based on guidance from 9ID training personnel. However, the most extensively used training areas are the grasslands areas (Plate 60) due to the

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* VCI_1 data for the HMMWV, 8X8 wheeled combat vehicle, and M60A3 tank are 20, 29, and 20, respectively.

** VCI_{50} data for the HMMWV, 8X8 wheeled vehicle, and MA60A3 tank are 45, 65, and 50, respectively. VCI_{50} is calculated from the WES VCI model which is described in the Analysis of Ground Mobility Models (ANAMOB) study (Rula and Nuttall 1971). This model is empirical and is based on field tests.

absence of trees and shrubs (e.g., training areas 14 and 15, Plate 61). Also, the Environmental Office of the Directorate of Engineering and Housing at Fort Lewis has stated that the Rainier Training Area would be effectively off-limits.

Effects of Vehicle Traffic

32. It was determined that 10, 50, and 1,000 vehicle passes over the entire terrain of the potential traffic area presented the best estimate of the low, medium, and high tactical scenarios, respectively. In general, a higher number of vehicle passes results in a higher level of disturbance (i.e., deeper rut depths) until the ground clearance of the vehicle is reached. This situation, however, does not occur in a linear fashion. Ten, 50, and 1,000 vehicle passes represent threshold values where a rate change in vehicle passes versus rut depth occurs.

33. Plates 15 through 32 show the soil disturbance maps for the calculated number of passes, for each vehicle force structure, and surface condition. Note that the principal vehicle for the 3-3-5 and 4-3-3 vehicle force structures is the same (i.e., M998 HMMWV); therefore, Plates 15 through 20 are representative of both of these force structures. Plates 21 through 26 are representative of the 4-3-3 vehicle force structure only with the 8X8 wheeled combat vehicle as the principal vehicle. Plates 27 through 32 are representative of the 5-5-0 vehicle force structure only with M60A3 tank as the principal vehicle. Figures 2 through 7 summarize the data graphically for detailed analysis. Note that in Figures 2 through 7, "DIST. NOGO" refers to the percentage of soil disturbance NOGO. For the Fort Lewis study area the percentage of urban/off-limits area is 28.3 percent. The percentage of open water is 1.3 percent. The chart values plus the percentage of urban/off-limits and open water area values equal 100 percent.

34. The following is an analysis of soil disturbance levels for 10, 50, and 1,000 vehicle passes, respectively. In the following discussion, soil disturbance NOGO's, urban, off-limits, and open water areas were not included (see Figures 2 through 7) because for training purposes they would not be maneuvered.

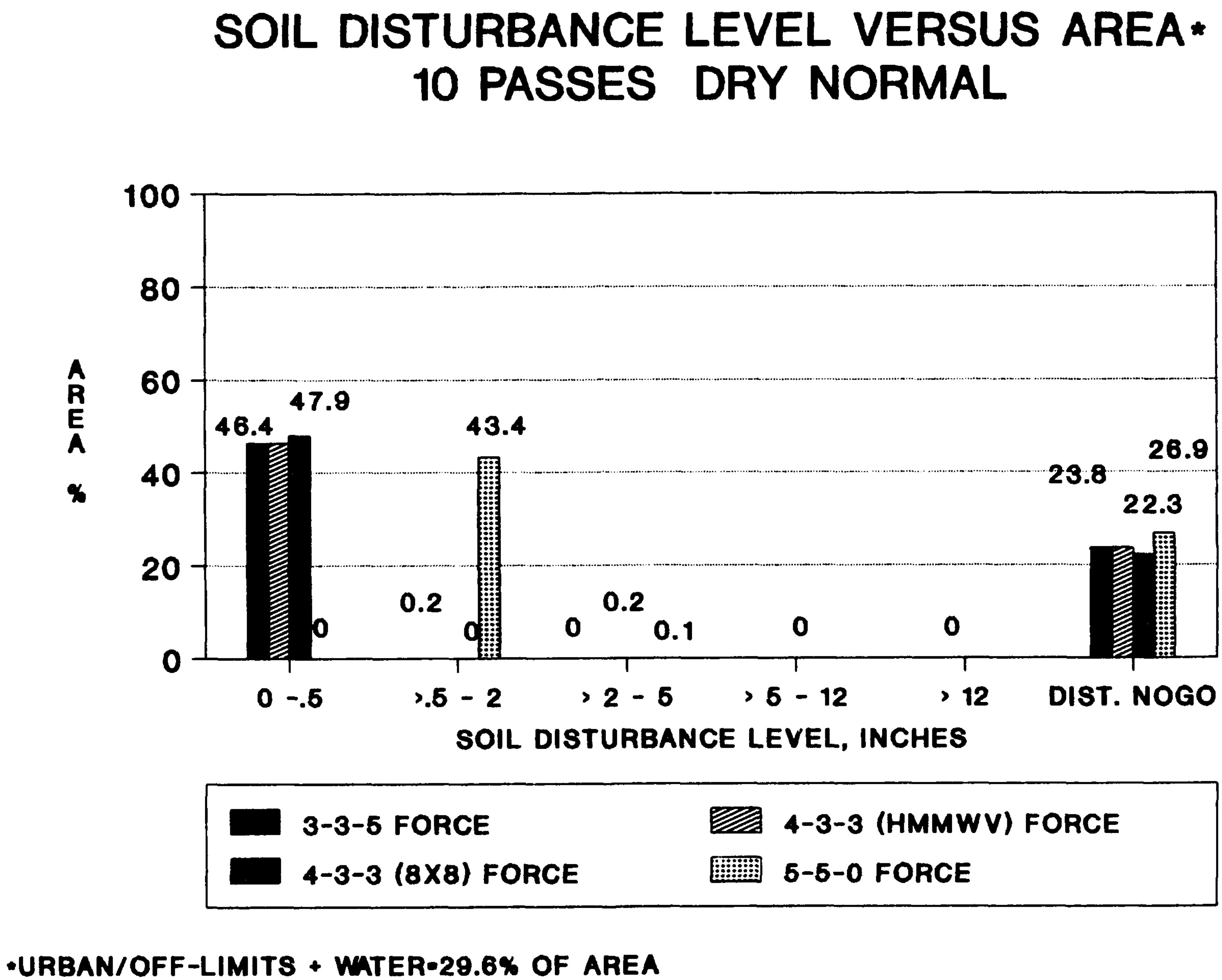


Figure 2. Ten pass disturbance level versus percent area for each force structure in the dry normal surface condition

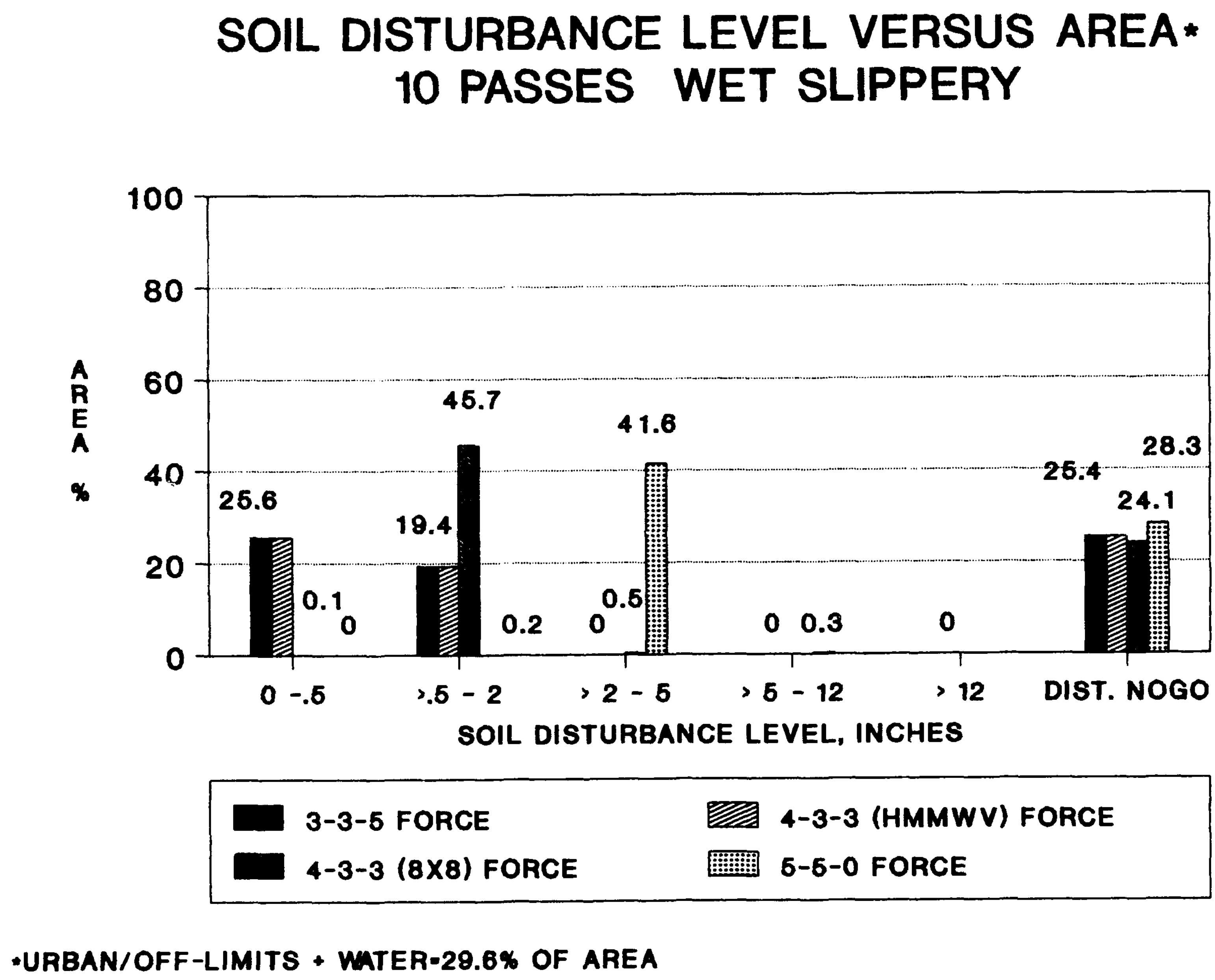


Figure 3. Ten pass disturbance level versus percent area for each force structure in the wet slippery surface condition

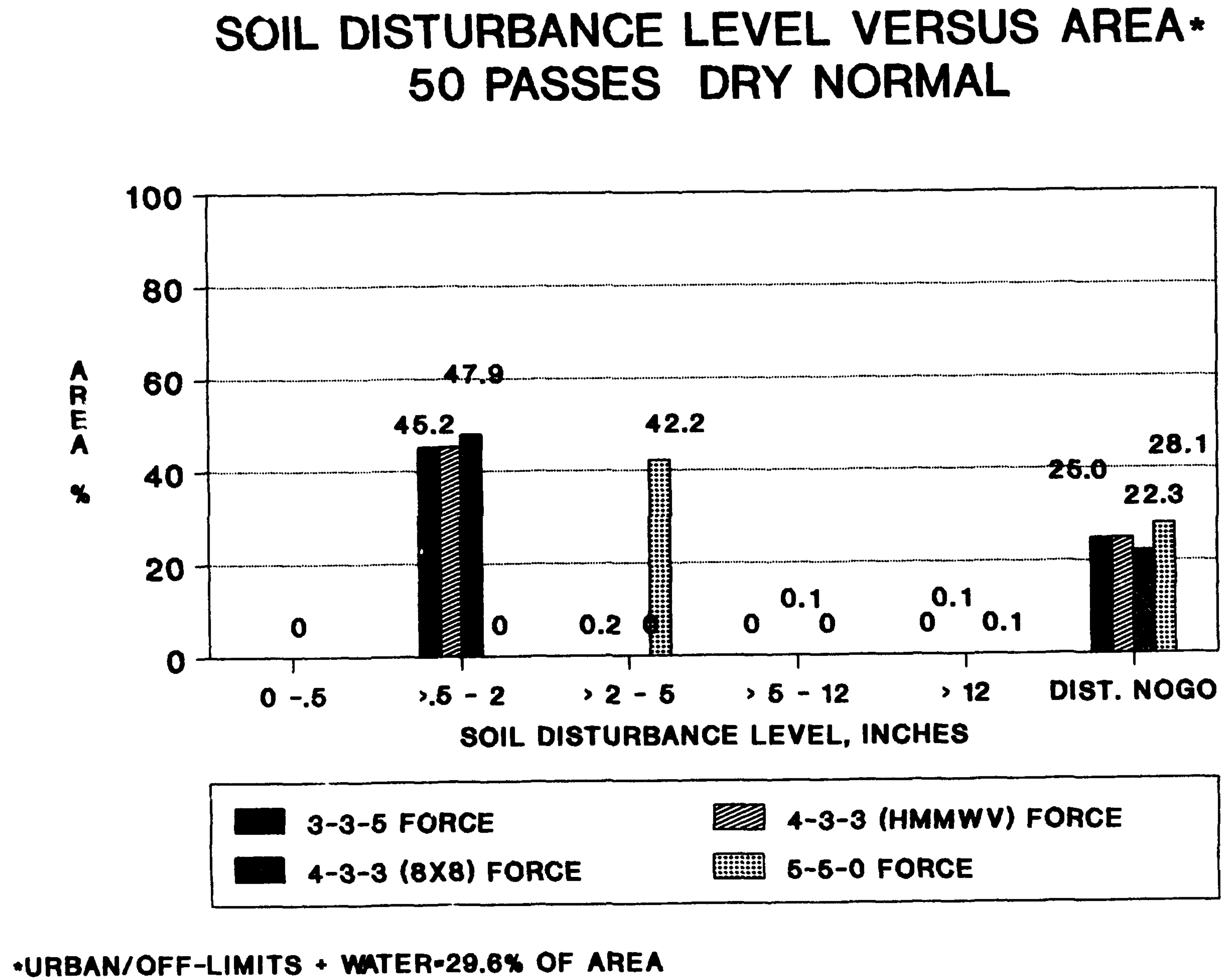
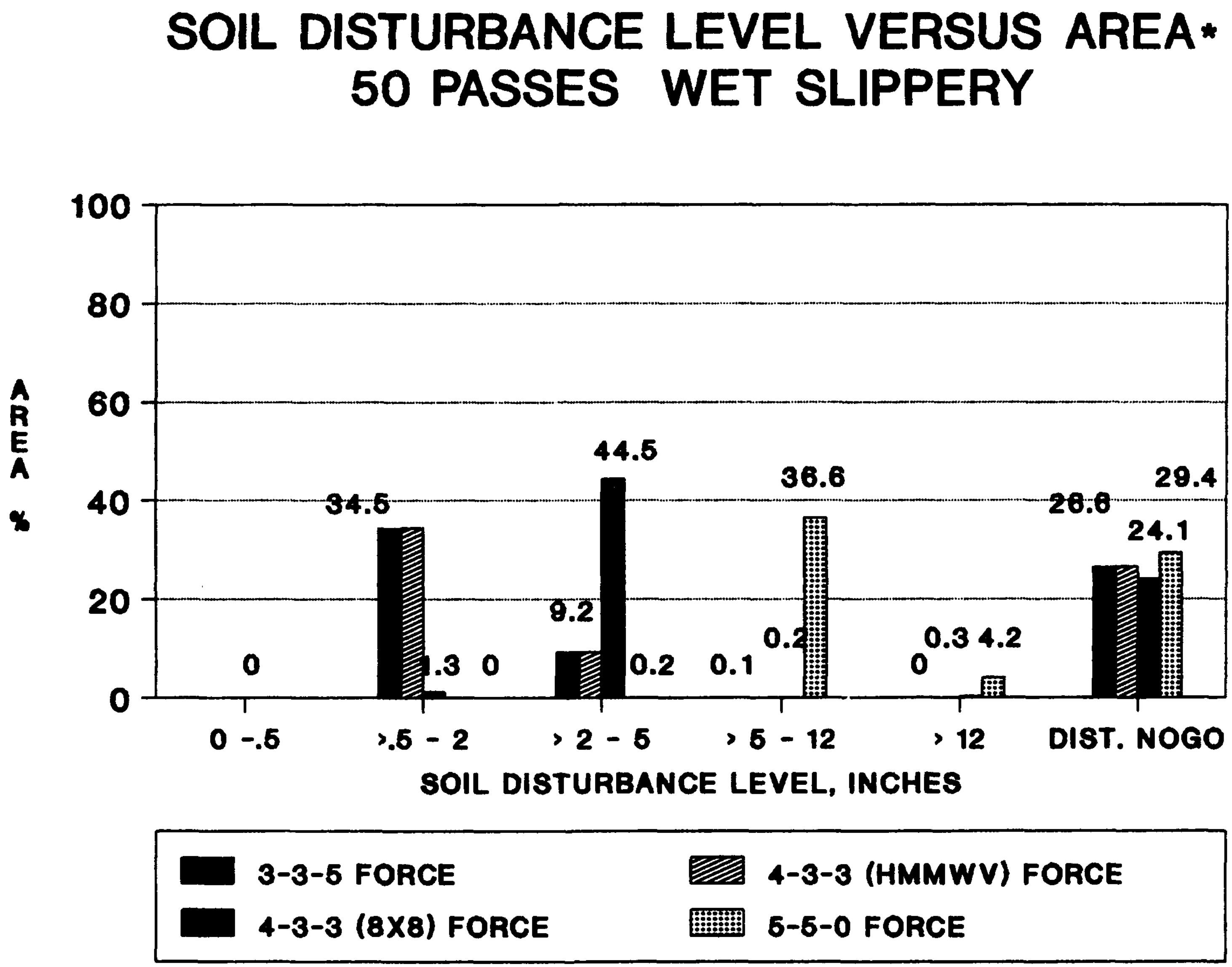
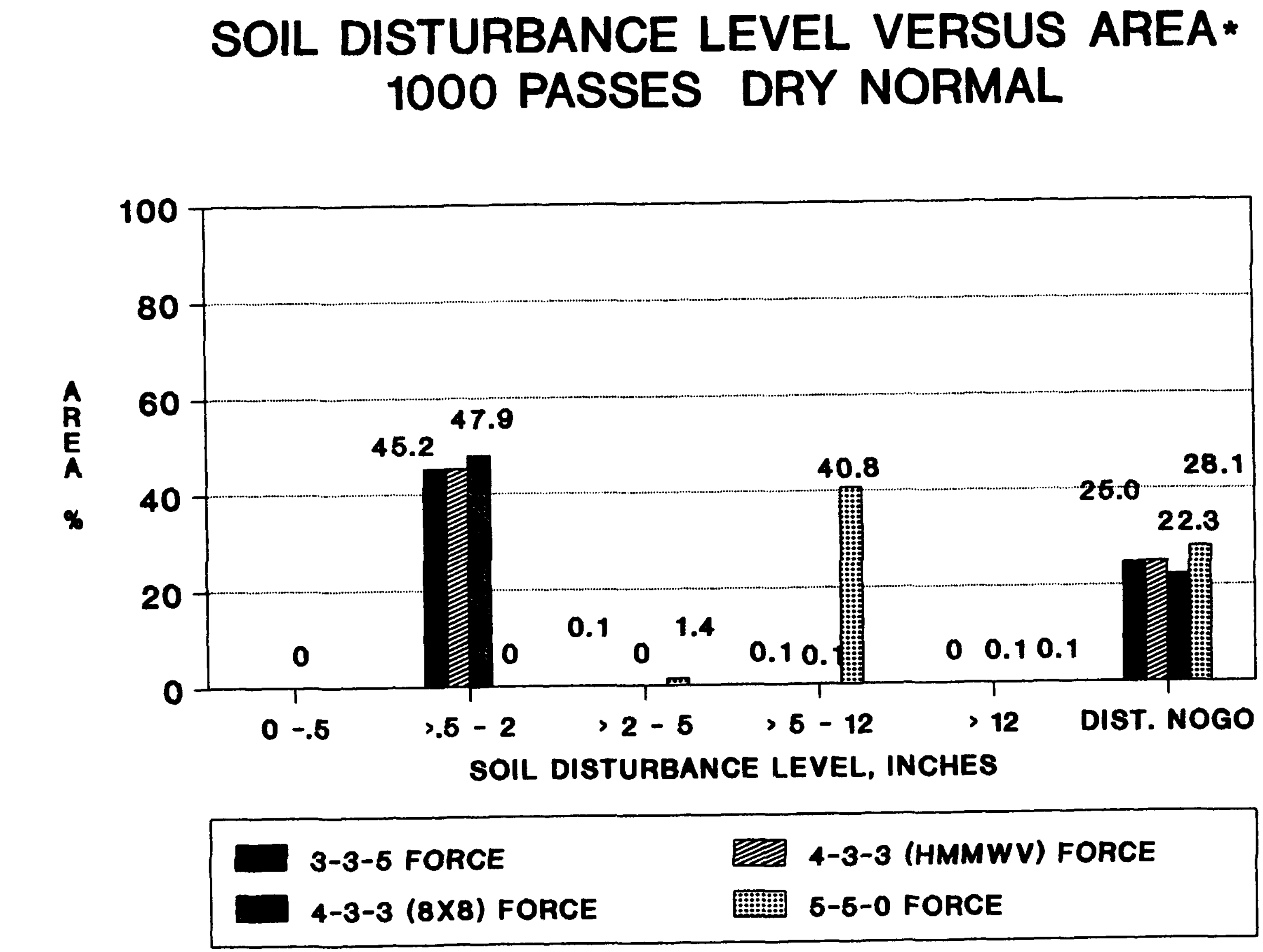


Figure 4. Fifty pass disturbance level versus percent area for each force structure in the dry normal surface condition



*URBAN/OFF-LIMITS + WATER=29.6% OF AREA

Figure 5. Fifty pass disturbance level versus percent area for each force structure in the wet slippery surface condition



*URBAN/OFF-LIMITS + WATER=29.6% OF AREA

Figure 6. One thousand pass disturbance level versus percent area for each force structure in the dry normal surface condition

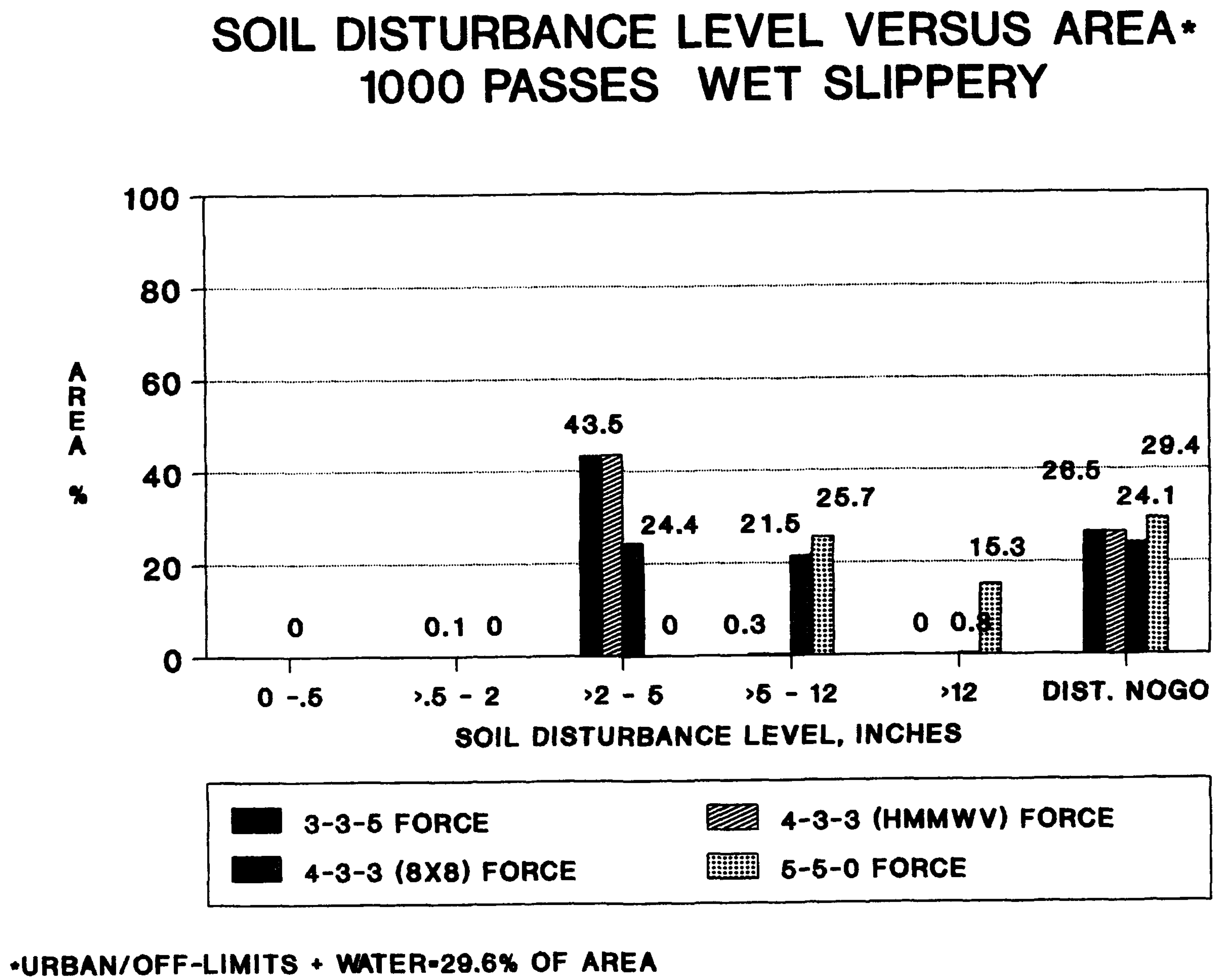


Figure 7. One thousand pass disturbance level versus percent area for each force structure in the wet slippery surface condition

10 Passes

35. For the 3-3-5 and 4-3-3 (HMMWV) vehicle force structures, over 40 percent of the soil disturbance occurred in the 0- to 1/2-in. class with less than 1 percent of the soil disturbance occurring in the 1/2- to 2-in. class for the dry normal surface condition. In the wet slippery surface condition, approximately 26 percent of the soil disturbance occurred in the 0- to 1/2-in. class while approximately 19 percent of the soil disturbance occurred in the 1/2- to 2-in. class. For the 4-3-3 (8X8) vehicle force structure, approximately 48 percent of the soil disturbance occurred in the 0- to 1/2-in. class in the dry normal surface condition. In the wet slippery surface condition, over 45 percent of the soil disturbance occurred in the 1/2- to 2-in. class. For 5-5-0 vehicle force structure, over 40 percent of the soil disturbance occurred in the 1/2- to 2-in. class with less than 1 percent occurring in the 2- to 5-in. class in the dry normal surface condition. In the wet slippery surface condition, over 40 percent of the soil disturbance occurred in the 2- to 5-in. class with less than 1 percent occurring each in the 1/2- to 2-in. and 5- to 12-in. classes.

50 Passes

36. For the 3-3-5 and 4-3-3 (HMMWV) vehicle force structures, over 40 percent of the soil disturbance occurred in the 1/2- to 2-in. class with less than 1 percent of the soil disturbance occurring the 2- to 5-in. class in the dry normal surface condition. In the wet slippery surface condition, approximately 35 percent of the soil disturbance occurred in the 1/2- to 2-in. class and approximately 9 percent of the soil disturbance occurred in the 2- to 5-in. class. Less than 1 percent of the soil disturbance also occurred in the 5- to 12-in. class. For the 4-3-3 (8X8) vehicle force structure, approximately 48 percent of the soil disturbance occurred in the 1/2- to 2-in. class with less than 1 percent each occurring in the 5- to 12-in. and >12-in. classes in the dry normal surface condition. In the wet slippery surface condition, approximately 45 percent of the soil disturbance occurred in the 2- to 5-in. class with about 1 percent soil disturbance occurring in the 1/2- to 2-in. class. Less than 1 percent of the soil disturbance also occurred in the 5- to 12-in. and >12-in. classes each. For the 5-5-0 vehicle force structure, over 40 percent of the soil disturbance occurred in the 2- to 5-in. class with less than 1 percent occurring in the >12-in. class in the dry normal surface condition. In the wet slippery surface condition, approximately 37 percent of

the soil disturbance occurred in the 5- to 12-in. class with about 4 percent soil disturbance occurring in the >12-in. class. Less than 1 percent soil disturbance also occurred in the 2 to 5-in. class.

1,000 Passes

37. For the 3-3-5 and 4-3-3 (HMMWV) vehicle force structures, over 45 percent of the soil disturbance occurred in the 1/2- to 2-in. class with less than 1 percent soil disturbance occurring each in the 2- to 5-in. and 5- to 12-in. classes in the dry normal surface condition. In the wet slippery surface condition, approximately 44 percent of the soil disturbance occurred in the 2- to 5-in. class with less than 1 percent soil disturbance occurring each in the 1/2- to 2-in. class and the 5- to 12-in. classes. For the 4-3-3 (8X8) vehicle force structure, approximately 48 percent of the soil disturbance occurred in the 1/2- to 2-in. class with less than 1 percent soil disturbance occurring each in the 5- to 12-in. and >12-in. classes for the dry normal surface condition. In the wet slippery surface condition, 24 and 22 percent soil disturbance occurred in the 2- to 5-in. and 5- to 12-in. classes, respectively. Less than 1 percent soil disturbance occurred in the 1/2- to 2-in. and the >12-in. classes each. For the 5-5-0 vehicle force structure, approximately 41 percent of the soil disturbance occurred in the 5- to 12-in. class with about 1 percent soil disturbance occurring in the 2- to 5-in. class and less than 1 percent soil disturbance occurring in the >12-in. class in the dry normal surface condition. In the wet slippery surface condition, approximately 26 percent of the soil disturbance occurred in the 5- to 12-in. class and about 15 percent occurred in the >12-in. class.

PART V: SOIL EROSION IMPACTS

Objective

38. The objective of this section is to explain erosion thresholds and rates within the Fort Lewis maneuver areas subjected to variable factors of climate, terrain, and military vehicle activities. The following paragraphs outline the factors influencing soil erosion, a description of soil erosion processes, the estimation of soil erosion in Fort Lewis, and the impact of soil erosion on the Fort Lewis environment.

Soil Erosion in Environmental Impact

Soil as a resource

39. Soil is America's greatest natural resource as a seed bed and nutrient source for vegetation, a foundation for structures, and a construction material. As a construction material, the term "soil" is used to include disaggregated rock materials without regard to specific pedogenic characteristics (silt, sand). In Fort Lewis the term "soil" is used to describe disintegrated rock materials. Soil data used in estimation of erosion impacts were taken from Soil Conservation Service maps and data for Fort Lewis and surrounding areas (Snyder, Gale, and Pringle 1973 and Zulaf 1979). The Fort Lewis soil resource is the surficial material used as a simulated battlefield of a temperate terrain. As a simulated terrain analogous to other areas throughout the world, it is necessary to maintain ground surface training conditions, landform configurations, and vegetation areas.

Significance of soil loss to environmental systems

40. The maintenance of existing soil conditions in Fort Lewis is important to both training and minimization of any negative impacts on other environmental systems. Erosion by flowing water will have such negative impacts as removing surface soil layers containing plant nutrients, gullying the surface and thereby forming barriers to vehicle and troop movements, and causing water pollution creating water saturated soil barriers (mud). Increased sediment in local streams may also impact fish and wildlife (e.g., salmon), especially in the rivers near the training areas. Although minimal to

nonexistent at Fort Lewis, wind erosion of surface soils may expose plant roots, thereby increasing the possibility of activities in killing the vegetation. During concentrated field troop activities, wind transported soil may, on few occasions, negatively impact troop respiration and navigation.

Factors Influencing Soil Erosion

Physical properties of soil

41. Soil fragments/constituents have varying characteristics of chemical composition, density, water content, and physical shape. These characteristics in conjunction with factors of parent rock material, climate, grain size percentages, age, organic content, vegetation cover, and topography give a unique character to each soil. Soils sharing similar characteristics are grouped into a soil type. In Fort Lewis there are nine soil types indicative of unique combinations of soil forming factors. Each soil type has a series of physical properties including compactability, trafficability, liquid limit, and permeability (see paragraphs 9 through 17). Soil compactibility refers to the amount of soil deformation resulting in a lesser than initial soil volume. Soil compaction may result from traffic, shaking, or settling due to water saturation.

Drainage network

42. The development of drainage networks is the product of precipitation type and distribution, surface geology, rock structure (folds, faults, fractures), orientation of rock formation, recent topography, and tectonic history of an area. The drainage system of Fort Lewis has developed in response to these factors over the last several million years. Training activities will not significantly alter the overall drainage system or system characteristics, however, localized accumulation of sediment or gullying may take place. If such local changes do occur, the impact will affect the flexibility of training options. As gullies increase in depth-to-width ratio, for example, the first effect will be that the gully becomes a barrier to wheeled vehicles. Secondly, the gully will increase in size until tracked vehicles cannot bridge the gap. Gullies may become a barrier to troop movement, and will significantly lengthen the time necessary for troops to cross the areas. Although few gullied areas exist in Fort Lewis, changes in maneuver activities, stream conditions, vegetation, etc., can contribute to more gully

formations or enlargement of existing gullies. Gullies range in size from 1 ft to several feet in depth.

Vegetation

43. Vegetative cover of an area develops in response to various factors including the microclimate, soil type, soil nutrients available, moisture, temperature, and slope. Vegetative cover increases soil permeability, holds soil in place, and protects the soil from erosion. Vegetation helps lessen erosion by decreasing the velocity of erosive forces of wind and water flowing over a soil and the interception of raindrops protecting bare soil from the relatively high energy of raindrop impact.

Purpose

Identify the impact of vehicles on soil

44. Natural phenomena of wind movement and water flowage, moving vehicle tires or tracks, and troop movements (foot traffic) all put a series of stresses on soil. Vehicle traffic imparts normal and shear stress on the soil particles. The stresses are transferred from particle to particle within the soil. At some depth and distance laterally from the disturbance, the initial energy input is totally dissipated, and there is no effect on the soil beyond that zone. The effects of traffic in Fort Lewis will be the crushing of vegetation, grinding of soil particles against each other, relative movement between soil particles, disaggregation of soil particles, and transport of soil material. Dead vegetation will increase the availability of soil to erosion and change the chemical effect on the soil from one of actively extracting nutrients to an effect of organic decay. Smaller clods and individual grains are then more susceptible to aeolian and fluvial erosion. Some sediment will be caught, perhaps temporarily, in vehicle tire treads and tracks. This sediment will be transported up into the near surface atmosphere and subsequently be released from the treads or tracks. This material so placed in the atmosphere will either settle near the release point due to its mass, or be transported by wind to the nearest area where the wind velocity is insufficient to continue transporting the material. That material which settles will, by virtue of its kinetic energy, impact the soil surface and

thereby impart energy to possibly cause the release of additional sediment into the atmosphere.

45. The greatest immediate physical effect on soils due to vehicle and troop movement is the disintegration of soil grain aggregates consisting of few to perhaps thousands of individual grains (various sizes). The cohesiveness or strength of the grains to resist disintegration depends upon the grain composition(s) and integrity of any natural mineral cementing agents. Cementing agents may consist of silicates (quartz, chalcedony, etc.), calcium carbonate, ion compounds, or any combination of these cements and many others. Physical stress applied to the aggregates may either fracture the cement and/or the grains thereby producing smaller grains or aggregates. These resulting smaller than original materials are more easily eroded by wind or water. The disaggregation also produces greater surface area. This greater area provides more area for chemical weathering (decomposition) by water and atmospheric gases.

Soil disturbance and sediment yield

46. Technically, soil erosion is the uplifting of a soil particle from its position at rest. Once uplifted, the particle is transported a distance that may vary from less than a millimeter to perhaps tens of kilometers. Eventually, the particle will be deposited when the transporting media energy necessary to transport the particle has diminished and the media has lost its carrying capability. The phenomena of erosion, transport, and deposition are all important at Fort Lewis. Erosion, transport, and deposition of soil particles occurs at Fort Lewis as it does everywhere else on earth. In the common use of the term "erosion", it is implied that the soil material is lost from a given parcel even though the material may be redeposited in an adjacent parcel. Soil erosion for agricultural areas is denoted by tons of soil loss per acre per year. This presentation of data is an average for an entire farm. This average indicates the assumed loss of soil from the farm based on soil types of varying erodibility. There is little attention paid to the fact that some of the soil material will be deposited in an adjacent parcel of land (same or adjacent farm land), thereby attributing to a soil gain for the acquiring area. At Fort Lewis, the determination of soil loss was done for each parcel of land knowing that traffic would impact some areas more severely than others. Parcel-by-parcel impact was determined because the information was needed to determine vegetation loss within each parcel. However, it must

be realized that the soil removed from the most severely impacted parcel may be deposited on an adjacent parcel and never leave Fort Lewis. It must be understood that soil eroded from a given parcel at Fort Lewis does not imply that all the eroded material is immediately entering and being transported by rivers in the area. For the purpose of this report, all activities of soil movement caused by vehicle traffic was termed "soil disturbance," the redistribution of the disturbed soil by natural processes such as wind and water was termed "erosion," and the material actually predicted to leave Fort Lewis was termed "sediment yield". For example, soil erosion may be 40 tons/acre/year, but the sediment yield (that portion leaving Fort Lewis) from this parcel may only be 4 tons/acre/year. To put it in perspective, 40 tons/acre/year of soil erosion is approximately 0.25 in. of soil eroded from a one acre parcel per year. Sediment yield analyses were beyond the scope of this study.

Delineate and estimate areas and amounts of soil disturbance caused by vehicular traffic

47. The greatest effect of increased soil disturbance will be in any area defined as a training area. Any training area (Plate 61) will have traffic activity in direct contact with soil materials. These soils are susceptible to disturbance, and the degree of disturbance will be a function of soil properties, moisture content, season, nature of vehicle track or tread, and the vehicle activity and load. In Fort Lewis the greatest erosion will be caused by water during and after training activities. Fort Lewis is located in an area of temperate climate with relatively high moisture contents in the soil. Under these climatic conditions, wind erosion of soils will be extremely limited and most probably will only result in localized temporary conditions of low visibility. The quantities of wind transported soils and the accumulation of these soils in other areas and streams will be minimal and perhaps immeasurable. The silt and fine sand fractions contained in the soil and that generated by vehicular traffic may initially be transported down into the coarser gravely sections of the substrate by gravity and water. Flowing water known as fluvial erosion will be the primary erosive force within Fort Lewis.

Environmental Factors Influencing Erosion

Regional geologic setting

48. Pacific Border Province. The Pacific Border Province consists of several sections of geologically contrasting history. Fort Lewis lies within the Puget Trough section. The Puget Trough section, Willamette-Puget Lowland, is approximately 400 miles long and averages about 50 miles in width. The section extends southward between the Cascade Mountains and the Coast Ranges. The section is further divided into four subsections. The Puget Sound subsection contains the Fort Lewis study area. Two attributes distinguish this subsection from the adjacent subsections. First, the subsection is the only one that has been glaciated and secondly, the area has not yet undergone a complete isostatic adjustment to the melting away of the ice overburden. The result of the sea level rise associated with continental ice sheet melting is that some lowland areas exposed during pleistocene time are being inundated by sea water. Puget Sound is considered to be that of a drowned valley.

49. During the most recent continental glaciation numerous mountain glaciers from the mainland of British Columbia entered the depression between Vancouver Island and the mainland. The two major lobes of this advance spread westward and southward. The southward lobe advanced through the Puget Trough to about 10 miles south of Olympia, WA. Geologic evidence indicates that as many as four glacial advances may have moved southward through the trough. The Puget Sound ice lobe moved southward against the base of the Cascade Range on the east and built a prominent end moraine against the range. These deposits are part of what is called the Vashon age glacial tills. These tills consist of beds of gravels, sands, and clay with intercalated beds of till and peat of pre-Vashon age. The small mountain glaciers flowing westward from the Cascade Range were minor glaciers and never extended as far as the lower reaches of their own valleys. The lower reaches of the valleys were, however, blocked by the Puget Sound glacial mass. This ice blockage produced lakes in the lower reaches of the valleys. These lakes in turn are represented by glacial lake sediment deposits.

50. Pleistocene/Holocene history. Fort Lewis occupies a glacial outwash plain, the geologic material of which consists of layers of unconsolidated gravely sands, silts, clays, and mixtures of these that have been laid down by a succession of glaciers, usually to depths in excess of 200 ft.

Typically, the upper portion of this material, laid down during the Vashon glacial epoch 13,500 years ago, consists of three layers identified from bottom to top as advance outwash, till, and recessional outwash. Advance outwash consists of stratified, medium to coarse sand with gravel or coarse sandy gravel that was laid down by water flowing in front of the advancing glacier. Glacial till is a compact to very compact layer of unsorted clay, silt, sand, and gravel that is essentially impermeable, and recessional outwash is granular material similar to advance outwash that was laid down by water from the receding glacier.

51. There are no extensive surface exposures of consolidated or otherwise naturally hard rocks reported within Fort Lewis. Surface materials consist mainly of a deep blanket of glacially derived recessional outwash which overlies several sequences of other successively older formations of fine- to very coarse-grained glacial debris. Locally along a few deeply incised streams, there are very narrow and discontinuous exposures from moderately to highly consolidated beds of till and tillite. Some of these beds have considerable lateral extent but are mostly buried by many feet of loose glacial debris of variable particle size. The overall thickness of all these materials is several tens to several hundreds of feet.

Soils

52. Soils of Fort Lewis. Soils on the Fort Lewis Reservation range from excessively drained, very gravelly and cobbly sands developed from glacial till to highly organic peat and muck soil which occur in some of the depressions and other very poorly drained areas. In general, the glacially derived soil material is many tens of yards thick. Most surface soils on the reservation are from slightly acid to strongly acid, but with increasing depth, become less acid. Except for the peats and mucks, most soils are low in organic matter. However, some soils, especially those with a forest cover, have a thin surficial layer of partly decomposed organic matter a few inches thick.

53. The most extensive soils on the reservation are the Everett and Spanaway soils. They have developed on from nearly level to rolling glacial outwash deposits composed of poorly sorted gravel and sands with varied amounts of cobbles. These soils are somewhat excessively drained (permeability of 1.96 to 5.91 in./hr); runoff is low due to the porous nature of the soil. Sand and gravel suitable for many construction uses occur in abundant

quantities. These soils form on upland plains and on slopes ranging up to 30 percent.

54. Other soils include sandy bottomland soils covering most of the Nisqually River floodplain and very poorly drained organic soils in scattered swampy depressions or basins. The floodplain soils commonly have a very dark gray fine sand or fine sandy loam surface layer of about 8 in. thick. The subsoil and substratum continues as a sand or sandy loam but with increasing depth. Lenses or stratified layers of coarse-textured materials become common. These soils are subject to seasonal flooding unless diked. Thus, their suitability for many engineering uses is severely limited.

55. The very poorly drained organic soils are scattered throughout the reservation but their total areas are not large. In terms of the Unified Soil Classification System most of these soils are classified as peat or organic silt.

56. The alluvial soils that occur in bottomland positions along major drainages are deep, mostly well-drained and commonly stratified with coarse and fine-grained material in the substratum. These include riverwash, recent deposits of loose cobblestones, gravel, sand, and some small areas of silt.

57. Soil development process rates. The time necessary for the formation of the various soils at Fort Lewis is moderately short. The climate is greatly tempered by winds from the Pacific Ocean and summers are fairly warm. During the summer rainfall is extremely light, but frequent rain occurs in late fall and winter (75 percent occurring during October through March); annual rainfall ranges between 35 and 45 in. The average temperature in the winter is 40.5°F and the average daily minimum is 33.1°F. In the summer average temperature is 62°F and the average daily maximum is 76.4°F.

58. Influence of geologic history on soils. The parent rock material available for the formation of soils in Fort Lewis is relatively young rock material. In most instances the material is at most 15,000 years old. These conditions in conjunction with the climatic conditions throughout the area for the last 15,000 years indicate that the soils are mature soils. The soils lack the development of thick horizons in many areas.

59. Variability of soils on the landscape. The variability of the soil types in the study area are limited in range and composition. Most of the area consists of sands and gravels soils on the slopes and, in some cases, the hill top locations. In the lowlands and small depressions the soils are

highly organic mucks and silty mucks. The entire area is well vegetated, and along with high moisture content coarse soils, wind erosion is virtually non-existent. Both the fine and coarse soil types are indicative of the glacial and fluvial history of the Fort Lewis area.

60. Erodibility of soils. The erodibility of the soils is a function of many variables. Vegetation, sediment size fractions, eroding fluid velocity, and viscosity, etc., all affect the erodibility of soil. Vegetation dissipates the energy of the fluid and thereby reduces its velocity and sediment transport capacity. Wind at higher velocities can transport up to medium sand size fractions of sediment, and usually transports the larger fractions within one meter of the ground surface. Water can transport larger fragments in suspension and can generally carry the same size fractions of sediment a greater distance than can wind. Fine sand fractions, and often smaller size material, are deposited in valleys downwind of hills. The deposition results from the loss of transport capacity of the winds as they mix with more stagnant valley air. Water can, on sufficient slope, transport large quantities of material by suspension or saltation (bed load rolling and bouncing). The soils most susceptible to erosion are the clays, silt, and sand fractions.

61. Soil compaction may, in some instances, increase the resistance of soil to erosion. Compaction results in a closer packing of soil grains. The grains, being more closely packed, may be physically interlocked, whereby a grain being uplifted by erosive forces is held in place by friction and overlapping of neighboring grains. The effectiveness of this resistance to erosion will be lessened by the introduction of moisture after the initial moisture adhesion threshold is exceeded. Initially, a moisture increase will introduce a grain-to-grain cohesive force and strengthen the soil to resist erosion. However, when the moisture content increases to near saturation, the cohesive forces decrease, grain-to-grain friction is reduced, and buoyancy increases. These effects increase erosion potential by running water.

62. Compaction of a soil, as mentioned earlier, reduces the volume of a given soil. This reduction in volume is expressed on a soil surface in a variety of forms such as that containing a rain water puddle. If tracked vehicles or tires cause the compaction, the linear compaction trough is a rut. The characteristics of the soil and vehicle causing compaction determine the rut depth and also the total soil disturbance. Lateral soil disturbances adjacent to the rut may cause increases soil erosion rates by disaggregation

and separation of soil constituents. Both the rut and adjacent materials are remolded.

63. Rainfall also has many effects. The rain impacting within the rut falls on a surface that is less permeable than the surrounding soil due to grain close packing within the rut. With the continued rainfall, the rut will accumulate surface water more rapidly than the surrounding soil areas. A sloping rut will then contain flowing water capable of eroding the rut bottom soil. The disturbed material, adjacent to the rut as it becomes saturated, will slump into the rut. The slumped material may then be transported by flowing water within the rut. The rut will also form a trunk channel for any surface water flowing downslope to the rut. Similarly, snow/ice melting will erode in ruts as runoff occurs. The rutted soils may be less compacted due to winter maneuvers (as compared to summer) due to existing winter soil ice and expansive effects of refreezing if pressure melting has occurred beneath the wheel or track.

Climatic influences

64. Precipitation regime. Taking into consideration the transport capacity of water and climate regime, the maximum impact of water erosion will accompany fall and winter runoff and long frequency storm (rain) events. The highest average monthly precipitation for the winter months is approximately 7 in. (absolute monthly maximum being approximately 13 in.).

65. Wind. The January through March period has the highest frequency (approximately 2.7 percent) of days with wind velocity greater than 16 knots (18.4 mph). The remainder of the year has less than a 1.7 percent frequency. The period with the greatest frequency of winds in excess of 16 knots is within the period with the highest precipitation. The wind erosion of sediment is reduced by the higher moisture content of the sediment.

66. Temperature. The mean daily minimum temperatures for Fort Lewis range from 32° to 52°F, and the mean daily maximum temperatures ranges from 44° to 75°F.

Soil Erosion Processes

Erosion during the dry cycle, wind

67. Maneuver-caused wind erosion impacts. If the velocity of the air in an open environment exceeds 2.25 mph, turbulent flow is initiated (Bagnold

1941). Since most winds exceed this velocity, the necessary turbulence for earth material particle movement is achieved (Chepil and Woodruff 1963). The surface, particle, and meteorological factors all influence the erodibility of sediment.

68. Several surface factors are significant in determining the wind erodibility of soils including grain cementation, topography, density, etc. Surface roughness is also a significant factor. Wind velocity approaches zero with decreasing elevation above the soil/atmosphere interface. If the surface is vegetated, contains boulders or cobbles, of if the surface has rock outcrops, the zero wind velocity will be at a higher elevation. The zero velocity elevation may only be less than 6 in. in either condition, but even less than 1 in. is significant to alter the intensity of wind erosion. The zero velocity elevation is also significant in controlling another important surface factor, moisture content. Soils, even in arid environments, have moisture contents that are a function of precipitation, relative humidity, and soil pore space moisture. The moisture content of the surface material affects the cohesiveness of the soil. The cohesive forces of water increase the soil cohesiveness until near saturation of the soil occurs. With saturation, the cohesiveness effects of water is greatly diminished.

69. A soil composed of only submicron particles is nonerodible even when subjected to gale force winds. However, when these particles are mixed with particles 5 to 50μ in diameter, the submicron particles become highly erodible (Hilst and Nickola 1959). Due to interparticle cohesion and low roughness associated with fine particles, winds that are capable of moving large diameter grains may not be capable of moving small diameter sediment such as silt and clay. Consequently, a homogeneous surface of silt or clay may be almost impervious to the effects of winds. Threshold velocities for undisturbed soils increase as overall clay content increases. When large aggregates of soil particles are considered, factors which act to decrease soil aggregate size (free-thaw) decrease the necessary threshold velocities thereby making a surface more susceptible to erosion.

70. The major impact of maneuvers is the mixing of various grades of particles sizes, disaggregation of larger soil materials, and initiation erosion/transport by lifting particles into the wind (transport zone). This lifting is done by tank tracks, motor vehicle tires, and soldier foot traffic. Particles so lifted and transported impact the soil surface downwind, thereby

knocking (bumping) other particles into the transport zone. Such successive impacts (chain reactions) can create dust and sand storms.

71. In maneuver-caused impact studies conducted by Marston (1986) at Fort Bliss, grassland flats were distinguished from the dune sites on the basis of microtopography, vertical wind velocity profile, vegetation, and soil depth. The complete lack of aeolian transport in grassland flat sites was the most noteworthy contrast with the coppice dune sites. The vegetation coverage at Fort Lewis is from grassland to forest, both of which will decrease wind velocities and prevent virtually all wind erosion except for that initiated by surface disturbance.

72. Marston's study also included modeling of maneuver impact on sand transport. The model indicates that threshold velocities exhibit rapid recovery following heavy maneuver activity to values reflecting the regeneration of a surface crust with the next precipitation event.

73. Marston's study indicates that:

a. Values of threshold wind velocity are depressed and supply of loose sand is increased for aeolian transport by mechanical breakup of the surface crust, pulverizing particles to finer sizes as well as truncating and bisecting aeolian land forms.

b. The effects of maneuvers on the threshold are minor compared to the effects on antecedent precipitation, or the destruction is less effective than is the regeneration of the crust.

c. The effects of maneuvers on dune microtopography are more persistent due to preservation of the impacts by the same surface crust.

d. To minimize impacts, training maneuvers should be scheduled when winds are low and the threshold velocity is high (the crusts have formed).

74. Basic mechanics of aeolian processes. Problems associated with sand and dust movement by wind have been outlined by Cooke et al. (1982) and Goudie (1983) in terms of the responsible agent process such as deflation-abrasion, transport, and deposition. Deflation causes loss of soil fertility, exposure of plant roots, removal of seeds, and scouring and abrasion of structures. Dust in transport reduces visibility which can in turn result in vehicle accidents, helicopter delays or accidents, and harm to personnel health. The deposition of sand and dust in ditches, over roads and runways, and contamination of surface waters can all make field maneuvers difficult or impossible.

75. The threshold velocity is best considered as a dynamic variable in space and time, depending on the nature and persistence of a surface crust according to research conducted in the Fort Bliss area by Marston (1986). The effects of maneuvers on threshold wind velocity are short-lived, with values adjusting quickly upward with precipitation events subsequent to the impact.

76. Tank maneuvers cause substantial declines in both vegetation density and cover. Such declines will affect soil stability, surface roughness, wind velocity and dynamics near the surface, sediment entrainment, and sediment transport. Due to these factors, terrain types determine many of the attributes of soil erosion. At Fort Lewis it is not only the soil types and wind velocity that determine erosion, but also the vegetation distribution and types. Large forested areas downwind of an eroding area will decrease wind velocity, thereby cause deposition of most of the sediment load. The finer (clay, silt, etc.) sediment fractions may be entrained in the moving air and be carried above the trees and eventually be deposited outside the perimeter of Fort Lewis.

77. <u>Factors influencing wind erosion.</u> The critical factors influencing wind erosion of an unvegetated surface are wind velocity, surface roughness, surface composition (size fractions), and surface disturbance. All of these factors are considered significant in soil erosion when conditions are dry. Increasing the moisture content of a soil will significantly increase the cohesive forces withi the soil and decrease the soil erodibility. A continued increase in soil moisture to the point of saturation causes a reduction in the cohesiveness. When saturated, the soil may flow in response to gravitational forces.

<u>Erosion during wet cycle, running water</u>

78. Erosion of earth materials by natural processes such as water and wind erosion is a function of the energy of the eroding media and the stability of the surface materials subjected to the erosive forces. Water can transport large quantities of sediment, uplift large masses of material, and initiate large scale mass wasting (landslides). Wind is less viscous and less dense than water. Therefore, wind will not be as significant an eroding agent as water in the Fort Lewis study area. The stability of the earth materials being eroded can be related to slope, degree of decomposition and disintegration, and magnitude of the eroding forces.

Factors that affect rates of
water erosion of soil at Fort Lewis

79. The factors that affect soil erosion rates depend upon soil parameters, many of which are related to natural factors and others related to the effects of land use. Various soil loss equations are used to determine loss rates, and these equations usually include such factors as rainfall and runoff, soil erodibility, slope length, slope steepness, management techniques, and conservation practices (Zingg 1940, Smith and Whitt 1947, Browning, Parish, and Glass 1947, Musgrave 1947, Van Doren and Bartelli 1956, Hudson 1961, Wischmeier and Smith 1978). Total runoff and runoff rate and consequently soil erosion increase directly with rain amount and intensity. Infiltration rates of precipitation vary considerably, but fine grained materials in general have lower hydraulic conductivities. Coarse materials with initially high conductivities may undergo infiltration by fine grained material, thereby resulting in low conductivities. Fine grained material is difficult to detach but easy to transport. Coarse material is usually easier to detach but difficult to transport. Medium coarse materials are relatively easy to detach and transport. Interrill erodibilities of soils ranging in texture from clay to sandy loam varied from 4.9 to nearly 40.7 t/acre (Meyer and Harmon 1984) during a 3.9-in. rain at a rate of 2.8 in./hr. The clay soils were least erodible. In soil erosion rates, studies for silt soils (3.9-in. rain) averaging 26.7 t/acre were lost. In the same study loam soils lost 18.2 t/acre and clay loams lost 9.7 t/acre. These data result from studies in Iowa and can be generally related to other areas; however, the major factor other than soil type is soil development (structure and organic content). A more highly developed soil will have a lower erosion rate. The undisturbed soils in Fort Lewis have low erosion rates.

80. Sediment transport capacity of runoff increases rapidly as the flow channel gradient increases (Meyer et al. 1984). Sand-sized sediment transport by shallow, concentrated flow is low on a 0.2 percent slope, but increases 10 to 100 percent on a 1 percent slope. The erosion rate increases 5 to 50 times with a slope increase from 1.0 to 2.5 percent. The erosion rate doubles at a 5 percent slope. This indicates that areas of low slope (Plate 1) at Fort Lewis will be less susceptible to erosion than will the areas that are greater than 5 percent slope (85 percent).

81. Preliminary model determinations for surface impact effects of vehicles at Fort Lewis were conducted assuming conditions of the soils to be either wet or dry. In dry conditions, 50 passes of a tank would result in disturbance to depths of 2 to 5 in. In 1,000 passes, the impact would be greater than 5 in. but less than 12 in. Thousands of passes would be required to cause impacts deeper than 12 in. under dry conditions. In contrast, wheeled vehicles in dry conditions would only have a slight (0.5 to 2 in.) disturbance over virtually all of the maneuver area. Cross-country movements of the wheeled vehicles would require ten passes for disturbance of up to 1.2 in.

82. Wet conditions have a significantly greater disturbance effect. The effect is not significant with slight to moderate wetting. However, with greater quantities of water in pore spaces, engineering characteristics and cohesiveness characteristics of the soils change. The wet season tank traffic map (Plate 32) displays from high (5 to 12 in.) to severe (>12 in.) disturbance for 1,000 passes. As soil approaches the saturated condition, soil/water cohesive and friction forces decrease. The ruts or cleat depressions caused under more saturated soil conditions favor the establishment of vegetation by trapping seeds although the species of vegetation may not be desirable. The depressions also maintain higher moisture contents by accumulating and possibly ponding runoff precipitation. Clay and silt particles carried in runoff waters also settle in the depressions. These fine sediments improve the soil texture and facilitate moisture retention in subsequent precipitation events, provided the ruts and depressions do not enhance erosion and their own erosional destruction.

83. The effect of any physical activity on the surface materials imparts energy to the material and can cause compaction, crushing, shearing, erosion, etc. Under a tank track the major effects would be compaction and disaggregation of soil constituents. The activity would be most pronounced directly beneath the cleats. In the track intercleat area and areas marginal to the track, the effect on the soil would be destruction of soil integrity and shearing, both of which increase erodibility of the earth materials by wind and water. The increased erodibility is due to the loosening or breaking of soil intergranular cement (minerals precipitated between particles).

84. Iverson et al. (1981) studied the effects of off-road vehicles on soil compaction, water infiltration rates, and soil erosion in the Mojave

Desert of California. His results indicate that vehicle tire effects increase soil compaction to a depth of several decimeters and that soil bulk density increased logarithmically with the number of vehicle passes. The rainfall infiltration rates similarly changed drastically. Prior to compaction, the runoff of water required 1.57 to 2.36 in. of rainfall. After compaction 0.43 in. of rainfall per hour was required to produce surface water ponding and runoff. Surface runoff from compacted areas was five times greater than from undisturbed areas. Sediment yields from the effect of compaction, etc., were 10 to 20 times greater. Although Fort Lewis is not an arid region, the coarse gravels throughout the area will retain less moisture than will finer grained sediments (fine sand, silt, and clay). In effect, the large particle size of coarse sediments is not conducive to moisture retention, and the physical compaction, etc., of the materials is much like that of a desert region.

85. Similar studies conducted by Prose (1985) examined the effects of an M-3 type tank on a bajada (slope 0 to 3 deg) which may have grain factors similar to glacial outwash plains as found in the study area. The standing ground pressure of the tank was 14.8 psi. Penetrometer tests conducted in tank track marks revealed a great increase in penetration resistance from 0 to 7.9 in. depth. The increased resistance was up to 50 percent greater. A significant increase was also noticeable to a depth of 11.8 in. The substrate was also affected laterally to a distance of 19.7 in. from the tank track. Compaction was greatest in areas with the highest fraction of fine-soil materials. Prose's study indicates that elimination of the effects of soil compaction would take approximately 100 years. He also felt that the associated soil loss should be considered a permanent soil loss since regeneration of desert soils requires many centuries. In the Fort Lewis area the soil damage is not considered permanent. Soil would be regenerated in probably less than a century. This regenerated soil would be thin and of low grade until revegetation established a higher organic content.

86. The results of traffic over soil materials causes track marks (ruts). These marks impede lateral surface runoff and in so doing channelize the flow of water. Rilling (erosion channels) can be initiated in tank disturbed areas with a slope of 1 to 2 deg. Channelized water flow has the increased capacity to erode sediment and initiate gully formation. The quantity of fine disassociated earth materials susceptible to erosion prior to

vehicle passage is increased by processes described above. The channelization and increased quantities of fine fractions are primarily responsible for the increased sediment load carried by surface runoff. Any track disturbances that transect a surface parallel to the slope enhance erosion potential by providing flowing water a long reach. A long reach increases fluid flow velocity and therefore transport erosion potential.

87. Evidence of water erosion at Fort Lewis. Examination of aerial photographs* of the Fort Lewis study area reveals two principal scales of drainage networks on the landscape. A large, well-developed river flows to the northwest in the western half of the area. This well-developed channel of a perennial stream has probably been evolving in a similar manner for several thousands of years. Many tributary creek channels may be seen in many areas; however, the major tributary flows southwestward, draining the northeast section of the area. Although the greatest erosion at Fort Lewis is fluvially related, the major water courses are not, in most cases, surrounded by areas of steep slopes. Where steep slopes are adjacent to water courses, the slopes are well vegetated and appear to be stable land masses without evidence of mass wasting.

Estimation of Possible Soil Erosion Rates

Erosion during the dry cycle

88. The primary factor of soil erosion during the dry cycle is wind. Precipitation in the form of rainfall occurs frequently, and what rainfall does occur infiltrates the soil quickly. The duration and intensity of precipitation determine the availability of moisture for absorption into organic material and soil constituents. The high moisture content of the soils, high frequency of rainfall events, high relative humidity, and great extent of vegetative cover all cause short duration events of dry conditions. Therefore, the amount of soil loss that occurs during the dry cycle is a function of the amount of wind energy available to erode disturbed soil during short intervals of dry conditions. Soil erosion amounts calculated for the dry cycle are based on wind erosion only.

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* Aerial photographs supplied by US Army Engineer District, Seattle, WA.

89. In areas of bedrock or large rock debris, the natural erosion rate is relatively insignificant as compared to areas disturbed by traversing vehicles. Areas considered "urban/off-limits" will have erosion, but the erosion is limited by natural agencies. These "urban and off limits" areas are indicated on the soil erosion severity maps as a separate category with no designation of erosion rates. The "no erosion" areas are areas where no erosion is expected due to heavy vegetation preventing vehicle activity, vegetative and moisture factors indicate that erosion is below the limit of detection, and/or rock exposed is bedrock or large blocks undergoing erosion due to natural agencies only. For example, heavy vegetation standing in a humid area will have no erosion due to wind.

90. The effects of wind and fluvial erosion will vary with conditions of the soil, vegetation, etc. In some instances, the various factors and conditions will indicate a merging of two previously separate erosion rate categories. This is a result of the algorithm and ranges of erosion rate factors (map legend).

91. Development of the wind erosion algorithm. In order to estimate the amount of wind erosion in the Fort Lewis study area where wind erosion may occur, an algorithm was developed based on existing methods for estimating the amount of erosion due to wind. The wind erosion algorithm is based on the Soil Conservation Service (SCS) method used to estimate wind erosion which considers various factors of the soil including wind erodibility group (WEG) and a climatic factor (C) (Chepil 1945, Woodruff and Siddoway 1965, Skidmore and Woodruff 1968). The wind erosion algorithm for this study was developed in consultation with SCS personnel in Pierce and Thurston Counties, Washington. The algorithm used for calculating total amount of erosion for the four vehicle scenarios during the dry period utilizes the standard SCS wind erosion equation plus a factor for soil disturbance by vehicular activity and a factor for the number of vehicle passes.

92. Data considered. Data used in developing the wind erosion algorithm include the WEG and allowable soil loss values (T) for each soil type taken from SCS data. Within a given area, usually a county, a multitude of soil types are mapped due to their unique characteristics. These soils can be grouped on the basis of their grain size, moisture content, etc., as well as wind erodibility. Each group WEG has similar tons/acre/year loss due to wind erosion. These groups are developed primarily on grain size

characteristics due to diversity, complexity, and variability of moisture contents. For this study, WEG factors were established by examining grain size data and relating the factors to experience in erosion studies conducted at the WES. Soil moisture data were included in establishing the WEG because the worst case scenario was used (i.e., the condition of total dry surface conditions). A factor for depth of soil disturbance by vehicles and a factor for the number of vehicle passes were also derived. Using this algorithm, calculations were made for each 164- by 164-ft (50- by 50-m) pixel area for estimating maximum possible erosion due to wind during the dry period. The wind erosion algorithm is stated as:

$$E(wind) = C \times I \times D \times M/T$$

where

E(wind) = maximum possible soil erosion rate during the dry cycle in tons/acre/year

C = climatic factor for wind erosion (0.05)

I = wind erosion factor for erosion group, where for

- WEG (GP), I = 1.0
- WEG (GM, GC), I = 3.0
- WEG (SP), I = 7.0
- WEG (SM, SC), I = 35.0
- WEG (CLML), I = 50.0
- WEG (CL, PT), I = 86.0

D = soil disturbance factor, where

- Depth of disturbance = 0 - 0.5 in., D = 1.1
- Depth of disturbance >0.5 in., D = 1.2

M = number of vehicle passes factor, where

- Low density traffic, 10 passes, M = 1.0
- Medium density traffic, 50 passes, M = 3.0
- High density traffic, 1,000 passes, M = 10.0

T = SCS soil loss factor (tons/acre/year) = 1.0

93. Data not considered. Parameters not considered in calculating wind erosion during the dry period include the occurrence of individual precipitation events, sediment thrown into the air by vehicle tracks (tires), spatial differences in wind direction and intensity in relation to vegetation stands,

etc., and spatial differences in soil moisture. It must be emphasized that wind erosion is not a significant factor at Fort Lewis.

94. Discussion of dry normal condition maps. Examination and interpretation of the erosion maps for the dry season for the vehicular force structures indicates that vehicular traffic can cause some sediment erosion during the dry periods (Plates 33 through 35, 39 through 41, and 45 through 47). It is apparent, when examining the maps, that when the sediment is disturbed by vehicles the susceptibility of the soil to erosion is increased. A primary factor, however, in generating soil erosion due to wind is the number of vehicular passes. The main maneuver areas will be the areas of maximum possible wind erosion, however, this erosion is still minimal. Coarse grained sediment (coarser than sand) even when traversed by vehicles has virtually no contribution to soil erosion. It must be emphasized that wind erosion of sediment at Fort Lewis is negligible and that fraction leaving the Fort Lewis proper is immeasurable and can be considered insignificant.

Erosion during the wet cycle

95. Erosion during the wet cycle was estimated through the consideration of erosion due to running water only. An assumption was made that during the wet cycle, soil moisture was significantly high enough to eliminate the probability of soil erosion due to wind action. Consequently, the total amount of soil erosion for the wet cycle was estimated using a water erosion algorithm (developed by WES), stated as:

$$E(water) = T + T \times K \times H \times D \times S$$

where

E(water) = maximum possible soil erosion rate during the wet cycle, in tons/acre/year

T = SCS soil loss factor (tons/acre/year)

K = SCS soil erodibility factor (varies from 0 to 39, depending on soil type)

H = channel occurrence factor, where

If a spring occurs in parcel, H = 1.0

If upper canyon channel in parcel, H = 1.1

If lower canyon channel in parcel, H = 1.2

If permanent channel in parcel, H = 1.3

D = depth of disturbance factor, where

If 0 - 0.5 in., D = 1.0

If >0.5 - 2.0 in., D = 1.1

If >2.0 - 5.0 in., D = 1.2

If >5.0 - 12.0 in., D = 1.4

If >12.0 in., D = 1.6

If NOGO, D = 1.0

S = slope factor, where

If 0 - 2 percent, S = 1.0

If >2 - 5 percent, S = 1.1

If >5 - 10 percent, S = 1.2

If >10 - 20 percent, S = 1.3

If >20 - 40 percent, S = 1.4

If >40 percent, S = 1.6

96. Development of the water erosion algorithm. The development of an algorithm for erosion during the wet cycle was based on the consideration of a number of factors, including the erodibility of the soil (K) and the allowable erosion factor (T) obtained from data, a slope degree factor derived from topographic maps, the occurrence of various types of channels on the landscape, and the depth of soil disturbance by vehicle force structure. This algorithm was developed by WES researchers based on extensive field experience in geomorphological and soil erosion studies.

97. Data not considered. Data not considered in the development of the wet cycle soil erosion algorithm include the influence of a track versus a wheel on erosion by running water, the orographic effect of the landscape, the slope length, the influence of vegetation, the change of soil factors by vehicular traffic, and the nonhomogeneous distribution of traffic. Tracks have different effects on surficial soils with respect to erosion by running water than wheels. Tracks may increase infiltration rate through soil disturbance and increasing surface roughness which decrease runoff and soil erosion. However, wheels concentrate flow and decrease infiltration of the soil through soil compaction, thereby increasing runoff and soil erosion. Wheels may also concentrate flow obliquely along slopes instead of downslope, thereby decreasing runoff and soil erosion as would be caused by up/down slope ruts. Cross slope and oblique slope wheel tracks catch water and prevent the rapid movement down the principle hill slope. The oblique and cross slope tracks

have less of a gradient than does the primary slope and, therefore, flow velocities are less. Both tracks and wheels widen stream channels at crossings and increase local stream bank erosion resulting in contributing soil to the stream channel. Thus, it may be seen that wheels and tracks have complex impacts on the soil in terms of erosion by running water. No attempt was made to quantify these differing impacts on the soil in terms of erosion by water.

98. Data considered. A major factor in the development of soil erosion due to running water is the length of the slope. Unfortunately, data were not generally available for inclusion of the slope-length factor in the wet cycle soil erosion algorithm. An additional effect of slope on soil erosion is the concentration of vehicular traffic in corridors on higher slopes. In many areas, especially those of lower slopes, as the slope increases, vehicles, both tracked and wheeled, will select trails for traffic. These trails will become areas of more excessive erosion.

99. Discussion of wet slippery condition maps. Examination of the soil erosion maps for the wet cycle for all vehicle force structures indicates that erosion during the wet cycle is considerably more than during the dry cycle (Plates 36 through 38, 42 through 44, and 48 through 50). The principal reason for this is that large quantities of rainfall during the wet cycle. Consequently, runoff and related soil erosion are maximized. An exception to this is the relatively slow melting of snowfall which accumulates over the winter. The melted water infiltrates into the subsurface when sufficient warming has occurred to thaw the soil. The snow melt water does not contribute to erosion and reduces potentially high run-off volumes in spring snow melt.

100. Use of the wet slippery condition erosion maps. Comparison of the soil erosion maps for the wet cycle with those for the dry cycle shows the relative influence of the soil erodibility factor and slope factor for the wet cycle versus the traffic and number of pass factors for the dry cycle. During the wet cycle, the depth of the disturbance may actually be a positive factor in increasing the infiltration capacity of the soil itself, thereby inhibiting erosion. If precipitation is insufficient to cause flowage between depressions made by a single track or tire, the water holding depression becomes a small infiltration basin. Such a basin network helps recharge the subsurface water supplies. When flowage between depressions occurs, the erosive and transportive abilities of the water can become significant.

Relative soil erosion severity

101. The impact of soil erosion during both the dry and wet cycles (12 months) as a function of allowable soil loss may be seen in Plates 51 through 59 (soil erosion severity). Although soil material may have been lost, the severity of erosion impact is an index of how much the erosion destroyed the soil's ability to function in the ecosystem. If soil was removed, but regeneration kept pace with the loss, no soil erosion impact occurred as far as maintaining the training realism is concerned. The "soil disturbance severity" maps show the maximum erosion for each 164- by 164-ft (50- by 50-m) parcel at Fort Lewis with respect to erosional loss and soil regeneration. The assumption is that every parcel gets all of the vehicle traffic considered in the analysis. These maps, like Plates 33 through 44, are useful for predicting areas of relative amounts of soil erosion. The soil erosion severity maps display areas having specific ratios of soil loss to soil generation. In areas with a soil severity index of less than one, the soil regeneration rate is sufficient to maintain a soil resource. Soil material is lost, but the soil forming processes recover a soil system status over a sufficient period of time. Since most of the soil eroded in the 164- by 164-ft (50- by 50-m) parcel will be deposited in another parcel in Fort Lewis, the maps do not represent soil loss or sediment yield. Plates 51 through 59 indicate the amount of soil that may be mobilized by erosion. Deposition of mobilized or remobilization of the same soil is not accounted for in the analyses. Ninety percent of all of the sediment mobilized by vehicular traffic will remain within an area due to redeposition of the sediment. This estimate is based on previous field experiments, research, and observations conducted by WES. Transport of sediment is not a continuous process, most material mobilized by natural forces is retained in many areas during its movement to ultimate deposition in oceans. Lower slope regions and valley bottoms may retain sediments for scores, hundreds, or thousands of years.

Soil Erosion Recommendations

Minimizing soil erosion by area selection

102. The environmental impact of soil disturbance at Fort Lewis due to vehicular traffic may be minimized several ways. An obvious way to reduce

the potential for soil disturbance is to restrict traffic to centers of activity connected by arteries (tank trails and roads). Since only a few passes by wheeled or tracked vehicles are necessary to completely destroy the surface vegetation and disturb the soil to a depth of 1 in., total elimination of traffic in all but selected areas (activity areas and connecting corridors) would substantially reduce the amount of soil disturbance. The soil that was eroded from the corridors and activity areas would be redeposited nearby, with the possible exception of stream crossings, where eroded soil might be ultimately transported out of the Fort Lewis area into the adjacent river and creeks. Examination of aerial photographs of Fort Lewis reveals that the practice of establishing trails and roads connecting obvious locations for military activity actually occurs, and many large tracts in maneuver areas on Fort Lewis exhibit minimum environmental impact due to managed maneuver activities. Establishment of activity areas and corridors between them is in keeping with standard battlefield operations.

103. Areas of silty or clayey soils are highly susceptible to wind erosion and should be avoided when possible during dry, windy periods. Long steep slopes dissected by many small channels and gullies are obviously prone to erosion by running water and are likely areas for significant soil erosion impact. Areas of wind shadow and gentle topography minimize the potential for soil erosion throughout the year and offer the best locations for vehicle traffic to reduce soil erosion.

Minimizing soil erosion by time-of-year activities

104. Soil erosion may also be reduced substantially by considering the time of year for training on different areas of Fort Lewis. Training during the months of greatest precipitation should be minimized in the areas most subject to erosion by running water. During periods of maximum wind velocity, upland slopes covered by silty soils should be avoided to prevent wind erosion.

105. An integrated training program which considers all three of the above recommendations could substantially reduce the amount of soil erosion which may be produced by training activities.

PART VI: EFFECTS OF TRAFFIC ON SELECTED NATURAL RESOURCES

Background

106. This section introduces the information base used to evaluate the effects of military vehicle traffic on selected natural resources. It includes a recapitulation of vehicle disturbance and erosion data and introduces basic environmental data. Note that all references to the 3-3-5 force structure also include the 4-3-3 (HMMWV) force structure.

Disturbance by vehicle traffic

107. As described in paragraph 28, five levels of soil disturbance were identified for Fort Lewis: minimal, slight, moderate, high, severe, and NOGO. Tables 1, 2, and 3 show the number of acres in each disturbance level, by force structure, for both dry-normal and wet-slippery conditions. These data were obtained by multiplying the total Fort Lewis acreage by the percentages from Figures 2 through 7. Note that, in general, as the traffic moves away from the 3-3-5 force structure, the level of disturbance shifts toward the more disturbed end of the spectrum for both the dry-normal and wet-slippery conditions.

108. NOGO areas for all force structures and conditions are primarily associated with closely spaced vegetation (especially in the Ranier Training Area), the steep embankments along the Nisqually River, and soil-associated problems such as traction and strength. The percent of the area the representative vehicles in each force structure can access and therefore potentially affect is significantly different ($P \leq 0.05$). Averaged over all three scenarios and both wet and dry conditions, the 4-3-3 (8X8) force structure can access 47.2 percent of the installation. The 3-3-5 and the 5-5-0 force structures can access 45.0 and 42.0 percent, respectively.

Soil erosion

109. Potential for soil erosion at Fort Lewis is slight. See Part V of this report.

Vegetation associations

110. A cover type map was prepared by Shapiro and Associates, Inc. (1989) and personnel of the Environmental Resources Section of CENPS. The map was prepared from 1987 aerial photography, 1968-1981 7.5-min quad maps, and

Table 1

Acres Affected by Disturbance Level, Low Scenario (10 Passes)*

Force Structure, Disturbance Level	Dry-Normal Acres/Percent	Wet-Slippery Acres/Percent
3-3-5/4-3-3 (HMMWV)		
Minimal	40,256 (46.4)	22,210 (25.6)
Slight	174 (0.2)	16,831 (19.4)
Moderate	0	0
High	0	0
Severe	0	0
NOGO	20,649 (23.8)	22,037 (25.4)
4-3-3 (8X8)		
Minimal	41,558 (47.9)	87 (0.2)
Slight	0	39,649 (45.7)
Moderate	174 (0.2)	434 (0.5)
High	0	0
Severe	0	0
NOGO	19,347 (22.3)	20,909 (24.1)
5-5-0 (M60A3)		
Minimal	0	0
Slight	37,653 (43.4)	174 (0.2)
Moderate	87 (0.1)	36,092 (41.6)
High	0	260 (0.3)
Severe	0	0
NOGO	23,338 (26.9)	24,553 (28.3)

* Urban/off-limits = 24,553 acres (28.3 percent); water = 1,128 acres (1.3 percent).

Table 2

Acres Affected by Disturbance Level, Medium Scenario (50 Passes)*

Force Structure, Disturbance Level	Dry-Normal Acres/Percent	Wet-Slippery Acres/Percent
3-3-5/4-3-3 (HMMWV)		
Minimal	0	0
Slight	39,215 (45.2)	29,932 (34.5)
Moderate	174 (0.2)	7,982 (9.2)
High	0	87 (0.1)
Severe	0	0
NOGO	21,690 (25.0)	23,078 (26.6)
4-3-3 (8X8)		
Minimal	0	0
Slight	41,558 (47.9)	1,128 (1.3)
Moderate	0	38,608 (44.5)
High	87 (0.1)	174 (0.2)
Severe	87 (0.1)	260 (0.3)
NOGO	19,347 (22.3)	20,909 (24.1)
5-5-0 (M60A3)		
Minimal	0	0
Slight	0	0
Moderate	36,612 (42.2)	174 (0.2)
High	0	31,754 (36.6)
Severe	87 (0.1)	3,644 (4.2)
NOGO	24,379 (28.1)	25,507 (29.4)

* Urban/off-limits = 24,553 acres (28.3 percent); water = 1,128 acres (1.3 percent).

Table 3

Acres Affected by Disturbance Level, High Scenario (1,000 Passes)*

Force Structure, Disturbance Level	Dry-Normal Acres/Percent	Wet-Slippery Acres/Percent
3-3-5/4-3-3 (HMMWV)		
Minimal	0	0
Slight	39,215 (45.2)	87 (0.1)
Moderate	87 (0.1)	37,740 (43.5)
High	87 (0.1)	260 (0.3)
Severe	0	0
NOGO	21,690 (25.0)	22,991 (26.5)
4-3-3 (8X8)		
Minimal	0	0
Slight	41,558 (47.9)	87 (0.1)
Moderate	0	21,169 (24.4)
High	87 (0.1)	18,653 (21.5)
Severe	87 (0.1)	260 (0.3)
NOGO	19,347 (22.3)	20,909 (24.1)
5-5-0 (M60A3)		
Minimal	0	0
Slight	0	0
Moderate	1,215 (1.4)	0
High	35,397 (40.8)	22,297 (25.7)
Severe	87 (0.1)	13,274 (15.3)
NOGO	24,379 (28.1)	25,507 (29.4)

* Urban/off-limits = 24,553 acres (28.3 percent); water = 1,128 acres (1.3 percent).

1975-1981 National Wetlands Inventory maps. Air photo interpretation was used to draft a cover type map which was verified in the field. Fourteen major Vegetation associations or map units were identified (Table 4 and Plate 60). A description of the mapping approach and cover type classifications was reproduced in Tab 1 on page 102. A detailed list of classifications for Fort Lewis is given in Tab 2 on page 108.

111. To calculate acreage determinations for the area of potential traffic in Table 4, we assumed an equal ratio of cover types (excluding water) within areas designated as urban/off-limits on Plates 15 through 32 and over

Table 4

Areal Extent of Cover Types

Cover Type	Total Land Area		Area of Potential Traffic*	
	Acres	Percent of Total Land Area	Acres	Percent of Potential Traffic Areas
Bare ground	280	0.3	197	0.4
Emergent marsh	682	0.8	480	0.9
Coniferous forest	43,680	50.0	30,751	55.5
Deciduous forest	2,104	2.4	1,481	2.7
Mixed forest	2,040	2.3	1,436	2.6
Forested swamp	409	0.5	288	0.5
Young forest	7,184	8.2	5,058	9.1
Grassland	14,297	16.4	10,065	18.2
Cleared grassland	2,583	3.0	1,818	3.3
Mixed grassland	3,340	3.8	2,351	4.2
Open water	1,237	1.4	0	0
Shrubland	1,415	1.6	996	1.8
Scrub/shrub swamp	679	0.8	478	0.9
Urban	7,273	8.3	0	0
Total	87,203**	99.8†	55,399	100.1†

* Area of Potential Traffic = Total Land Area - Urban/Off-limits Designation-Water in Plates 11 through 32.

** These acres do not equal the base acres from paragraph 2 due to a difference in the data sources and digital processing techniques.

† Percentages do not total 100 percent due to rounding.

the entire installation. The urban/off-limits designation covers 29.6 percent of Fort Lewis (impact, ammo storage, and cantonment areas; golf course; and Weir and Johnson Prairies). For example, if a cover type was 1,500 acres in size, then 1,056 acres (1,500 × 0.704) was tallied in the area of potential traffic.

112. A more realistic and vehicle-specific estimate of the area which might receive traffic would reduce the acreage further. For example, the forest stands in training areas 16 through 23 (Plate 61) are not accessible by the M60A3. Many of the wetlands are in terrain that is completely or partially included in the disturbance NOGO.

Plants and animals

113. Plant species, vegetation associations, and wildlife and fish species of special interest and known or thought to be present on Fort Lewis are given in Table 5, with their status or reason for interest and associated

cover type. The Washington Natural Heritage Data System (WNDHS) (1989) was the source for the majority of the listings. Their designation of natural features was derived from a National Park Service survey (Chilcote et al. 1976) that identified typical or good examples of plant communities as candidates for preservation. In addition, the 1984 Fish and Wildlife Management Plan for Fort Lewis (Directorate of Engineering and Housing 1984) considers several featured or managed species or groups of species. The information in Table 5 was also compiled from Boyle (1985 and 1987), Jordan and Evermann (1969), Kozloff (1976), Franklin and Dyrness (1973), Munz (1973), and Verner and Boss (1980). The taxa in Table 5 are only a portion of those found on Fort Lewis, but are the primary focus of management and conservation activities on the installation. Plate 62 provides the location of key areas for many of these resources.

Special features

114. Water. The Nisqually River and ten tributaries on Fort Lewis are salmon and trout spawning areas. Spawning beds are located in tributaries and wetlands of the Nisqually, including Muck, Clear, Johnson, South, and Lacamas Creeks; Exter Springs; Watkins and Chambers Lakes; and Johnson and Viet Nam Village marshes. American, Chambers, Lewis, Spanaway, No Name, and 22 other small lakes are managed for a recreational fishery or as brood ponds. American Lake, Spanaway Marsh, and the Nisqually River are also part of the nesting and wintering areas for the bald eagle. A great blue heron nesting colony is located in trees at Bell Woods near American Lake.

115. Wetlands. All cover types classed as wetlands are shown in Plate 63. Not all the wetlands on Fort Lewis are in terrain that produces a NOGO condition for vehicles, and some are divided between NOGO areas and areas of potential traffic. Those 36 wetlands that are not completely encompassed by the most conservative NOGO condition (8X8 wheeled vehicle, dry conditions, 10 passes) are listed in Table 6 by their map coordinates, training area, and wetland type. Under dry conditions, the vehicles of all three force structures can access these wetlands. They are also accessible under wet conditions by the 4-3-3 (8X8) and 3-3-5 force structures. The 5-5-0 can enter these wetlands under a low and medium number of passes only.

116. Spanaway Marsh encompasses a nesting and wintering area for the bald eagle, and the Nisqually River and American Lake provide eagle fishing

Table 5

Biota of Special Interest, Reason for Interest, and Preferred Cover Types

Common and Scientific Name	Reason for Interest	Preferred Cover Type
PLANTS AND ASSOCIATIONS		
White-topped aster, Aster curtus	Federal Candidate, State Sensitive	Natural grasslands
Small-flowered trillium, Trillium parviflorum	State Sensitive	Several wooded or brushy cover types
Idaho fescue grassland, Festuca idahoensis	WNHDS Listings, Natural Feature	Natural grasslands
Douglas fir forest, Pseudotsuga menziesii	WNHDS Listing, Natural Feature	Coniferous forest
Oregon white oak woodland, Quercus garryana	WNHDS Listing, Natural Feature	Deciduous forest
Lodgepole pine forest, Pinus contorta	WNHDS Listing, Natural Feature	Coniferous forest
Quaking aspen forest, Populus tremuloides	WNHDS Listing, Natural Feature	Deciduous forest
Douglas fir/snowberry-oceanspray community, Symphoricarpos spp., Holodiscus discolor	WNHDS Listing, Natural Feature	Coniferous forest
Bigleaf maple - black cottonwood forest, Acer macrophyllum-Populus trichocarpa	WNHDS Listing, Natural Feature	Deciduous forest
Ponderosa pine - douglas fir forest, Pinus ponderosa	WNHDS Listing, Natural Feature	Coniferous forest
Low elevation freshwater wetland	WNHDS Listing, Natural Feature	Emergent marsh

(Continued)

(Sheet 1 of 3)

Table 5 (Continued)

Common and Scientific Name	Reason for Interest	Preferred Cover Type
ANIMALS		
Western pond turtle, *Clemmys marmorata*	Federal Candidate, State Threatened	Water, wetlands, and edges (shorelines)
Great blue heron, *Ardea herodias*	Under consideration for State listing, featured species	Forests, wetlands, water
Green-backed heron, *Butorides striatus*	Under consideration for State listing,	Wetlands, water
Osprey, *Pandion haliaetus*	Under consideration for State listing, featured species	Coniferous and mixed forests, water
Bald eagle, *Haliaeetus leucocephalus*	Federal Threatened, State Threatened, Featured species	Coniferous forest, water
Streaked horned lark, *Eremophila alpestris strigata*	Under consideration for State listing	Grasslands
Purple martin, *Progne subis*	Federal Sensitive	Wetlands
Western bluebird, *Sialia mexicana*	Federal Sensitive	Edges between forests and open areas
Oregon vesper sparrow, *Pooecetes gramineus affinis*	Under consideration for State listing	Grasslands
Pacific water shrew, *Sorex bendirii*	Under consideration for State listing	Forested swamps, water
Western gray squirrel, *Sciurus griseus*	Under consideration for State listing	Deciduous and mixed forest
Black-tailed deer, *Odocoileus hemionus columbianus*	Featured species	Edges of all cover types

(Continued)

(Sheet 2 of 3)

Table 5 (Concluded)

Common and Scientific Name	Reason for Interest	Preferred Cover Type
Ruffed grouse, *Bonasa umbellus*	Featured species	Edges, deciduous and mixed forest, wetlands
Wood duck, *Aix sponsa*	Featured species	Deciduous and mixed forest, wetlands water
Coastal cutthroat trout, *Oncorhynchus clarki*	Migratory	Maintained in lakes Sea-run in Nisqually and tributaries
Rainbow trout (steelhead) *Oncorhynchus mychiss*	Managed species	Landlocked in lakes Sea-run in Nisqually and tributaries
Kokanee (landlocked sockeye salmon), *Oncorhynchus nerka*	Managed species	American Lake
Chum salmon, *Oncorhynchus keta*	Migratory	Sea-run in Nisqually and tributaries
Coho salmon, *Oncorhynchus kitsutch*	Migratory	Sea-run in Nisqually and tributaries
Chinook salmon, *Oncorhynchus tshawytscha*	Migratory	Sea-run in Nisqually and tributaries
Pink salmon, *Oncorhynchus gorbuscha*	Migratory	Sea-run in Nisqually and tributaries

(Sheet 3 of 3)

Table 6

Location and Type of Wetland Not Encompassed by the Disturbance NOGO Condition

Training Area Number	UTM Coordinate	Wetland Name	Wetland Type*
A East	311220	Curry woods	OW
A East	308229	Farrell Marsh	SS
2	300172	Sequalitchew Lake	OW
2	290175	Unnamed**	FO/SS
4	272093	Unnamed	OW
4	259117	Unnamed	SS/FO
4	267099	Unnamed	SS/FO
4	272130	Unnamed	SS/FO
4	320105	Unnamed	FO/OW
6	328078	Unnamed	FO/OW
6	330070	Unnamed	FO/OW
6	332054	Brandenberg Marsh	EM/OW
7	360160	Unnamed	SS
8	390148	Unnamed	SS/OW
9	415159	Unnamed	FO/OW
11	446092	Unnamed	SS/FO
12	374091	Johnson Marsh	OW
12	380091	Johnson Marsh	OW
12	370080	Johnson Marsh	FO/SS
15	431068	South Creek	OW
15	426070	South Creek	OW
16	330035	Lewis Lake	OW
18	282031	Unnamed	FO/FD
19	260010	Unnamed	FO/OW
19	269021	Unnamed	FO
20	244014	Unnamed	OW/FO
20	239006	Unnamed	OW/FO
20	234991	Unnamed	OW/EM
20	229990	Unnamed	FO/OW
22	190980	Unnamed	SS
23	234012	Unnamed	FO/OW
23	162990	Unnamed	SS/EM
23	170988	Unnamed	OW
23	150993	Unnamed	FO/SS
23	164964	Unnamed	OW
23	174991	Unnamed	EM

* See Tabs 1 and 2 for wetland type symbol definitions.

** Unnamed wetlands may have a name not found on the Fort Lewis Special Map.

areas. All wetlands on Fort Lewis are expected to have value for several of the species of interest noted in Table 5.

117. Special habitats. In addition to sites for salmon, eagles, and herons, the vicinity of an osprey nest in training area 20 and prairies with white-topped aster in training areas 7, 20, 21, and 22 are of special concern. These are located on Plate 62.

Impact Assessment

Introduction

118. The primary impacts addressed in this study related to the alteration or destruction of soil structure and vegetation and subsequent effects on fish and wildlife caused by the different vehicle force structures. The disturbances from traffic, as reported in earlier parts of this report, represent the worst case scenario; i.e., all but the obvious exclusions (e.g., impact areas, Weir Prairie) are assumed to be affected. Because of practical constraints such as the narrow access point to training area 16 (Plate 61) and the difficulty of maneuvering in wetland soils, the actual impact may occur on a much smaller percentage of the area. However, cumulative impacts on soils and vegetation from repeated use could bring the total impact on a localized area to 100 percent. Because of these ambiguities, specific acreages and locations are not reported; indices and percentages are used to show relative impacts among the various force structures.

Basis for impact assessment

119. Soil, plants, and animals are closely related to each other. Climate and the chemical and physical properties of the soils in large part determine the form and species composition of plants that will be supported on the site, and biotic processes of the plants alter the soil over time. Activities of animals also affect soil properties, e.g., burrowing by earthworms and moles aerates the soil and increases fertility and organic matter (Brady 1974).

120. Direct effects of traffic on the soil include compaction (Merriam and Smith 1974, McEwen and Tocher 1976, Dawson, Countryman, and Fittin 1978, Goran, Radke, and Severinghaus 1983) and physical rearrangement or loss of soil layers, e.g., reduction or removal of organic matter (McEwen and Tocher 1976, Goran Radke, and Severinghaus 1983). Indirect impacts include decreased

pore space and water availability, decreased water infiltration, and increased run-off and erosion (McEwen and Tocher 1976, Goran, Radke, and Severinghaus 1983). These effects depend on the characteristics, timing and intensity of traffic, with impacts generally increasing as traffic approaches a threshold. After that threshold is reached, no additional direct damage occurs. For example, once compacted, the soil does not respond to additional traffic with additional compaction (Cole 1979, Goran, Radke, and Severinghaus 1983, Merriam and Smith 1974, McEwen and Tocher 1976). Under dry conditions, disturbance from the 3-3-5 and 4-3-3 (8X8) force structures does not increase from 50 to 1,000 passes (Figures 3 and 4). However, indirect impacts su as erosion can continue to increase.

121. In addition to the impacts of soil disturbance on plants, the removal of vegetation <u>without</u> significant soil disturbance can affect various site characteristics. Above ground vegetation and associated roots protect and hold the soil in place. Vegetation removal typically results in loss of soil nutrients, decreased fertility, reduction or elimination of the humus layer, soil instability and increased erosion. A one-time vegetation removal event may require years for the soil/site conditions to equilibrate.

122. The model used to predict soil disturbance from vehicles does not consider compaction, so this impact cannot be quantified. Compaction from any source (wildlife or hiking trails, vehicles) negatively affects plants by reducing soil aeration and moisture-holding capacity so that plant growth is reduced or eliminated. Compaction by motorized/mechanized vehicles can restrict plant growth, although it is difficult to quantify (Lacey and Severinghaus 1981). Effects on animals that live below the surface include death or displacement, depending on the severity of compaction. High soil moisture decreases soil resistance to compaction because water acts as a lubricant, thereby increasing the ability of soil particles to move and lodge against each other (McEwen and Tocher 1976, Sheehan and Clampitt 1984). However, the negative effects of this compaction may in some cases be offset by the ponding effects (see paragraph 100). The root zone of a tree extends a minimum of 10 yd from the trunk (Spurr and Barnes 1980) and intermingles with those of other trees. If those roots are affected, thereby affecting growth, nearly any area within a forest is susceptible to damage from traffic. Generally, bottomland species can tolerate more compaction than upland species (Merriam and Smith 1974, Dawson, Countryman, and Fittin 1978).

123. Direct effects on vegetation include crushed or exposed roots (Merriam and Smith 1974, McEwen and Tocher 1976), crushed or broken vegetation, immediate death, inability of roots to penetrate compacted soil (Goran, Radke, and Severinghaus 1983, Environmental Laboratory 1986), and disrupted building of root reserves (Sheehan and Clampitt 1984, Wilson 1988). Areas being cleared for mechanized use experience 80 percent injury to limbs, roots, or trunks during the felling process (Severinghaus, Riggins, and Goran 1979). Under conditions of heavy disturbance with deep rutting that destroys the rooting zone, little or no vegetation can grow. Indirect effects of traffic on vegetation are reduced plant vigor and photosynthetic efficiency from physical damage (Severinghaus, Riggins, and Goran 1979, Goran, Radke, and Severinghaus 1983), reduced resistance to drought and cold from a shallow root system, and delayed death because of loss of vigor and tolerance to adverse conditions.

124. In addition to direct and indirect effects on specific plants, changes in species composition and dominance occur. Disturbance alters the competitive advantage of native species by generally favoring exotics (Cole 1979, Goran, Radke, and Severinghaus 1983, Sheehan and Clampitt 1984, Wilson 1988). Plants with short growth forms are favored by removing shading which would otherwise reduce growth rate (Wilson 1988). Those with little tolerance for direct sunlight are negatively affected by reduced shading (Johnson and McCormick 1979, Johnson et al. 1985).

125. Minor disturbance results from one-time traffic, with impacts primarily to surface vegetation (Landin and Doerr 1983, Goran, Radke, and Severinghaus 1983). Further disturbance results in break down of organic matter and removal of the top layers of soil. With increased disturbance, sensitive plant species are destroyed, and vegetation composition shifts to those species that are tolerant of disturbance. In Douglas fir forests, the surface and litter layers provide a microenvironment necessary for recruitment of new trees (Spies and Franklin 1988); destruction of these features will affect species composition of the stand over time.

Prediction of vegetation loss

126. One way to estimate the effects of traffic on vegetation associations is to examine their structural complexity. Several regional studies in a large number of vegetation associations have shown the importance of complexity to the quality of these ecosystems (e.g., Thomas et al. 1979, Brown

1985); one way to describe complexity is with the number of layers present. Short (1984) found a strong relationship between the number of vertical layers present and the potential number of wildlife species that could be supported on site. Other studies have shown that a higher number of layers allows more habitat complexity, and that basically "more is better". More complexity refers to the maximum number of layers for each type; e.g., the maximum number of layers in grassland is less than in mature forest. That does not reduce the importance of the grasslands as a cover type and wildlife habitat.

127. Eight layers have been identified on Fort Lewis that contribute to habitat quality by increasing complexity when they are present and functioning. The soil and vegetation layers and identifying numbers are:

1 subsurface	5 midstory
2 surface	6 subcanopy
3 litter	7 canopy
4 understory (herbaceous)	8 tree bole

In addition to their ecological significance, these layers can be used to quantify and understand impacts. The maximum number of layers identified is eight. Each layer may or may not be present at a single point on the ground; e.g., immature forests may have a sparse midstory and understory because of too much shading. But within a sampling plot in a mature or older forest stand in optimum condition, all eight will be represented.

128. The subsurface includes the root zone; for example, the Spanaway and Everett soils have "many very fine roots" in the top 18 in. of soil (USDA 1979). The subsurface also has a large population of associated invertebrates and burrowing animals. The surface is a very thin layer, perhaps with a layer of humus 1 in. thick. The litter layer in a grassland includes down and dead grass, while in a forest it includes fresh leaves, sticks, logs, and low-growing plants such as fungi. The understory layer in a forest and shrubland includes herbaceous vegetation and low woody shrubs less than 3 ft tall. In a grassland, the understory is the uppermost layer ("canopy"). The midstory layer is present in shrublands and forests, and includes shrubs and young trees. The subcanopy is composed of trees whose foliage has not yet reached the overstory, and the canopy is made up of the tallest, most mature trees. The tree bole is considered a layer because it provides a surface for wildlife use and it can be affected by vehicles.

129. The number of layers potentially present in each cover type and thought to be affected by disturbance are in Table 7. The 13 classes remaining (minum urban) in the area of potential traffic (Table 4) were reduced to three for calculations in predicting impact. All wetland types and open water were excluded because of their sensitivity to disturbance and high fish and wildlife value (environmental NOGO areas*). Bare ground was excluded because of its transient nature, small extent, and low wildlife value. Shrubland and young forest types were combined because of their similar structure, as were the three forest types and the three grasslands. Combining all forest types is simplistic but also realistic because vegetation is highly variable over time and space, and is affected by management and natural events. For example, a typical deciduous forest has fewer layers than a coniferous forest, but logging practices or a hot fire can temporarily reverse that (Hall et al. 1985).

130. It is assumed that the surface, subsurface, litter and understory layers will each respond to disturbance in the same way, and that all woody layers will respond in the same way. Because of a positive relationship between disturbance level and number of passes, it is assumed that a positive relationship to opportunity for damage exists. In minimum and slight disturbance, there is insufficient traffic to cause loss to the woody layers above the shrub layer. But with moderate disturbance, the opportunity is greater so the probability also rises and damage to the tree bole is expected. It is also assumed that there is no significant vegetation and soil recovery between passes.

131. To predict the relative impact of each force structure, Table 8 was constructed based on the percentage of vegetation that might be lost in each level of disturbance. These percentages were based on personal observations, studies at other installations, and literature on recreation impacts. Percentages were the same across cover types with the exception that they were increased for Layers 1 through 4 in trees, reflecting greater damage to those components in shaded areas than in open areas (Cole 1979).

132. The rationale for the predicted losses includes the following. Bury, Lukenbach, and Busack (1978) reported in Sheridan (1979) that "moderate"

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* Environmental NOGO areas are not equivalent to soil disturbance NOGO areas referred to in other sections of this report.

Table 7

Layers Present and Thought to be Affected by Disturbance

Distrubance Level	Grasses (4)	Shrubs (5)	Trees (8)
Minimal*	3,4	3,4,5	3,4,5
Slight*	2,3,4	2,3,4,5	2,3,4,5
Moderate	1-4	1-5	1,2,3,4,5,8
High	1-4	1-5	1-8
Severe	1-4	1-5	1-8

* Data were not available to determine if Layer 1 is affected by these levels of disturbance; excluding it may be a conservative decision.

Table 8

Predicted Percent Loss of Vegetation by Disturbance Level and Layers

Disturbance	Dry-Normal		Wet-Slippery	
Level	Layers 1-4	Layers 5-8	Layers 1-4	Layers 5-8
Minimal	10	5	25	10
Slight	25	15	50	30
Moderate	50	30	100	75
High	100	75	100	100
Severe	100	100	100	100

and "heavy" off-road vehicle use reduced shrub biomass by an estimated 50 and 70 percent, respectively. In areas of concentrated activity, 95 percent loss occurred. Goran, Radke, and Severinghaus (1983) reported that vegetation was disturbed to a greater degree during the wet cycle at Fort Riley, Kansas. Herbaceous vegetation in open woodlands or in meadows is less susceptible to trampling than herbaceous vegetation in forest shade (Cole 1979, McEwen and Tocher 1976). Damage to shrubs and forbs is greater than to grasses because of morphological differences and resilience, and recovery of understory vegetation in open areas is faster than in shaded areas (Cole 1979).

133. For each disturbance level, the magnitude of the impact on each cover type was obtained by applying the percent loss of vegetation in Table 8 to each affected layer within each cover type (Table 7). The percentages for all layers within a disturbance level were added and then divided by the total percentage available (number of vegetation layers × 100) to obtain a weighting factor. For example, the impact of minimal disturbance to shrubs in dry weather would be:

Layer 3 = 10 percent	Total layers available = 5
Layer 4 = 10 percent	Total percentage available = 500
Layer 5 = 5 percent	

Total = 25 percent
Therefore, the weighting factor = 25/500 = 0.50.

Table 9 shows the weighting factors by disturbance level for each cover type. These weighting factors will be used to establish an index of relative impact.

<u>Comparison among force structures</u>

134. The index of disturbance between wet and dry conditions for each force structure and cover type is shown in Tables 10, 11, and 12. The 3-3-5 force structure was used as the baseline for comparing relative impacts of the proposed force structures. The following calculations were used to establish the index:

Acres for Index = (percent of area in disturbance level from Tables 1-3) × (area of potential traffic from Table 4) × (weighting factors from Table 9).

The acreage obtained in each disturbance level was then totaled for each cover type and divided by the baseline for that same cover type to produce the index of relative impacts within each cover type. Weighting factors and relative impacts cannot be compared among cover types because no judgment could be

Table 9

Weighting Factors for Distrubance Levels

Distrubance Level	Cover Type Grasses	Shrubs	Trees
Dry			
Minimal	0.050	0.050	0.031
Slight	0.188	0.180	0.113
Moderate	0.250	0.500	0.325
High	1.000	0.950	0.875
Severe	1.000	1.000	1.000
Wet			
Minimal	0.128	0.120	0.075
Slight	0.375	0.360	0.225
Moderate	1.000	0.950	0.688
High	1.000	1.000	1.000
Severe	1.000	1.000	1.000

Table 10

Relative Impacts of Force Structure on Grasslands

Dry Conditions

Force Structure	Scenario (Passes) Low (10)	Medium (50)	High (1,000)
3-3-5/4-3-3 (HMMWV)	1.00	1.00	1.00
4-3-3 (8X8)	1.03	1.08	1.07
5-5-0 (M60A3)	3.46	1.24	4.79

Wet Conditions

Force Structure	Scenario (Passes) Low (10)	Medium (50)	High (1,000)
3-3-5/4-3-3 (HMMWV)	1.00	1.00	1.00
4-3-3 (8X8)	1.67	2.05	1.05
5-5-0 (M60A3)	3.98	1.84	0.93

Table 11

Relative Impacts of Force Structure on Shrublands

Dry Conditions

Force Structure	Scenario (Passes) Low (10)	Medium (50)	High (1,000)
3-3-5/4-3-3 (HMMWV)	1.00	1.00	1.00
4-3-3 (8X8)	1.06	1.07	1.06
5-5-0 (M60A3)	3.34	2.59	4.77

Wet Conditions

Force Structure	Scenario (Passes) Low (10)	Medium (50)	High (1,000)
3-3-5/4-3-3 (HMMWV)	1.00	1.00	1.00
4-3-3 (8X8)	1.68	2.03	1.08
5-5-0 (M60A3)	3.97	1.93	0.98

Table 12

Relative Impacts of Force Structure on Forests

Dry Conditions

Force Structure	Scenario (Passes) Low (10)	Medium (50)	High (1,000)
3-3-5/4-3-3 (HMMWV)	1.00	1.00	1.00
4-3-3 (8X8)	1.06	1.08	1.07
5-5-0 (M60A3)	3.38	2.67	6.93

Wet Conditions

Force Structure	Scenario (Passes) Low (10)	Medium (50)	High (1,000)
3-3-5/4-3-3 (HMMWV)	1.00	1.00	1.00
4-3-3 (8X8)	1.69	2.21	1.28
5-5-0 (M60A3)	4.61	2.88	1.36

made on the relative value of each layer to each cover type. Each cover type is shown in its own table.

135. Tables 10, 11, and 12 should be viewed in a relative sense and all comparisons should be made only within columns by condition (sets of three). Comparisons between columns (scenarios) are invalid due to the use of different baselines. Under dry conditions, within each scenario and for all three cover types, the amount of impact increases only slightly for the 3-3-5 force structure to the 4-3-3 (8X8) force, which seems to indicate the HMMWV and 8X8 wheeled vehicle will impact all three cover types similarly. However, impact increases to a greater degree for the 5-5-0 force structure, in which tracked vehicles are dominant.

136. Under wet conditions, the analysis is more complicated. In a low-use scenario, the relative impacts increase in the same manner for all three cover types as they do for dry conditions, although the magnitude is larger. This same pattern is also seen in Fort Lewis forests for medium-use and high-use scenarios. However, for grasslands and shrublands under medium-use and high-use scenarios, the impacts increase with the 4-3-3 (8X8) force and then decrease slightly for the 5-5-0 force. We feel this may be explained by one or more factors. First, there may be some threshold values being met, resulting, for example, in no difference in disturbance levels between the medium and high-use scenarios in the north half of Thirteenth Division Prairie. Second, since the amount of NOGO acreage increases under wet conditions, the acreage to which the index applies decreases. Third, as mentioned previously, soils compact more easily under wet conditions than under dry conditions. Thus, the absolute damage is greater under wet conditions than dry conditions. The index used is relative to "baseline" conditions, the baseline being the 3-3-5 force structure. Under wet conditions and at high use (1,000 passes), the damage from each force structure is so great that there is little difference in relative impact values. This same situation holds true for the medium use scenario (50 passes) although the 4-3-3 (8X8) force structure, possibly due to greater weight per contact area (psi), shows greater relative impacts than either 3-3-5 or 5-5-0 force structures.

Effects on plants

137. The biota listed in Table 5 will be affected based on where they occur relative to access by vehicles. Each listed plant species, community,

or animal is briefly discussed below. Impacts are based on the direct and indirect effects of traffic such as damage to trees by vehicles.

138. White-topped aster (Aster curtus). This aster is a perennial forb endemic to native grasslands of the Puget Trough and Williamette Valley. Restricted primarily to glacial outwash prairies, the prairies of Fort Lewis support the largest known population of this species. The two major threats to the aster are the use of tactical vehicles in military maneuvers and the encroachment of woody species, primarily Douglas fir and Scotch broom (Cytisus scoparius) on the prairie.

139. Studies at Fort Lewis have identified Idaho fescue grasslands as the preferred habitat for the white-topped aster (Sheehan and Clampitt 1984). Gaps between fescue clumps allow forbs, including the aster, to occur. However, degradation of the prairie results in sod-forming grasses that eliminate these gaps, thereby reducing the forb component. The largest populations of this plant are associated with those prairies with least disturbance. Analysis of the relative impacts of soil disturbance and fire has concluded that disturbance adversely impacts the aster but fire has a positive impact. Controlled fires are beneficial in reducing invasion by woody species.

140. The white-topped aster colonies occurring in the Ranier Training Area are protected from mechanical disturbance by being designated off-limits. Any change of the status that would allow vehicles into the training area would have a detrimental impact on the white-topped aster, with the magnitude of impact dependent upon the type and amount of traffic. There are an additional 15 colonies on Fort Lewis, although 13 are very small (Sheehan and Clampitt 1984). A colony at the North Gate is in an off-limits area, but an estimated 18,000 plants on 20 acres at the McChord South Gate are accessible to traffic.

141. Small-flowered trillium (Trillium parvifolium). This plant occurs from Pierce and Thurston Counties in Washington south to northern Oregon. It occurs in damp hardwoods or mixed forests, usually with dense shrub undergrowth. It is typically found in an ecotone between upland Douglas fir and a riparian zone. Reclassified by Soukup (1980), this species has been misclassified Trillium albidum, found primarily in Oregon, or T. chloropetulum, found in British Columbia. The exact location of these plants on Fort Lewis is not available, but they are in the vicinity of the 13th Division Prairie. If they

occur along Muck Creek or another stream, they may be protected because of NOGO conditions, or may be near a river crossing site.

142. Idaho fescue grassland (Festuca idahoensis). Native prairies are a distinctive feature of the Puget Sound area. The occurrence of prairies is thought to be due to (a) the presence of droughty, coarse soils derived from glacial outwash, (b) frequent buring by natural causes, Indians, and early settlers (Franklin and Dyrness 1973). Since settlement, the extent of this type has decreased due to fire exclusion, overgrazing, and conversion to other uses. An important aspect of this prairie is that it is the preferred habitat for the white-topped aster, and the Weir prairie on Fort Lewis represents one of the larger extents of this type. This association is used by the WNHDS as an indicator for the possible presence of aster colonies. Impacts of vehicular disturbance are negative, resulting in the fescue decreasing and other species, primarily scotch broom, increasing. The ability of this prairie to support aster populations decreases with disturbance, so the off-limits designation for Johnson and Weir Prairies is beneficial.

143. Douglas fir forest (Pseudotsuga menziesii). Half of Fort Lewis is composed of coniferous forest, and Douglas fir constitutes about 90 percent of the coniferous forest. In addition to occurring in extensive stands, Douglas fir is invading many prairie sites, aided by fire-control efforts. The location of the listed community is the forest land around Weir Prairie. The primary reason for this community appearing on the sensitive list is that it is representative of significant natural vegetation. It is doubtful that this community type per se is threatened.

144. Due to the extent of this type, it is difficult to envision military maneuvers at Fort Lewis as having a profound impact on its status (e.g., becoming sensitive, threatened, or endangered). However, tank and other vehicular activity can definitely injure tree trunks, destroy young seedlings, and compact soil, thereby having a long-term impact on Douglas fir recruitment and health in individual stands. For example, young seedlings are an important part of timber management at Fort Lewis and shelterwood cuts are made specifically to encourage natural regeneration. The spacing of these cuts (35-50 ft) creates an ideal situation for use by heavy vehicles. Overall, damage to young seedlings either natural or planted, could have a large impact on forest management.

145. Oregon white oak woodland (Quercus garryana). Oregon white oak groves are a notable feature of the Puget Sound which are not common elsewhere (Franklin and Dyrness 1973). The gravely soils are sufficient droughty to allow Oregon white oak to occur; they exist in numerous locations throughout the installation. Two specific occurrences of this community at Fort Lewis are as follows:

a. Oak savanna with prairie. According to Washington Department of Natural Resources, not much of this type remains. This example occurs in the Weir Prairie and is therefore in the off-limits area; it will not be affected by traffic.

b. Oak shrub. This oak community is located on Monette Hill and is probably an edaphic climax due to droughty soils. Although significant acreage of oak shrub exists in Washington, most areas are degraded, and only one preserve exists of this type. Effects of maneuvers on this community could be high. It is accessible by all force structures and will receive severe disturbance with the 5-5-0 force and some disturbance by the others.

146. Lodgepole pine (Pinus contorta). Lodgepole pine stands are scattered through the Puget Trough, associated with prairies or wetlands. The stand listed includes trees that are "very large and, presumably very old" (Chilcote et al. 1976) located along Spurgeon Creek. The priority of this listing is low, however, and more suitable representatives of this type may be found.

147. Quaking aspen (Populus tremuloides). Quaking aspen is rarely found in western Washington (Franklin and Dyrness 1973). One community was identified by the Washington Natural Heritage Program; it occurs along Spurgeon Creek in proximity to the lodgepole pine community. It is listed primarily because of its rare occurrence in this general area. Access to this type is not possible by vehicles representing the 5-5-0 force structure. Both types of wheeled vehicles can reach the area and cause minimal to moderate disturbance. Additional communities were identified by the Fort Lewis Forestry staff at grid coordinates 251114, 383098, 421109, 258025, and 224000. The communities at 422110 and 259023 are located in soil disturbance NOGO areas under all conditions and will receive no disturbance. The community at 382099 will only receive minimal disturbance for the 3-3-5 force structure wet/dry 10 passes and the 4-3-3 (8X8) dry 10 passes. The communities at 251112 and 223000 will receive minimal to slight disturbance under dry conditions for the 3-3-5 and 4-3-3 (8X8) force structures. Also, under dry

conditions for the 5-5-0 force structure, the community at 251112 will receive no disturbance while the 223000 community will receive slight to moderate disturbance. Under wet conditions, the community at 251112 will receive minimum to moderate disturbance for the 3-3-5 force structure, slight to high disturbance for the 4-3-3 force structure and no disturbance (NOGO) for the 5-5-0 force structure. The 223000 community will receive minimum to moderate, slight to high, and moderate to severe disturbance for the 3-3-5, 4-3-3 (8X8), and 5-5-0 force structures, respectively.

148. Douglas fir/snowberry-oceanspray. This community, next to an oak woodland at Monette Hill, may be one of five known occurrences in Washington. Though a rare type, this location is of poor quality, and Douglas fir is considered climax due to the droughty soils. The status and exact nature of this commuity requires field verification which is scheduled for January 1990 (Personal Communication, Mr. Rex Crawford, Washington Natural Heritage Program, 1 Nov 89).

149. Red alder (Alnus rubra). This community occurs on moist sites in nearly monotypic stands and is the principal hardwood species of Fort Lewis. It is actively managed by the forestry staff, and it is second only to Douglas fir in importance, quantity, and extent. Current management practices consist of maintaining red alder on good sites, but converting marginal sites to Douglas fir. The most extensive stands of this community occur on the Rainer Training Area. Due to logistical constraints of accessing this area, training has historically been less than on the northern portion of Fort Lewis. The impact of training on red alder will depend largely on the amount of training which occurs in the Rainer Training Area.

150. Bigleaf maple-black cottonwood. This type occurs along streambanks and in moister sites. The community listed constitutes a riparian strip along the Nisqually River at Carter Woods. Most accessible Pacific Northwest riparian forests have been degraded (Mutz et al. 1988, Johnson and Jones 1977, Raedeke 1988) but this community is of sufficient quality that it is "not likely to be duplicated elsewhere" (Chilcote et al. 1976). Vehicles can maneuver in the land between the bluff and the river and cause impacts.

151. Ponderosa pine-douglas fir forests. This is one of the few, and perhaps the only, ponderosa pine stands in western Washington. Ponderosa pine generally invades prairies, to be eventually replaced by Douglas fir. Without management such as selective logging and controlled burning, this will occur

on Fort Lewis; maintaining the pine will require identifying and protecting prairies where ponderosa pine is invading.

152. Low elevation freshwater wetland. According to Franklin and Dyrness (1973), there are abundant poorly drained sites in the Puget Sound area. The largest low elevation freshwater wetland on Fort Lewis is Spanaway Marsh, a herbaceous Douglas spirea (Spiraea douglasii) marsh. The area is significant because of its size, although it has had some disturbance (Shea 1981). It is encompassed by a disturbance NOGO.

Effects on animals

153. Western pond turtle (Clemmys marmorata). Habitat includes all bodies of water on Fort Lewis (Brown 1985), although it has "not been sighted in the recent past" on the installation (Directorate of Engineering and Housing 1984). It lays eggs in moist soil and sand on shorelines. Water is assumed off-limits to vehicles and the shorelines are usually wet or wetlands, so no impact to the turtle is predicted because of a lack of vehicle access.

154. Great blue heron (Ardea herodias). One heronry was identified by Fort Lewis wildlife personnel as being active in 1987 but not in 1988. The heronry appears to be nearly encompassed by the disturbance NOGO condition for all force structures (see Plate 62). There is no current training next to the heronry and little evidence of past training use (Adams, personal communication, 19 April 1990). The majority of the herons' diet is fish, obtained from shallow water, e.g., mudflats, marshes, lake borders. They also eat a variety of other vertebrates from wetlands and occasionally adjacent uplands. Some great blue heron colonies can become habituated to human disturbance, but even then they have a tolerance level beyond which their feeding and reproductive activities are interrupted and therefore reproductive success reduced. Short and Cooper (1985) recommended the following guidelines. For optimum feeding conditions year-round, there should be no disturbance for 4 hrs after sunrise or 4 hrs prior to sunset, or human activities should not occur within 110 yd (or slow-moving vehicles within 55 yd). During the nesting season, tolerance to human disturbance is greater if the activity is on water than on land; Vos, Ryder, and Graul (1985) recommended a disturbance-free zone of 165 yd on water and 275 yd on land.

155. Green-backed heron (Butorides striatus). This species is closely tied to wetlands and water, both of which should be protected from vehicle activity. Nesting may be either solitary or colonial (Landin 1985); isolated

nests are occasionally in non-wetlands vegetation, but would be difficult to locate and protect.

156. Osprey (Pandion haliaetus). The osprey requires lakes and rivers for feeding and large trees for nesting. A nest in coniferous forest near Finander Lake has been successful for several years. Access is possible by vehicles in all three force structures, but access by currently used vehicles has not affected nest success to this time. Effects of disturbance on the osprey are highly variable, probably differing with individual birds and their past experience (Henry 1986).

157. Bald eagle (Haliaeetus leucocephalus). The wintering and nesting area at American Lake (Plate 59) is in an off-limits designation or urban and off-post in all directions except the southwest, where it joins training area 2. Under the best conditions for vehicle mobility (wheeled vehicles, dry conditions), training area 2 is 60 percent impassable. Therefore, little impact to the eagle from other force structures in that area should occur. The Spanaway Marsh site is half included in a NOGO condition and half coniferous forest and accessible. Traffic in the accessible area could cause minimal to severe disturbance and could, therefore, impact the eagle. Impacts on eagles from human intrusion depend on the time of year, distance between the bird and humans, and effective distance between the two (screening) (Stalmaster et al. 1985). The large wintering and nesting area along the Nisqually River can be maneuvered in if vehicles can get there, so a negative impact may be possible. The eagle area along Muck Creek is in the impact area.

158. Streaked horned lark (Eromophila alpestris strigata). This species is an inhabitant of grasslands interspersed with open areas, and it nests on the ground (Bent 1926). Vehicle traffic will affect it by increasing the extent and percent of bare ground which reduces nesting area and production of food (seeds and inverterbrates). The inconspicuous nests may be destroyed by vehicles.

159. Purple martin (Progne subis). In the Pacific Northwest, the purple martin nests near water and feeds on insects near and over water. The potential change in force structure at Fort Lewis will not affect this species if wetlands and water are protected from vehicles access.

160. Western bluebird (Sialia mexicana). Preferred habitat for the western bluebird is open areas with scattered trees, such as the edges of

grasslands with invading woody vegetation. Habitat features of perches, nest sites, and adequate vegetative cover for production of invertebrates for food are needed (Verner and Boss 1980). No negative impact on the western bluebird is expected; the extent of suitable habitat may increase with vehicle disturbance that increases edge. The nest box program on Fort Lewis is also beneficial.

161. Oregon vesper sparrow (*Pooecetes gramineus affinis*). This bird prefers grasslands and early successional stages without shrubs, so the grassland and cleared grassland cover types should provide the best habitat on Fort Lewis. However Tab 1 indicates, many grassland areas are being invaded by woody vegetation. Food of the vesper sparrow includes insects, spiders, and seeds (Verner and Boss 1980), which are produced in areas with adequate herbaceous cover. As the extent and percent of bare ground increase, food items will decrease. The vesper sparrow nests on the ground, so nesting will also be affected by reduced herbaceous cover and some vehicle movement. Degradation of the prairie through invasion of woody species or increases in extent of bare ground will negatively affect this species.

162. Pacific water shrew (*Sorex bendirii*). This small mammal eats aquatic insects and invertebrates found near the water (Maser et al. 1981). It is a riparian forest species which probably nests in the forest. Its extent of movement is expected to be small, so protection of near-bank vegetation and streams from traffic should eliminate any impacts from the proposed change in force structure.

163. Western gray squirrel (*Sciurus griseus*). Deciduous or mixed forests in the uplands and riparian zones provide all habitat requirements for this species. Impacts from training are expected to be minor or nonexistent, because the layers on which squirrels depend are not affected by most traffic.

164. Black-tailed deer (*Odocoileus hemionus columbianus*). This is a species of coniferous and mixed forest edge. Habitat requirements given by Wallmo (1978) include early stages of plant succession with both browse and grasses and a mixture of plant communities. Management for the deer is compatible with disturbance such as fire and logging, so vehicle disturbance that does not destroy the vegetation will also provide benefits. Some impact within the forests would occur from loss of the understory and midstory layers which provide cover and some food, if no regeneration occurred. Deer in Minnesota were displaced from their ranges by a response to even low level

disturbance from snowmobiles, although habitation occurred to some degree (Dorrance, Savage, and Huff 1975). A similar response probably occurs to military vehicles.

165. Ruffed grouse (*Bonasa umbellus*). Adequate food, cover, and nest sites for this species on Fort Lewis are found in forests that possess a mixture of stand ages. Impacts from traffic would be on the understory and midstory components, primarily affecting protective cover, and the herbaceous and shrub layer in openings which would reduce the food supply of insects for young grouse.

166. Wood duck (*Aix sponsa*). The wood duck is a cavity nester (either in large trees or nest boxes) that requires shallow water and understory cover in proximity. It also feeds in wetlands. Excluding vehicles from all wetland types would negate any impact from the proposed action.

167. Fish. The 15 managed fish species which occur at Fort Lewis can be categorized into those species stocked and managed in land-locked lakes such as American, Lewis, and smaller lakes, and those species that are sea-run. Two species of trout, the rainbow (*Oncorhynchus mychiss*) and the cutthroat (*Oncorhynchus clarki*), occur under two conditions: (a) in stocking programs in land-locked lakes for recreational fishing, and (b) as native, sea-run species that spawn in the Nisqually River tributaries. As sea-runs, cutthroats are referred to as coastal cutthroats and rainbows are referred to as steelheads. While these species are intolerant of turbidity with greater than 10 percent fines (Raleigh et al. 1984) and of in-water disturbance on their spawning beds, they tolerate lake and stream conditions well enough to provide recreational fishing at Fort Lewis. Any training activity that would cause increased stream and lake turbidity could impact the sea-run populations of these fish during spawning and other life stages spent within Fort Lewis waters. Training activities which drastically disturb soil and/or remove vegetation could also result in sedimentation of streams from upland sites. Transport of eroded sediments would generally occur under wet conditions resulting in degradation of stream conditions. Turbidity can affect the ability of these fish to feed. Suspended solids can silt in and destroy spawning areas. Erosion and runoff will cause both effects.

168. Four species of migratory salmon occur in Nisqually River and its tributaries, with spawning occurring in Muck Creek, Cabin Creek, Johnson Creek, Vietnam Village Marsh, Johnson Marsh, Clear Creek, Chambers Lake,

Watkins Lake, South Creek, Lacamas Creek, and Exter Springs. These species are the chum (Oncorhynchus keta), coho (O. kisutch), pink (O. gorbuscha), and chinook (O. tshawytscha). Considerable effort has been expended at Fort Lewis to provide clean, disturbance-free spawning areas for these species and an active salmonid management program is in place (Directorate of Engineering and Housing 1984). Life requirements of these sea-run species range from the need for clean gravel/cobble spawning beds to clear free-flowing water for fry and juveniles throughout the Nisqually River system (Bilby 1988). Hatching success in the coho shows an inverse relationship to fine sediments (<3.3 mm). Coho fry emergence was high when the substrate had <5 percent fines, but dropped sharply when the fines were $\geq$15 percent (McMahon 1983), and chinook fry survival decreases with fines higher than 10 percent (Raleigh, Miller, and Nelson 1986).

169. Increase in training and equipment under wet conditions would occur during the time period of hatching and movement of fry out of small streams and into larger bodies of water. Increases in training and equipment under dry conditions would occur when fish of these species are small or of variable sizes and have generally moved downstream into larger bodies of water; i.e., the lower reaches of Muck Creek and the Nisqually River. Disturbance of water during stream crossings under uncontrolled conditions would increase turbidity levels immediately downstream of the crossing and add to general turbidity further downstream. The improved crossing system already in place may be adequate to prevent this from happening, but should be evaluated in light of potential new traffic.

170. Managed fish species occurring in land-locked lakes (large-mouth bass (Micropterus salmoides), black crappie (Pomixis nigrosaculatus), bluegill (Lepomis macrochirus), pumpkinseed (Lepomis gibbosus), rock bass (Ambloplites rupestris), yellow perch (Perca flavescens), brown bullhead (Ictalurus nebulosus), and channel catfish (Ictalurus punctatus)) are assumed in this report to be unimpacted by the proposed changes in training and equipment. These recreationally-fished species are generally more adaptable, tolerate more water turbidity and disturbance, and are generally restocked under guidelines outlined in Part IV of the Fort Lewis natural resource management plan (Directorate of Engineering and Housing 1984). In addition, the kokanee (Oncorhynchus nerka) occurs in American Lake where it is managed and stocked by the Washington Department of Wildlife. No impacts from

increased training are expected on kokanee due to American Lake's relatively urban setting and occurrence in a disturbance NOGO area.

171. Other. Although not listed in Table 5, a highly visible insect species unique to the Pacific Northwest is thatching ants (Formica obscuripes Forel) (Akre 1986). They were observed on Fort Lewis primarily under large trees, where they create nest mounds up to 4 ft high, and in the grasslands in the Ranier Training Area where the mounds were 1 ft tall or less. These ants are beneficial, and are fierce predators on other insects (Akre 1986). Their mounds are constructed entirely of organic material, making them highly subject to fire. Where they have occurred in training and impact area meadows, nests can be completely destroyed by fire. In addition, soldiers have been observed torching mounds (Personal Communication, Mr. Gary Steadman, Fort Lewis, May 1989).

Recommendations

172. Fort Lewis contains unique natural resources and provides an important addition to the Puget Sound fishery through the Nisqually River and its tributaries. Its extensive forested areas and the occurrence of special species and communities highlight its role in the region. The numerous wetlands on the installation are important for fish and wildlife habitat, as water storage and recharge areas, and as sediment traps. The lakes on Fort Lewis are an excellent source of recreation. The installation can support multiple uses, as it currently does.

173. Because of the apparent existence of disturbance thresholds in the force structures evaluated, and also because of the time, expense, and unpredictability of restoration efforts, vehicle use should be concentrated on resistant areas and areas that are already impacted. Location and timing of new activities should be planned in light of soil, water, and biotic resources as well as training needs. Proper timing of training exercises is critical because it reduces damage and prolongs the life of the facility, as well as reducing vehicle wear and tear and increasing safety. Defining the most appropriate location and timing related to resources requires consideration of interaction and some trade-offs, as illustrated in Table 13.

174. From the standpoint of soil disturbance, soil compaction, and water erosion, traffic in the wet season (October through March) should be

Table 13

The Occurrence or Intensity of Selected Activities

	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
Precipitation[1]	###	%%%	%%%	///	///	///	---	///	///	%%%	###	###
Plant dormant season[2]	XXX	XXX	XXX								XXX	XXX
Soil susceptib-ility to compaction[3]	###	///	///	///	---	---	---	---	---	///	###	###
Potential wind erosion[3]	---	---	---	---	---	---	---	---	---	---	---	---
Potential water erosion[3]	###	///	///	---	---	---	---	---	---	///	###	###
Salmon spawning and rearing[4]	///	///	XXX	***	***	***	***	///	###	###	###	%%%
Bald eagle breeding[5]	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX				
Osprey breeding[5]			XXX	XXX	XXX	XXX	XXX	XXX				
Great blue heron breeding[5]		XXX	XXX	XXX	XXX	XXX	XXX	XXX				
Ground-nesting birds breeding[6]			///	///	XXX	XXX	XXX	XXX				

1. --- = <1 in., /// = 1-3 in., %%% = 3-5 in., ### = >5 in.
2. Based on Soil Survey of Pierce County Area, Washington, (USDA 1979). Dormant season is from date of first freeezing temperature in fall, 5 of 10 years, at 28° F or lower, to date of last freezing temperature in spring, 5 of 10 years, at 28° F or lower.
3. --- = light, /// = moderate, ### = severe.
4. Chinook and chum salmon, from Brown (1985). /// = chinook, pink, chum XXX = chinook, pink, and juvenile chum, *** = chinook and juvenile chum. ### = chinook, coho, and chum, %%% = chinook and chum.
5. From Brown (1985).
6. /// = horned lark, XXX = horned lark, vesper sparrow, and ruffed grouse, from Brown (1985).

minimized. To reduce damage to plant growth, the month of April should have minimal traffic. This is when plants break dormancy in response to moisture and rising temperature. Vehicle disturbance is lower in dry months so a site can withstand more traffic, but that is also the time for nesting by ground-nesting birds, and a time when the eagles, ospreys, and herons are foraging to feed young. Some salmon spawning occurs year-round, so any time sediments are added to streams there will be negative impact.

175. Because soil is the base resource, it should receive the heaviest weight in a trade-off analysis among resources. Maintaining the soil will help keep sediments out of water and help preserve vegetative cover. The next priority resource is vegetation, expressed both by layers and as species associations. Preservation of vegetation cover will reduce soil erosion. Maintaining the maximum number of layers possible and protecting wetlands and other special communities will help preserve total wildlife species richness.

176. The next weighting could be species of animals, but this is not necessary in many cases. Continuing the practice on Fort Lewis of establishing off-limits areas and buffer zones will accommodate many of the remaining concerns. For example, Directorate of Engineering and Housing (1985) mentions scheduling activities around the presence of eagles, and the Weir and Johnson Prairies should provide undisturbed nesting for the vesper sparrow and horned lark.

177. The following suggestions pertain largely to the resources listed in Table 5. All recommendations on protection of a natural feature such as a vegetation community are predicted on field verification of the condition and extent of the feature. When recommendations from the literature that were given in metric measurements were used, they were converted to standard measures and rounded upward.

178. To minimize the impact of maneuvers on white-topped aster, several recommendations were made by Sheehan and Clampitt (1984). The primary recommendation was to restrict activities to the poorer quality prairies, thereby protecting the white-topped aster which occurs in the higher quality prairies. Additional protection and management options are also available, such as controlled burning to maintain the grassland, although prevention of disturbance provides the most benefit. These actions will also benefit the horned lark and vesper sparrow, which occur in grassland communities.

179. The off-limits designation of Weir and Johnson Prairies protects prime white-topped aster habitat and should be maintained, and the borders of those designated areas checked against the current extent of grassland. The maps show that the south end of Johnson Prairie is not entirely encompassed in a NOGO area. The white-topped aster colony at McChord South Gate is adjacent to the ammo storage area, and could be protected by extending the northwest corner of that off-limits designation to encompass another 20 acres, apparently without significantly affecting training activities. Because of its degraded nature, the low numbers of aster, and high vehicle use on the 13th Division Prairie, no protection or conservation measures for aster in that area are recommended.

180. The lodgepole pine community at Spurgeon Creek is in the extreme corner of the installation and is largely surrounded by terrain that makes it part of the disturbance NOGO condition. Posting that area off-limits would be beneficial to the pine community and would not significantly affect maneuvers.

181. All wetlands and open water should be considered for an off-limits designation by all vehicles. This would conserve a variety of important resources in general and certain features specifically. For example, nonimpacted and undisturbed shorelines with adequate cover allow wildlife safe access to water to drink, adequate over-bank cover is a habitat requirement of coastal cutthroat trout and provides cover for salmon fry and smolts, and maintenance of vegetation around water and wetlands helps trap sediment.

182. For the three wetland classes in Table 4, the Fort Lewis total is 1,770 acres; 482 of these are located in off-limits area, leaving 1,228 acres in areas that can potentially receive vehicle use. It may be necessary to establish priorities for protection. Possible criteria include use by a featured species, use by any of the other species on Table 5, extent of disturbance that could be caused by vehicles based on the traffic model, distribution of wetland types, and size of wetland.

183. Control of sediments reaching the wetlands and water is necessary for optimum habitat conditions for fish and wetland-dependent species. Excessive influx of sediments to a wetland will alter its successional status, potentially moving it towards a drier condition. A high sediment load in the streams of Fort Lewis will impact the salmon and other fish species. Major sources of sedimentation are the vehicle fording areas. Each designated crossing should be evaluated to be sure it has a concrete or gravel/cobble

ford in place prior to equipment changes. Upgrades in existing crossings and establishment of additional crossings that are constructed to lessen turbidity and to discourage unofficial crossings may be necessary, under the proposed force structure changes.

184. Quantification of the amount of sediment that could be added to the streams is not possible at this time. We recommend monitoring the sediment load during a small number of training exercises under a variety of conditions (number and type of vehicles, wet versus dry weather). The results would help determine the need for management actions such as sediment traps.

185. The osprey and eagle areas should be re-evaluate for adequacy of a buffer zone related to changes in vehicle access from the potential change in force structure. Henry (1986) cited studies that recommended buffers around an osprey nest tree up to 440 yd. His recommendations were that all management activities (e.g., logging) within 45 yd of any nest tree be beneficial to that tree, that potential nest trees in the vicinity also be protected, and that human activities within 165-220 yd be eliminated during the nesting period. The range of distance for prohibited activities is dependent on topography and presumably its utility in screening.

186. The eagle as a species prefers areas with no human activities. Individual birds, however, as "remnant populations" (Peterson 1986) can successfully nest and overwinter if such disturbance is within their tolerance. The areas at Spanaway Marsh and along the Nisqually River should be examined for the likelihood of new vehicle access, since the possibility now exists, and for any necessary adjustment to the current 440-yd buffer. Stalmaster et al. (1985) suggested a territory zonation that would be appropriate for Fort Lewis, which includes a primary zone around the nest tree at all times and a secondary zone during the nesting season. The size and configuration of the secondary zone are based on screening cover; topography; proximity of water; and the presence of perch, roost, and alternate nest trees.

187. Good water quality is also needed by the eagle and osprey so that fish production is adequate and so water clarity and visibility, especially for the osprey, are high. Turbid water will reduce habitat quality and may eliminate feeding in the area. The recommendations given for water and wetlands will serve these species as well.

188. The current buffer of 200 ft around the heron colony should be verified or expanded. Short and Cooper (1985) and Vos, Ryder, and Graul (1985) recommended larger buffer zones.

189. To increase flexibility both in wildlife management and in planning training activities, staff at Fort Lewis should consider identifying potential habitats and limiting factors for the species of concern; i.e., locate and be ready to protect what could become the next or another heronry or osprey nest area, or select locations for additional wood duck nest boxes. Several Habitat Suitability Index models exist that might be helpful in this effort, or surveys by species experts could be arranged.

190. A conservation education program is highly recommended to introduce soldiers to the resources at Fort Lewis and to stress the importance of good environmental sense and stewardship in training exercises. For example, soldiers should be advised not to tamper with nest boxes. They should be made aware of the need to lessen sediment loads in streams in training areas, and how observing rules on crossing areas and bivouacking in areas away from wetlands can help accomplish this.

TAB 1

Approach to Cover Type Mapping and Resulting Cover Types

Prepared by Shapiro and Associates, Inc., Seattle, WA
June 1989

Approach

Aerial photographic interpretation began with the preparation of a base mylar overlay for each USGS Topographic Quadrangle in the study area. To create the base overlay a mylar sheet was laid on a topographic map and secured to the work surface. Reference points, such as the quadrangle boundaries, lakes, roads, and railroads were then traced onto the mylar overlay. This sheet was then overlaid on the aerial photograph and the vegetation community types were delineated using stereoscopes to view the aerial photographs. Tone, texture, and density were used as the photographic characteristics, or signatures, to distinguish one vegetation community from another. Draft vegetation maps were completed in pencil and copied onto blueprint paper for field use. Field surveys were conducted to verify preliminary habitat classifications, and to verify photographic signatures of different plant communities. In areas where a mixture of habitat types was evident, both habitat categories were identified on the map and separated by a slash. In these instances, the first habitat type was dominant and the second was subordinate. In areas where there was a mixture of habitat types, but the subordinate habitat comprised less than 15 percent of the total cover, only the dominate habitat classification was used to identify the community. The dominate and common subdominant plant species of each community type are identified in the plant community narrative section.

Field locations for verifying the draft vegetation map were chosen both randomly and where questionable habitat types or boundaries were identified on the aerial photographs. At each field location, a vegetation plot was established, with size of the plot dependent on the vegetation type. For example, a 10 meter by 10 meter area was used for forested sites, a two meter by two meter area was used for shrubs, and a one meter by one meter area was used for forbs. Plot locations were chosen randomly within habitat types and along a random compass direction. Data collected at each plot included type of vegetation community, percent cover of dominate and subdominant plant species, map location, date, perception of disturbance, surface soil texture, notes on landform and topography, and any relevant observations. The percent cover for trees, shrubs, and forbs was determined by viewing the vegetation within the plot and estimating the average percentage of cover, for the entire plot, for each plant species in each vegetation layer. The perception of disturbance was estimated for the general riparian zone where the plot was located and included notes on such activities as the number of stream crossings or signs of recent cattle grazing. The texture of the surface soil was determined by field estimates within the plot. Photographic slides of representative vegetation communities were also taken at most plots. Information recorded for each photograph included location, date, time of day, habitat classification, direction of photograph, and any relevant observations. Representative photos were numbered to cross-reference the field data sheets. The draft map designations were checked and when necessary revisions were made to the final maps.

Vegetation Classifications

Vegetation occurring on Fort Lewis was grouped into vegetation associations that were identifiable from the 1:24,000 scale black-and-white aerial photographs. These associations are the mapping units found on the vegetation maps. Descriptions of these associations are provided below.

Coniferous Forest (Fc)

The dominant tree species occurring in this association is Douglas fir (*Pseudotsuga menziesii*). Monotypic stands of this tree are very common on Fort Lewis. Western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*) are found with Douglas fir in areas with finer-textured soils and increased soil moisture. The understory consists of scattered shrubs. Dominant understory species are snowberry (*Symphoricarpus albus*) and swordfern (*Polystichum munitum*). Indian plum (*Oemleria cerasiformis*) and Himalayan blackberry (*Rubus discolor*) are also present. In moderate-to-highly disturbed understories, Scot's broom (*Cytisus scoparius*) is the dominant shrub. Brome grass (*Bromus* sp.) is the dominant groundcover species.

Coniferous forests are managed for timber production over much of the military reservation. Most of these forests are second and third-growth stands of Douglas fir. Many of the older stands have trees uniformly spaced as the result of select-cutting. Both select-cutting and partial clearcutting are the modes of harvesting timber at Fort Lewis. Under partial clearcutting, the land is cleared of all trees except for widely scattered seed trees.

Deciduous Forest (Fd)

Deciduous forests occur along watercourses and are interspersed around the periphery of prairie areas. Dominant tree species along most watercourses are black cottonwood (*Populus trichocarpa*) and Oregon ash (*Fraxinus latifolia*). Commonly, Oregon white oak (*Quercus garryana*) is present. Red alder (*Alnus rubra*) and bigleaf maple (*Acer macrophyllum*) occasionally occur. Adjacent to some creeks, nearly monotypic stands of willow (*Salix* spp.) can be found. The understory of the cottonwood-ash forests is dominated by snowberry. Himalayan blackberry and Indian plum are also present. The groundcover is largely comprised of stinging nettle (*Urtica dioica*) and bedstraw (*Galium* sp.).

Interspersed around the borders of the prairie areas are groves of Oregon white oak. The understory is dominated by snowberry and orchard grass (*Dactylis glomerata*). Himalayan blackberry, Indian plum, cascara (*Rhamnus purshiana*), velvetgrass (*Holcus lanatus*), and common vetch (*Vicia sativa*) are also found.

With the exception of Red Alder (*Alnus rubra*), the deciduous forests are not managed for timber harvests. Overall, they make up a small percentage of the total forest cover occurring on Fort Lewis.

Mixed Coniferous/Deciduous Forest (Fm)

Mixed forests commonly occur adjacent to watercourses and along some hillslopes. The dominant trees are Douglas fir and bigleaf maple. Western red cedar, western hemlock, Oregon white oak, Oregon ash, and red alder also occur. The understory is a lush thicket dominated by vine maple (Acer circinatu), thimbleberry (Rubus parviflorus), oceanspray (Holodiscus discolor), salal (Gaultheria shallon), Indian plum, and snowberry. Oregon grape (Berberis nervosa), hazelnut (Corylus cornuta), Scot's broom, hawthorn (Crategus sp.), and cascara are also found. The dominant forbs include sword-fern, lady fern (Athyrium filix-femina). Oregon oxalis (Oxalis sp.) are bracken fern (Pteridium aquilinum). Stinging nettle, creeping buttercup (Ranunculus repens), and orchard grass are also present.

This association is common on river terraces where the soil is well-drained. Plant species and diversity indicate that soil moisture levels are likely higher than those levels occurring elsewhere on the outwash plain. Some select-cutting of the coniferous trees occurs in these mixed forest stands.

Young Forest (Fy)

This association is used to describe those forested areas that were clearcut or partially clearcut and are currently in the process of being reforested. The stands of new trees vary in age from 1 to approximately 15 years of age. Douglas fir is the dominant, and usually the only tree species occurring in this association. Plantings of Douglas fir produce a dense stand of trees by their tenth growing season. Scot's broom is the dominant shrub while the trees are very young. Snowberry, native blackberry (Rubus ursinus), Oregon grape, and oceanspray also occur. Vernalgrass (Anthoxanthum odoratum) and bluegrass (Poa sp.) are the dominant groundcover species. Bracken fern, orchard grass, velvetgrass, and fireweed (Epilobium angustifolium) are also present. Some young forest stands have very little Scot's broom occurring. These areas may have been chemically treated to eradicate this shrub as intensive forest management is practiced at Fort Lewis.

Shrubland (S)

Shrubland is a transitional plant association that occurs in areas that were cleared of forest vegetation and left to revegetate naturally. The dominant shrub species are snowberry, oceanspray, and Scot's broom. Other shrubs include cascara, Himalayan blackberry, Indian plum, hazelnut, and cutleaf blackberry (Rubus laciniatus). Scattered individual and clumps of young tree species also occur; Douglas fir and ponderosa pine (Pinus ponderosa) can be found in shrublands bordering conifer forests, and red alder and bigleaf maple are found in shrublands adjacent to deciduous forests. Orchard grass, bracken fern, and bluegrass dominate the groundcover species. Velvetgrass, fireweed, and bigroot (Marah oreganus) are also present.

Grassland (G)

This association represents those areas where grass and forb vegetation appears to be occurring naturally, as perceived from 1:24,000 scale black-and-white aerial photographs. Tree cover is less than 5 percent. Much of this association is found in the three native prairies: the 91st Division Prairie, the 13th Division Prairie, and Weir Prairie. Smaller grassland clearings are interspersed among the forestlands which surround each prairie. The grassland plant species very depending on the soil moisture regimes. In areas with higher soil moisture content, bluegrass dominates. Daisy (Compositae sp.), common vetch, English plantain (Plantago lanceolata), Canadian thistle (Cirsium arvense), velvetgrass, and bigroot are also present. Isolated clumps containing snowberry, rose (Rosa sp.), chokecherry (Prunus virginiana), and hawthorn are occasionally found. In areas with lower soil moisture content, Idaho fescue (Festuca idahoensis) and creeping bentgrass (Agrostis alba) dominate. Other dry-tolerant species occurring include camas (Lamassia sp.), and lupine (Lupinus sp.).

Because of the absence of trees and shrubs, the grassland areas on Fort Lewis are widely used for military maneuvers and as artillery impact areas. Disturbance varies considerably across the prairie areas; some areas show no signs of disturbance, while other areas contain numerous dirt roads and have occasional jeep and tank tracks across the vegetated ground. The disturbance in the artillery impact areas is assumed to be high. These areas were not accessible for field verification. The prairie areas show evidence of grassland fires in the form of scorched clumps of dead Scot's broom and burned tree bark on scattered groves of Ponderosa pine. These burns may be attributed to a combination of fires accidentally started from military maneuvers and fires intentionally started to maintain prairie vegetation and control the spread of Scot's broom. The invasion of Scot's broom into grasslands appear to be a serious management problem; some unburned areas contain up to 40 percent of this shrub. Scot's broom is an introduced shrub and provides little wildlife habitat compared to the native shrubs. In areas with a mix of coniferous forest and grassland vegetation, scot's broom is frequently a dominant species.

Mixed Grassland (Gm)

This association is a diverse plant community dominated by grasses and forbs, with frequent shrubs and scattered, isolated trees. Tree cover is less than 15 percent. The mixed grassland association is a transitional community occurring at the edge of prairies and in areas that were cleared of forest vegetation and left to revegetate naturally. Brome grass and bluegrass are the dominant ground species. Velvetgrass, Canadian thistle, wild strawberry (Fragaria sp.), bedstraw, common vetch, and trumpet honeysuckle (Lonicera ciliosa) also are present. Scot's broom, oceanspray, and snowberry are the dominant shrubs. Himalayan blackberry, Indian plum, and hazelnut can also be found. When bordering coniferous areas, this association contains Douglas fir as the dominant shrubs. Himalayan blackberry, Indian plum, and hazelnut can be also be found. When bordering coniferous areas, this association contains Douglas fir as the dominant species. Ponderosa pine occasionally occurs. Adjacent to deciduous forests, the mixed grassland community contains bigleaf maple and red alder as its tree components.

Cleared Grassland (Gc)

The cleared grassland association describes those areas that were cleared of forest vegetation and appear to be maintained as open space areas with little or no revegetation of tree and shrub species. The groundcover is dominated by bluegrass. Velvetgrass, fireweed, Canadian thistle, bedstraw, sheep sorrel (Rummex acetosella), and strawberry are also found. In some areas Scot's broom is a dominant species, with up to 40 percent coverage.

Seedlings and saplings of Douglas fir and young shrubs of oceanspray, snowberry, and Himalayan blackberry can also be found.

Bare Ground (B)

Bare ground represents those areas where vegetation was removed as the result of road construction and maintenance, sand and gravel extraction, military maneuvers, and artillery impacts. Frequently, Scot's broom, Himalayan blackberry, orchard grass, Canadian thistle, and fireweed occur along the edges of these bare areas.

Urban (U)

The urban category describes all the developed lands contained in and outside the cantonment areas of Fort Lewis. This category encompasses residential, commercial, industrial, and many military uses of the land. Vegetation within this category was not segregated into associations. Many ornamental tree, shrub, and groundcover species have been planted around the buildings and in open field areas. In general, where indigenous occurs, Douglas fir is the dominant tree species and Scot's broom is the dominant shrub. Orchard grass, velvetgrass, and Canadian thistle occur in unmowed areas.

Open Water (OW)

Open and standing water occurs in the lakes, ponds, and several of the wetlands found on Fort Lewis Military Reservation. This category was not used to describe rivers, streams, or creeks, unless these flowing water systems opened up into broader, more expansive areas that were discernible from the aerial photos. The aerial photos were flown in March of 1987, which corresponds with the region's wet season. Groundwater levels are normally high at this time of the year, and perched water tables are common. Many of the smaller wetlands containing open water in March would not contain open water during the drier summer months. In these instances, emergent and scrub/shrub wetland plant species would be growing where open water was previously standing However, the spring of 1987 was unusually dry and these aerial photos may show less open water areas than if the photos were taken during a spring with average precipitation. The common species occurring in these areas include soft rush (Juncus) canarygrass (Phalaris arundinacea) slough sedge (Carex obnupta), Douglas spirea (Spiraea douglasii), and willow (Salix spp.). In areas with permanent open water, yellow pond lily (Nuphar polysepalum) is occasionally present and cattails (Typha latifolia) commonly occur around the open-water edge.

Emergent Marsh (EM)

Many of the wetlands occurring on Fort Lewis contain a combination of vegetation associations (e.g., open water/emergent marsh, emergent vegetation associations (e.g., openswamp/scrub-shrub swamp). In the emergent marsh communities, the dominant species are reed canarygrass, and soft rush. Bulrush (Scirpus spp.), curly dock (Rumex crispus), field horsetail (Equisetum arvense), bluegrass, sheep sorrel, vetch, and Canadian thistle also occur. Oregon ash, willow, native rose, and Scot's broom occasionally are found in scattered clumps along the periphery of this association.

Scrub/Shrub Swamp (SS)

Scrub/shrub associations are dominated by Douglas spirea. Clumps of willow are commonly associated with spirea stands. Pacific ninebark (*Physocarpus capitatus*), rose, and western crabapple (*Malus fusca*) also occur. Oregon ash and red alder are occasionally scattered around the edge of this community. Ground species are normally sparse; lady fern can be found under some shrub canopies. Snowberry and salal are frequently found along the fringe of this association.

Forested Swamp (FO)

Forested swamps are dominated by black cottonwood and Oregon ash. Red alder is also found and Oregon white oak and bigleaf maple occasionally occur along the upland edge of these swamp areas. In those swamps with prolonged standing water, the sparse understory is made up of young cottonwood and ash saplings. The understory in less inundated areas is dominated by salmonberry (*Rubus spectabilis*). Douglas spirea, Pacific ninebark, twinberry (*Lonicera involucrata*), snowberry, and rose can also be found. Ground species occur as scattered patches beneath the understory; slough sedge and lady fern are the most common species. False lily-of-the-valley (*Maianthemum dilatatum*) and creeping buttercup are occasionally found.

TAB 2

Detailed List of Cover Type Classifications and Acres

Category	Acres
Bare Ground (B)	148.9
Bare Ground/Cleared Grassland (B/Gc)	119.3
Bare Ground/Mixed Grassland (B/Gm)	5.4
Bare Ground/Shrubland (B/S)	6.4
Emergent Marsh (Em)	139.8
Emergent/Coniferous Forest (Em/Fc)	15.6
Emergent/Forested Swamp (Em/Fo)	26.6
Emergent/Open Water (Em/Ow)	37.5
Emergent/Scrub/Shrub Swamp (Em/SS)	462.6
Coniferous Forest (Fc)	40,171.3
Coniferous Forest/Deciduous Forest (Fc/Fd)	563.7
Coniferous Forest/Young Forest (Fc/Fy)	29.6
Coniferous Forest/Grassland (Fc/G)	1,284.9
Coniferous Forest/Cleared Grassland (Fc/Gc)	82.3
Coniferous Forest/Mixed Grassland (Fc/Gm)	1,387.2
Coniferous Forest/Shrubland (Fc/S)	161.0
Deciduous Forest (Fd)	1,905.6
Deciduous Forest/Forested Swamp (Fd/Fo)	9.4
Deciduous Forest/Shrubland (Fd/S)	188.5
Forested Swamp (Fo)	131.9
Forested Swamp/Deciduous Forest (Fo/Fd)	8.9
Forested Swamp/Open Water (Fo/Ow)	160.3
Forested Swamp/Scrub/Shrub Swamp (Fo/SS)	107.4
Young Forest (Fy)	5,209.2
Young Forest/Coniferous Forest (Fy/Fc)	1,966.1
Young Forest/Shrubland (Fy/S)	8.6
Grassland (G)	11,550.2
Grassland/Emergent Marsh (G/Em)	2.5
Grassland/Coniferous Forest (G/Fc)	2,177.8
Grassland/Deciduous Forest (G/Fd)	3.7
Grassland/Mixed Coniferous/Deciduous Forest (G/Fm)	36.8
Grassland/Mixed Grassland (G/Gm)	442.1
Grassland/Shrubland (G/S)	83.7
Cleared Grassland (Gc)	909.5
Cleared Grassland/Bare Ground (Gc/B)	162.3
Cleared Grassland/Coniferous Forest (Gc/Fc)	1,472.6
Cleared Grassland/Mixed Coniferous/Deciduous Forest (Gc/Fm)	15.6
Cleared Grassland/Shrubland (Gc/S)	39.0

(Continued)

TAB 2 (Concluded)

Category	Acres
Mixed Grassland (Gm)	1,860.4
Mixed Grassland/Bare Ground (Gm/B)	28.2
Mixed Grassland/Coniferous Forest (Gm/Fc)	1,422.0
Mixed Grassland/Young Forest (Gm/Fy)	19.0
Mixed Grassland/Shrubland (Gm/S)	10.4
Open Water (Ow)	902.3
Open Water/Emergent Marsh (Ow/Em)	148.0
Open Water/Forested Swamp (Ow/Fo)	28.2
Open Water/Scrub/Shrub Swamp (Ow/SS)	158.3
Shrubland (S)	48.9
Shrubland/Coniferous Forest (S/Fc)	322.3
Shrubland/Deciduous Forest (S/Fd)	131.9
Shrubland/Mixed Coniferous/Deciduous Forest (S/Fm)	113.1
Shrubland/Grassland (S/G)	38.3
Shrubland/Scrub/Shrub Swamp (S/SS)	18.3
Scrub/Shrub Swamp (SS)	211.7
Scrub/Shrub Swamp/Emergent Marsh (SS/Em)	129.9
Scrub/Shrub Swamp/Mixed Coniferous/Deciduous Forest (SS/Fm)	20.5
Scrub/Shrub Swamp/Forested Swamp (SS/Fo)	190.7
Scrub/Shrub Swamp/Open Water (SS/Ow)	40.3
Urban (U)	7,273.1
Mixed Coniferous/Deciduous Forest (Fm)	1,820.4
Mixed Coniferous/Deciduous/Young Forest (Fm/Fy)	47.4
Mixed Coniferous/Mixed Grassland (Fm/Gm)	155.1
Mixed Coniferous/Shrubland (Fm/S)	16.8

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