DEMONSTRATION OF THE MILITARY ECOLOGICAL RISK ASSESSMENT FRAMEWORK (MERAF): APACHE LONGBOW–HELLFIRE MISSILE TEST AT YUMA PROVING GROUND

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

Acronym	Definition
AFCEE	Air Force Center for Environmental Excellence
ATTACC	Army Training and Testing Carrying Capacity (a vehicle-induced erosion model)
BN	Battalion
BNOISE2	Blast Noise 2, noise contour program
CSEL	C-weighted Sound Exposure Level
DEM	Digital Elevation Model
DNL	Day-Night Average Sound Level
DoD	U. S. Department of Defense
DOQQ	Digital Orthogonal Quarter Quad
EAA	Equivalent Acoustical Altitude
EDYS	Ecological Dynamics Simulation Modeling
EPA	U. S. Environmental Protection Agency
GIS	Geographic Information System(s)
HYMO	Hydrologic Model
IP	Impact Point
IRCC	Inverted Range Control Center
LCTA	Land Condition Trend Analysis
LFO	Low Flight Operations
L_{max}	Maximum Sound Level
LOAEL	Lowest Observed Adverse Effects Level
LOBLI	Lock-on Before Launch Inhibit
MCM	Master Control Module, NOISEMAP
MERAF	Military Ecological Risk Assessment Framework
MIM	Maneuver Impact Miles
MOA	Military Operations Area
MR_NMAP	Military Range NOISEMAP
MTI	Moving Target Indicator
MTR	Military Training Route
NEPA	National Environmental Policy Act
NOAEL	No Observed Adverse Effects Level
NOISEMAP	Noise contour program for aircraft overflights, not an acronym
SEL	Sound Exposure Level
SERDP	Strategic Environmental Research and Development Program of DoD
USACHPPM	U. S. Army Center for Health Promotion and Preventative Medicine
USAF	U. S. Air Force
UXO	Unexploded Ordnance
VTOL	Vertical Takeoff and Landing
YPG	Yuma Proving Ground

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EXECUTIVE SUMMARY

This ecological risk assessment for a testing program at Yuma Proving Ground, Arizona, is a demonstration of the Military Ecological Risk Assessment Framework (MERAF; Suter et al. 2001). The demonstration is intended to illustrate how risk assessment guidance concerning generic military training and testing activities and guidance concerning a specific type of activity (e.g., low-altitude aircraft overflights) may be implemented at a military installation. MERAF was developed with funding from the Strategic Research and Development Program (SERDP) of the Department of Defense. Novel aspects of MERAF include: (1) the assessment of risks from physical stressors using an ecological risk assessment framework, (2) the consideration of contingent or indirect effects of stressors (e.g., population-level effects that are derived from habitat or hydrological changes), (3) the integration of risks associated with different component activities or stressors, (4) the emphasis on quantitative risk estimates and estimates of uncertainty, and (5) the modularity of design, permitting components of the framework to be used in various military risk assessments that include similar activities.

The particular subject of this report is the assessment of ecological risks associated with a testing program at Cibola Range of Yuma Proving Ground, Arizona. The program involves an Apache Longbow helicopter firing Hellfire missiles at moving targets, i.e., M60-A1 tanks. Thus, the three component activities of the Apache-Hellfire test were: (1) helicopter overflight, (2) missile firing, and (3) tracked vehicle movement. The demonstration was limited to two ecological endpoint entities (i.e., potentially susceptible and valued populations or communities): woody desert wash communities and mule deer populations. The core assessment area is composed of about 126 km^2 between the Chocolate and Middle Mountains. The core time of the program is a three-week period, including fourteen days of activity in August of 2000.

The problem formulation for a test program consists of: the definition of assessment goals, a description of the military activities comprising the program, a description of the environmental setting, the selection of assessment endpoint entities, the description of exposure factors for those entities, and the development of a conceptual model depicting the relationship between stressors and endpoints. Assessment goals included the demonstration of the use of MERAF for the Apache Longbow–Hellfire test and the quantification of risks to woody vegetation communities of desert washes and mule deer populations. Key environmental features of the study area at YPG include barren desert pavement and tree-lined desert washes.

An activity-specific risk assessment framework was available to provide guidance for assessing risks associated with aircraft overflights. (This framework was developed as part of this SERDP-funded project). The primary stressors associated with helicopter overflights were sound and the view of the aircraft (visual stressor). The exposure to mule deer was quantified using Air Force sound contour programs NOISEMAP and MR_NMAP, as well as slant distances from helicopters to deer. The slant distance measure of exposure integrates risk from sound and view of the aircraft. Exposure-response models for the characterization of effects consisted of behavioral thresholds in units of A-weighted decibels (sound exposure level or maximum sound level) or slant distance. Limited sound thresholds were available for desert mule deer, and a distribution of slant distance thresholds was available for ungulates. The risk characterization used a weight of evidence approach and concluded that risk to mule deer behavior from the Apache overflight is uncertain, but that no risk to mule deer abundance and reproduction is expected.

An activity-specific risk assessment framework was not available to provide guidance for assessing risks associated with missile firing. The primary stressor associated with Hellfire missile firing is sound. Other minor stressors that are discussed include the detonation impact, shrapnel and fire. Exposure to mule deer was quantified using the Army sound contour program BNOISE2, as well as distances from the explosion to deer. Exposure-response models for the characterization of effects consisted of human "disturbance" and hearing damage thresholds in units of C-weighted decibels (sound

exposure level) and a distance-based No Observed Adverse Effects Level for moose and cannonfire. The risk characterization used a weight of evidence approach and concluded that risk to mule deer behavior from the Hellfire missile firing was likely for a negligible number of deer, but that no risk to mule deer abundance and reproduction is expected.

An activity-specific risk assessment framework was not available to provide guidance for assessing risks associated with tracked vehicle movement. The principal stressor associated with tracked vehicle movement is soil disturbance, and a resulting, secondary stressor is hydrological change. Water loss to washes and wash vegetation was expected to result from increased ponding, infiltration and/or evaporation associated with disturbances to desert pavement. Changes in hydrology were hypothesized to affect growth and survival of wash vegetation and/or the mule deer population. Additional stressors that are discussed include sound (no exposure information available), dust (minor) and erosion (minor). The exposure of wash vegetation to water loss was quantified using estimates of exposed land area from a digital ortho quarter quad aerial photo and field observations, a 30×30 m digital elevation model, the flow accumulation feature of ESRI ArcInfo, and a two-step process in which runoff was estimated from direct precipitation to a land area and from water that flowed from upgradient to a land area. Absolute water loss decreased with distance from the disturbance, downgradient in the washes; however, percentage water loss was greatest in land areas immediately downgradient of a disturbance. Effects on growth and survival of wash trees were quantified by using an empirical relationship derived from data in a masters thesis by L. S. Glass of Duke University. The risk characterization concluded that neither risk to wash vegetation growth or survival nor risk to mule deer abundance and reproduction is expected. The risk characterization was negative for both the incremental risk of the test program and the combination of the test and pretest disturbances.

A process for integrating risks is presented. However, a formal integration of risks from the Apache overflight, the Hellfire missile firing, and the tracked vehicle movement was not necessary because there were no risks to be integrated. That is, a positive assessment of risk to wash vegetation or the mule deer population was not the conclusion of any of the activity-specific risk assessments.

Two expansions of the scope of the MERAF demonstration are discussed qualitatively. These include risks associated with road development and risks resulting from the cumulative testing programs near the study area. Another expansion of the scope of the MERAF demonstration is discussed quantitatively. This is the risks associated with larger scale tracked vehicle disturbance than occurred in the Apache Longbow–Hellfire missile test ($200m \times 1000$ m area). Essentially, desert wash trees are at risk (at a small scale) from large-scale soil disturbances. Mule deer populations are not affected at the disturbance levels in the hypothetical scenarios.

Numerous areas for further research are presented throughout the risk assessment. These are intended to reduce uncertainty in the characterization of exposure and effects for the three activities in the Apache-Hellfire test.

Based on the low confidence and (sometimes arbitrary selection) of many of the assumptions and model parameters, we do not recommend that the quantitative results of this demonstration be used for management purposes at YPG.

1. INTRODUCTION

This ecological risk assessment for a testing program at Yuma Proving Ground (YPG), Arizona, is a demonstration of the Military Ecological Risk Assessment Framework (MERAF; Suter et al. 2001). The demonstration is intended to illustrate how risk assessment guidance concerning generic military training and testing activities (Suter et al. 2001) and guidance concerning a specific type of activity (e.g., low-altitude aircraft overflights, Efroymson et al. 2000, Efroymson et al. 2001, Efroymson and Suter 2001) may be implemented at a military installation. More specifically, the novel aspects of MERAF include: (1) the assessment of risks from physical stressors using an ecological risk assessment framework, (2) the consideration of contingent or indirect effects of stressors (e.g., population-level effects that are derived from habitat or hydrological changes), (3) the integration of risks associated with different component activities or stressors, and (4) the emphasis on quantitative risk estimates and estimates of uncertainty, to the extent that supporting data are available.

Another advantage of MERAF is that it is designed to provide data, tools and content for assessment and not just a structural framework. Its design is modular so that it can be efficiently used and updated for assessments of various site-specific training and testing programs or of programs at various sites that include common activities. For example, this demonstration uses a previously developed activity framework for ecological risks from low-altitude aircraft overflights (Efroymson et al. 2000), but focuses it to apply to helicopters at YPG (Chapter 3). That existing framework saved considerable time and labor in this demonstration, and the focused version will be even more useful for future programs involving helicopters at YPG. No existing activity-specific framework for missile firing was available, but the one developed for this demonstration (Chapter 4) can now be applied to future missile firing activities at any site. Similarly, the standard structure of activity frameworks allows ready incorporation of data or methodological advances from one assessment into the activity framework as it is applied to future assessments. These features should facilitate the spread of advances in assessment among training and testing facilities. In addition, the standard structure and content of the MERAF components should help to maintain the quality of assessments with changes in staff or contractors.

The particular subject of this report is the assessment of ecological risks associated with a testing program at Cibola Range of Yuma Proving Ground, Arizona. The program involves an Apache Longbow helicopter firing Hellfire missiles at moving targets, i.e., M60-A1 tanks. The demonstration is limited to two ecological endpoint entities (i.e., potentially susceptible and valued populations or communities): woody desert wash communities, and mule deer populations. The focus of the demonstration was chosen for four primary reasons: (1) the installation was enthusiastic about the demonstration, and environmental and testing staff provided in-kind support; (2) the test program included multiple activities; (3) one of the component activities was low-altitude helicopter overflights, for which an activity-specific risk assessment framework had already been written; and (4) the other two activities, tracked vehicle movement and munitions firing, were also deemed high priority activities by the *ad hoc* military advisory committee for the development of MERAF. The spatial and temporal scales of the program were not such that we anticipated substantial, population-level risks. That is, an *a priori* judgment that risks to plant communities or vertebrates were likely to be high was not a criterion for our choice of a case-study site.

As this is a demonstration, we describe models and measurements that might have been utilized, given additional resources and time, as well as the limitations of those that were used. Numerous assumptions were made about test parameters (e.g., daily flight paths) and environmental parameters (e.g., hydrology) so that the illustration of the process of risk assessment was possible even where data were lacking. An implementation of the framework by military personnel would not be as limited by the availability of classified or sensitive data, though it would be just as limited by the availability of exposure models and exposure-response relationships. It should be noted that this was a retrospective risk assessment; the test was already completed before the analysis was performed. Thus, we began the

assessment with the knowledge that the missile never missed the target and that the helicopter always landed on a helipad. Prospective risk assessments must consider a larger number of potential exposure pathways, in general, than retrospective assessments.

1.1 MILITARY ECOLOGICAL RISK ASSESSMENT FRAMEWORK (MERAF)

The EPA ecological risk assessment framework has become the standard basis for ecological risk assessment in the federal government, including the tri-services guidance for contaminated sites (Wentsel et al. 1996). Although most ecological risk assessments in the U. S. have been undertaken for the Superfund program and the commercial production of new chemicals, the EPA *Guidelines for Ecological Risk Assessment* are written broadly to apply to any chemical, physical or biological stressor (EPA 1998). However, few non-chemical applications of ecological risk assessment methodology exist (e.g., dam construction, Giers et al. 1998), and neither these nor the EPA *Guidelines* provide sufficient guidance for a risk assessor to conduct site-specific, quantitative risk assessments for multiple, non-chemical stressors, including those that act on hydrology or habitat and thus act only indirectly on an assessment endpoint entity.

MERAF elaborates on the EPA ecological risk assessment framework to make it more useful to the Department of Defense (DoD) training and testing community and to others performing similar, complex assessments. Thus, the EPA framework has been modified to address explicitly (1) risks from the imposition of multiple and diverse stressors on a site and (2) risks resulting from causal chains (Suter et al. 2001). The framework has been augmented to incorporate the fact that risks to natural resources imply other consequent risks, such as potentially limiting the ability to conduct training and testing activities on a site.

In this report and in MERAF, the term "program" refers to a set of activities that are carried out to accomplish a mission and about which a decision must be made. Thus, the Apache-Hellfire test that is the subject of this assessment may be a program, or all of the aviation activities on Cibola Range may be considered a program. An "activity" is a distinct set of actions that make up the program, and three such activities are helicopter overflights, off-road vehicle movement, and missile firing. Activities may be components of more than one program on the installation.

Prior to this demonstration, an activity-specific risk assessment framework was developed for low-altitude fixed-wing and rotary-wing aircraft as a subframework of MERAF (Efroymson et al. 2000, Efroymson et al. 2001, Efroymson and Suter 2001). Recommendations concerning the analysis of exposure and the analysis of effects in the framework will be utilized in this risk assessment.

1.2 POTENTIAL USES OF MERAF

MERAF may be used: (1) to assess cumulative risks from a new or altered activity or program, (2) to assess risks associated with a particular stressor that is common to multiple activities or programs (e.g., noise, erosion), or (3) to address management goals for a threatened or endangered species or other valued aspects of ecosystems that are potentially affected by multiple activities. Although this demonstration addresses risks from a test program to the environment, MERAF may also be used to assess risks from environmental change to a testing or training mission (Suter et al. 2001). Any substantive change to operations at an Armed Services base, range, Military Training Route (MTR), or Military Operations Area (MOA) requires the relevant service to evaluate environmental impacts, as defined in the National Environmental Policy Act (NEPA). Site managers may use risk assessment methodology to choose between two alternate overflight routes or two ranges at which to conduct a training or testing exercise. Cumulative impacts associated with multiple training and testing activities may also be estimated, as required by the NEPA. In addition, the military services are expected to

develop natural resource management plans in cooperation with state Fish & Wildlife organizations as part of the 1960 Sikes Act and 1996 Amendments (16 U.S.C §670a). Risks to particular resources from multiple activities may be estimated and presented in these plans (Suter 1999a).

Additional benefits of MERAF include: (1) the illustration of the need for integrated data systems, models and geographic information systems that may be utilized on installations and (2) the identification of temporal or spatial scales of stressors or ecological entities that will not be affected by a proposed or existing activity.

1.2.1 Training Versus Testing

This risk assessment demonstration is for a testing program, the Apache Longbow–Hellfire missile test using moving targets. MERAF is designed for use in both training and testing programs. It is assumed that training programs often have larger temporal and spatial scales and more intense activity (more aircraft, more vehicles, more troops) than testing programs, resulting in greater potential for risk to large-scale ecological populations and communities. For example, a training activity at Piñon Canyon Maneuver Site in southeastern Colorado, where mule deer movements were monitored, involved 2624 to 6619 troops per 2 to 3-week exercise, 30 to 50 helicopters on site at one time, and 584 to 2397 vehicles on site at one time (Stephenson et al.1996). A risk assessor must begin the assessment of a testing exercise that involves a single helicopter, a few vehicles, and a few personnel, with the assumption that this smaller-scale program will carry less risk. Where possible, we discuss qualitatively how a risk assessment would be conducted differently for a larger scale program.

1.3 ORGANIZATION OF REPORT

Following the introduction, the report is organized according to MERAF and the EPA ecological risk assessment framework. That is, the problem formulation, which specifies the goals, scope and methods for the assessment, is followed by the characterization of exposure, the characterization of effects, and risk characterization. In this demonstration, independent risk assessments are carried out for the component activities of the Apache Longbow–Hellfire missile test at YPG, following the integrated problem formulation in Chapter 2. Thus, Chapters 3, 4, and 5 are stand-alone risk assessments for the aircraft overflight, missile firing, and vehicle movement components of the test. Chapter 6 consists of the risk characterization for the integrated activities of the Apache Longbow–Hellfire missile test. Chapter 7 provides qualitative assessments of risks from road development, hypothetical expansions of the test program of interest, and additional programs in the area.

Appendix A represents Land-Condition Trend Analysis data for vegetation in the test area at YPG. Appendix B and C are the input files for MR_NMAP and NOISEMAP models, respectively. Appendix D is a table summarizing thresholds for effects of overflights on ungulates from Efroymson et al. (2000). Appendix E is a summary of field observations of the study area.

2. PROGRAMMATIC PROBLEM FORMULATION

The problem formulation phase of an ecological risk assessment is a planning process that is intended to ensure that the risk assessment is useful and defensible. In this section, the goals of the programmatic assessment are defined; military activities are described, along with their potential environmental consequences; the environmental setting is described; ecological endpoints are selected; exposure factors for those endpoints (e.g., home range, desert wash boundaries) are described, and conceptual models are developed. The problem formulation leads to the conceptual model for the program, which represents causal relationships between stressors associated with the component activities and ecological responses. In some assessments, a plan for collecting new data is developed during the problem formulation phase, but new data were not collected here. Chapters 3, 4, and 5 of this report contain problem formulation components (stressor descriptions) that are pertinent to only one activity (aircraft overflights, vehicle movement, or missile firing) of the test.

2.1 ASSESSMENT GOALS

The general goal of this ecological risk assessment is to demonstrate the use of MERAF for the Apache-Hellfire test. This goal is unique, in that it was defined through the DoD Strategic Environmental Research and Development Program (SERDP) statement of need that defined our research project, rather than through a particular need of YPG. Thus, the primary interested parties include: (1) YPG Environmental Sciences Program and Aviation and Air Drop Systems staff, (2) SERDP staff, and (3) Conservation Program staff at installations who may use MERAF. Most military ecological risk assessments would be performed in response to a regulatory requirement or a natural resources management need.

> The assessment goals are to demonstrate the use of MERAF for the Apache-Hellfire test and to quantify risks to woody vegetation communities of desert washes and mule deer populations.

More specifically, the assessment goal is to quantify risks to woody vegetation communities of desert washes and mule deer populations. The selection of these ecological assessment endpoint entities is described below. This assessment goal is based on the management goal to protect rare or valued vegetation communities and wildlife populations. (The demonstration of MERAF may also be considered a management goal.) The assessment goal is not comparative, in that there is not an alternative location or configuration for a prospective test. The test has already occurred. Thus, this demonstration is a retrospective risk assessment.

Secondary goals of the assessment are to discuss qualitatively the potential risks associated with road development, as well as the risks associated with a larger scale test program, and with additional programs on the installation.

2.2 DESCRIPTION OF APACHE-HELLFIRE TEST

2.2.1 Purpose and Integrated Description

The Apache Longbow–Hellfire missile test conducted in August 2000 was intended to test an engagement technique, i.e., "lock-on before launch inhibit" (LOBLI), that is, to avoid radar detection by locking onto a moving target (M60-A1 tank) after a Hellfire 2 missile is fired. The test consisted of an Apache Longbow helicopter shooting Hellfire missiles at a moving, tracked vehicle in Cibola Range of

Yuma Proving Ground. The test was conducted over a 3-week period in August, 2000. (A similar 3-week test had been conducted in October of 1998.) The first five days consisted of the helicopter and tanks setting up for the test. Tanks were driven by personnel, and there was no live fire. During the following 7-8 days, missiles were fired. Mission periods were four hours. The first two-hour period included the overflight, shot, and vehicle movement, and the second (that is not considered because of a lack of additional stressors) consisted of telemetry and diagnostics.

2.2.2 Component Activities of Test

For the purpose of this ecological risk assessment, the test is divided into three component activities: helicopter overflight, missile firing, and tracked vehicle movement. Risks associated with the three activities are integrated, to the extent possible, in Chapter 6.

> The Apache-Hellfire test is divided into three component activities, helicopter overflight, missile firing, and tracked vehicle movement.

An activity-specific ecological risk assessment framework (Efroymson et al. 2000) is available to provide guidance in assessing risk from low-altitude aircraft overflights but not for tracked vehicle movement or missile firing.

2.2.2.1 Overflight

The AH-64D Apache Longbow takes off from the Inverted Range Control Center (IRCC) or Comanche Flats. It is assumed in this assessment that all take-offs are from the IRCC. The Apache flies between 150-400ft AGL (above-ground level) during the test. The helicopter moves to one of five launch points and hovers at about 300 ft[1] AGL to acquire a line of sight. The helicopter fires. After launching, the Apache "locks-on" to the Hellfire to direct its route. (A Longbow carrying Hellfire missiles can lock-on before launch, or launch on coordinates and lock-on in flight.) The Apache flies in a northern direction to view the success of the shot, usually hovering within 500-m lateral distance from the tank. Then it returns to the IRCC. If the launch does not result in the detachment of the missile from the helicopter, it lands at the CM1 helipad so that the missile may be removed. This rare event is not modeled in this assessment. When needed, the helicopter refuels downrange at site 8 (approximately 5km E-SE of CM1); however, this action is not considered a component activity of the test for the purpose of this risk assessment demonstration.

The speed of the helicopter while flying is about 100 knots. For the overall mission, we assume an average velocity of 20 knots, considering that most shots occur at a hover (Bert Evans, Yuma Proving Ground, personal communication). The test included five launch points which are described in Sect. 2.2.2.2.

2.2.2.2 Missile firing

AGM-114L missiles, millimeter-wave seeker versions of the Hellfire 2 missile that are designed for use with the Longbow helicopter, were used in the test. These missiles are 1.78 m long with a body diameter of 178 mm, a wing span of 0.33 m and a weight of just under 50 kg (Jane's Information Group 2000). Localized fires following tank impact can last about 10 to 15 minutes before they are put out with an extinguisher; others go out by themselves. The shot range in the test was typically 4 to 6.4 km, in the middle of its minimum range of 500 m and maximum range of 9 km (Jane's Information Group 2000).

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[1] Distance units are reported in conventional units for the relevant discipline: the U.S. military convention of British units (feet) for altitude, the hydrological science convention of British units for soil depth and water infiltration (in), and the U.S. military convention of SI units (meters) for lateral distance. However, lateral speed is generally reported in knots.

Actual launch point coordinates were provided by Yuma Proving Ground but are not presented here (w indicates waypoint):
w46 (6 kilometers from target)
w49 (4 kilometers from target)
w50 (5 kilometers from target)
w51 (4 kilometers from target)
w52 (4 kilometers from target).

As stated above, firing occurs at 300 ft AGL. It is assumed that no sonic boom occurred. Missile impact occurred at various locations on the MTI Road (or a short distance off-road) between Red Hill Road and West Target Road. It is assumed that impacts occurred near the Pinkrock Impact Point (IP) at Northing 3665154 and Easting 742068 (NAD-27 coordinates).

It is assumed that there were no target misses.

The Hellfire missile does not have a depleted uranium head.

2.2.2.3 Tank movement

During the test, the remotely controlled tank targets move south (down slope) on the Moving Target Indicator (MTI) Road from the Red Hill Road intersection, and are fired at while driving along that road. After the test, they turn around at West Target Road or north of West Target in turnaround areas adjacent to the MTI road to begin a new test event. YPG staff indicate that the turnaround area is located in a borrow pit that was used to develop the road. However, for the purpose of this assessment, turnaround areas that were developed in the past two years are assumed to disturb existing desert pavement. The tanks are M60-A1 tanks. One to three targets are present during each event (i.e., 2-hr mission period). Spacing between targets is initially 70 m. Typical target maneuvers included the following:
- 3 targets travel at a constant velocity of 7.5 m/s (27 km/h) down MTI road, no maneuver
- 3 targets travel at a constant velocity of 7.5 m/s (27 km/h) down MTI road, first target turns off road and stops
- 3 targets begin at a velocity of 5 m/s (18 km/h); target 1 accelerates to 10 m/s; target 2 accelerates to 7.5 m/s
- 1 target turns 5 degrees, turns to 25 degrees, then accelerates to 7 to 8 m/s.

The target(s) which turned off-road traveled at a 5E to 20E angle to the road along a preexisting path. The remotely controlled targets never travel on open landscapes. The tanks do not travel through desert wash areas; MTI Road was constructed on desert pavement and represents an improved dirt trail.

Impacts of wheeled administrative vehicles are not considered as part of this test program.

2.2.3 Description of Additional Testing Programs in Study Area

The areas that are used for moving-target live fire include MTI Road, West Target Road, Red Hill Road and East Target Road. Future Hellfire tests may involve the use of two helicopters. Hellfire missiles have been fired into the ground at CM4, located at the intersection of

Additional test programs in the area involve rotary and fixed-wing aircraft, explosive weapons and tracked vehicles.

West Target and Target Boundary Roads, in the McAllister Wash watershed. Combat Systems also uses regions in Cibola Range to test tracked vehicles (YPG 2001). Some of the turn-around areas along MTI Road may have resulted in part from these tests.

Electro-optic targeting devices are tested and validated in Cibola Range by Aviation and Airdrop Systems personnel. These tests include the testing of sensors on the CM-1 hill, some of which are attached to helicopters. Corner reflector arrays and heat arrays are within a few kilometers of the MTI

Road, and in one test an F4 aircraft was overflown with sensors mounted on the aircraft which would ordinarily be on a missile. Direct fire and moving target ranges for testing these targeting devices are located south of West Target Road, near the 5-road intersection at the IRCC.

Rocket Alley in Cibola Range, south of the IRCC, has been used to test 2.75-inch rockets and ZUNI rockets (YPG 2001). This range is in the watershed of Indian Wash rather than McAllister Wash. Prospect Square, used both as an impact area and ammunition drop area, is heavily contaminated with unexploded ordinance. The area is upgradient from our site, spanning both the McAllister Wash and Indian Wash watersheds.

The *Final Range Wide Environmental Impact Statement* (YPG 2001) proposes to convert YPG into a multipurpose installation that would integrate testing with training and privatization activities. Thus, the study site could be utilized and disturbed beyond its current uses and disturbances.

2.3 ENVIRONMENTAL DESCRIPTION OF STUDY AREA

Yuma Proving Ground is located in southwestern Arizona, in the Sonoran Desert. The study area comprises the region in Cibola Range between the Chocolate and Middle Mountains, from the IRCC in the south to the intersection of Red Hill and MTI Roads in the North. The site is in the Lower Colorado River Valley Subdivision (also termed the microphyllous desert) of the Sonoran desertscrub vegetation community (Turner and Brown 1994). The Lower Colorado Valley is the driest region of the Sonoran Desert, with high temperatures, low precipitation, and low average plant cover (1 to 5%) (Ayres Associates 1996). As is true of a large fraction of YPG, the study area consists of desert pavement; xero-riparian wash habitat (tree-lined desert washes); and other minor soil types. Desert pavement is a tightly-packed layer of wind- and water-eroded pebbles. The closely-packed gravel-, pebble-, and cobble-sized rocks on the surface become coated with a varnish formed from manganese and iron oxides derived from the underlying soil, forming a hard, dark surface that absorbs and radiates substantial heat from the sun. This surface is resistant to plant germination and growth except where it is disturbed, and pavement probably sheds most of the rainfall to the wash areas.

> Key features of the Yuma Proving Ground environment include tree-lined desert washes and barren desert pavement.

The primary desert wash that may be impacted in the Apache Longbow–Hellfire missile test area is McAllister Wash. To the south and east is Indian Wash, which may also be downgradient from the study area.

2.3.1 Desert Wash Dynamics

The greatest fraction of floral and faunal biomass and diversity at YPG is found in the alluvial washes and their associated tributaries that contain relatively high levels of soil moisture (Bern 1995; YPG 2001, Arizona Game & Fish Department 1986). Desert shrubs and trees such as blue palo verde and desert ironwood predominate in the wash areas and provide important habitat and food sources for many wildlife species.

The low-moisture land areas outside of the washes, comprised primarily of highly impermeable desert soils, desert pavement, and barren rock surfaces, can be inhospitable habitat for all but the most adaptable desert plants and animals. In addition to the low infiltration of water, the absence of plants here on pavement has been attributed to the presence of large quantities of exchangeable sodium in the soil layer immediately beneath the pebbles (Turner and Brown 1994). These areas, however, serve an important function in diverting ephemeral runoff of precipitation to the wash communities during major storm events. Infrequent, high-intensity storms may be extremely important in recharging the water budget of the washes, and ultimately, in maintaining wash vegetation health (Shlesinger and Jones 1984,

McDonald 2000). In some cases, water flowing to the washes from runoff may be two or three times the amount of water from direct precipitation (McDonald 2000). Thus, direct, annual precipitation to a particular land area is not the only predictor of plant density (Schlesinger and Jones 1984).

In many desert regions surface vegetation and stony cover help detain runoff, but at YPG pavement has low vegetation cover and low permeability rates. Thus, during high storm events, much water is funneled to the washes. Disturbance to the pavement may result in some loss of runoff water to the washes by creating depressional areas that retain and pond water, exacerbating losses via evaporation and transmission through soil. In addition, microhabitats may be created where disturbance-adapted plants can become established, resulting in water that is retained and transpired, and thereby diverted from washes.

2.3.2 Meteorology

The amount, timing, and extent of precipitation defines the hydrology of the desert environment. Precipitation at YPG generally occurs in the late summer months and in winter. The late summer precipitation occurs as brief, geographically isolated, intense thunderstorms (as a result of storms from the Gulf of Mexico or the Gulf of California, or more commonly from convective activity). In winter, less intense, more widespread, longer duration rain showers occur (commonly cold fronts from the Pacific Ocean). Good precipitation data for YPG are available from the ASL Yuma Meteorological Team (Ayres Associates 1996). Between 1954-1995, the average annual total precipitation was 3.59 inches. Monthly totals are highly variable, with August having the highest average rainfall and May having the lowest (Table 2.1). High standard deviations indicate the variability of precipitation in the YPG region.

> Precipitation occurs in the late summer months and in winter. A 5-year-event storm would generate 1.0 inches of rainfall in one hour.

Table 2.1. Mean monthly precipitation for Yuma Proving Ground (inches, Ayres Associates 1996)

Month	Total ± SD
January	0.50 ± 0.55
February	0.34 ± 0.49
March	0.32 ± 0.51
April	0.14 ± 0.35
May	0.03 ± 0.08
June	0.04 ± 0.23
July	0.21 ± 0.41
August	0.57 ± 0.74
September	0.40 ± 0.65
October	0.34 ± 0.76
November	0.26 ± 0.47
December	0.42 ± 0.60

It is not unusual for half of total annual rainfall to occur in one month; the average ratio of highest monthly total rainfall for each year relative to the total annual rainfall for that year is 40.9%. The highest annual total rainfall was in 1992, when there was 10.27 inches of rain, with greater than two inches in August, December, and March. During the 1980-1995 period, with the 1992 exception, only in one other year was there a monthly total that exceeded 2 inches (August of 1989) (Ayres Associates 1996).

The two largest thunderstorm events, as measured by the maximum precipitation in a 24-hr period between 1954-1995, were 3.02 inches (55% of the annual total) and 2.4 inches (57% of the annual total). The annual average maximum precipitation in a 24-hr period was 1.46 inches, indicating that relatively large thunderstorm events account for at least approximately 40% of the annual total. Although the largest thunderstorm (as defined as rainfall total in less than 24 hr) in a given year *averages* about 1.5 inches, rainfall of that amount is clearly not an annual event. Ayres Associates (1996), using data from the *NOAA Atlas 2, Volume VIII-Arizona* (Hershfield 1961) to estimate rainfall in the Yuma Basin, used a multiplier to determine mass rainfall amounts for 1-, 6-, and 24-hr duration storms at 2-, 5-, 10-, 25-, 50-, and 100-year return periods. This analysis indicates that a mass rainfall amount of 1.5 inches in a 24-hr period occurs on average every 2-5 years. Looked at another way, a 5-year-event storm would generate the mass rainfall amounts of 1.0 inches, 1.5 inches, and 1.9 inches in 1-hour, 6-hour, and 24-hr durations. Given that few thunderstorms produce sufficient precipitation to initiate surface flow, it can be presumed that these high intensity storms, occurring relatively infrequently over a multi-year cycle, are the critical events for any runoff-related recharge of the water budget of washes.

Low-intensity rains in the winter months provide significant amounts of water to desert washes by direct precipitation, but are unlikely to be sufficient to generate runoff that would provide significant quantities of water to the washes, even in undisturbed environments.

Temperatures at Yuma Proving Ground are typical of low desert climates. The mean temperature for July is 42EC, and the mean temperature for December is about 16EC. Diurnal temperature gradients can be high, with an average of about 11EC (Palmer 1986).

Meteorology is generally considered as part of the background or "input" environmental conditions for an ecological risk assessment. However, the particular stressors associated with numerous meteorological events, such as hurricanes, sand storms, floods, and droughts, may also be integrated into an ecological risk assessment of military activities. Although most of these are not considered explicitly in this risk assessment, plant scars associated with drought, and the associated permeability of desert pavement and altered hydrology in small spots across the landscape, could be studied in the future.

2.3.3 Maps of Study Area

Soils and desert wash boundaries are depicted in Fig. 2.1. These map layers are critical to defining the habitat of woody wash vegetation and to determining the permeability of soil in the hydrological analysis of the test area (Chapter 5).

Maps of soil types, wash boundaries, and elevation are available, as well as aerial photos.

Individual 30-m resolution Digital Elevation Model (DEM) maps obtained from the USGS ftp site were mosaiced together (Fig. 2.2). The mosaicing process blends adjacent DEMs so that the seams are invisible. This resulted in a digital model of the terrain contours in the study area at YPG. The DEM mosaic was clipped to the same extent as the soil types layer (Fig. 2.1) so that information about the soil type within each 30-m cell could be obtained for the hydrological analysis (Chapter 5). To ensure that overland flows would travel into known washes, the wash areas were lowered one foot in the elevation model.

A Digital Ortho Quarter Quad (DOQQ), i.e., an aerial photo of the MTI Road, is depicted in Fig. 2.3. DOQQs of our study site were pasted ("mosaiced") together into a single GIS.

Fig. 2.1. Soil series, desert wash boundaries, and roads in study area of Cibola Range. The Apache-Hellfire test occurred in the area along MTI Road, in red, north and west of the 5-road intersection.
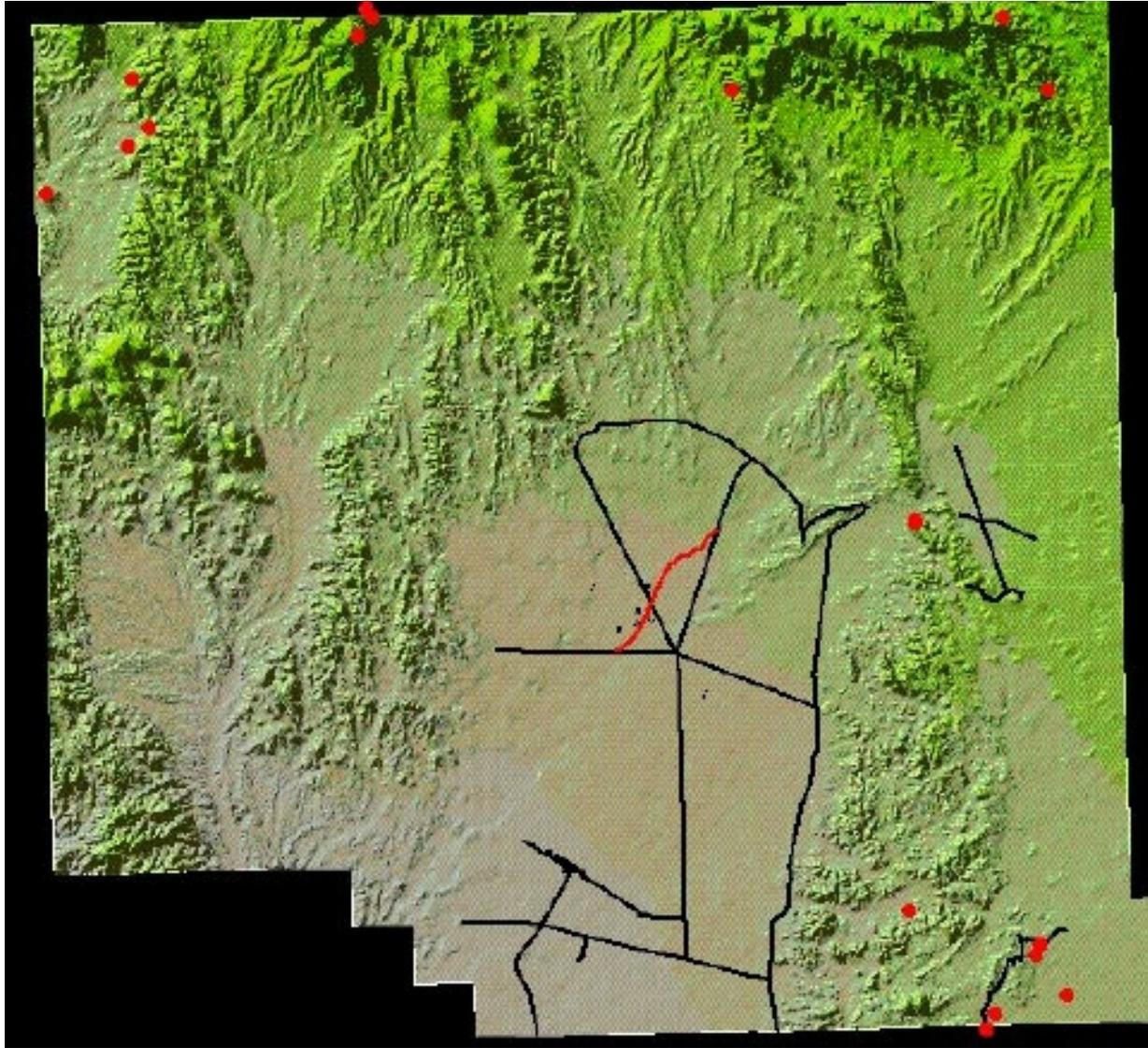
Fig. 2.2. A shaded relief digital elevation model of the study area in Cibola Range with water points in red. The Apache-Hellfire test occurred in the area along MTI Road, in red, north and west of the 5-road intersection.
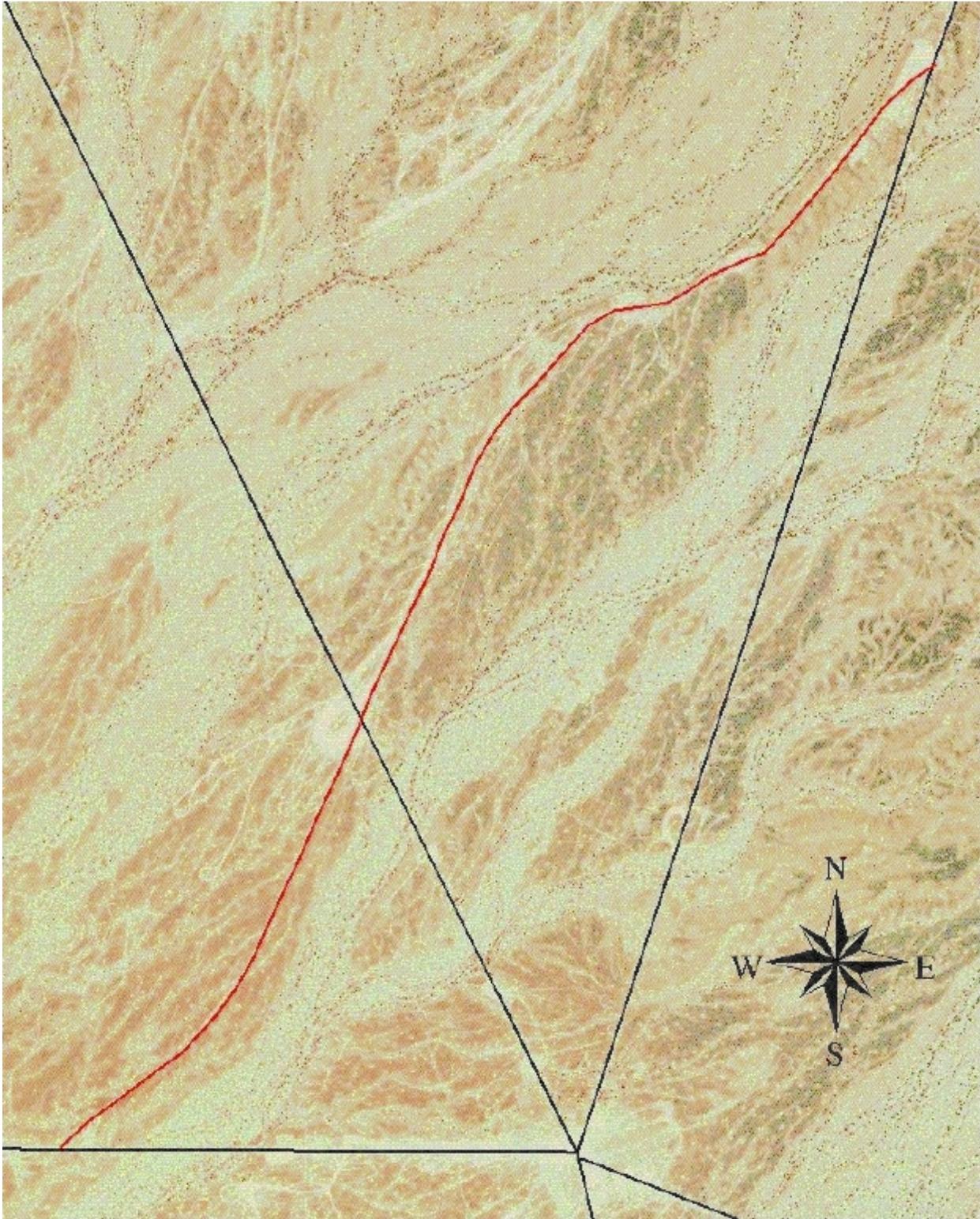
Fig. 2.3. A close-up, Digital Ortho Quarter Quad photo of the vehicular movement area in Cibola Range. The Apache-Hellfire test occurred in the area along MTI Road, in red, north and west of the 5-road intersection.

2.4 TEMPORAL AND SPATIAL SCOPE OF ASSESSMENT

The scope of the assessment is specified in the problem formulation phase of a risk assessment. That is, the risk assessor determines the area and time period that are the subject of the assessment. Three principal types of bounds may be defined:
C   bounds on the areas and times in which training and testing activities occur (core area and time),
C   bounds on the areas and times in which the indirect consequences of training and testing activities occur (influence area and time), and
C   bounds on the areas and times in which the endpoint species or communities occur (endpoint area and time).
In addition, a land manager may define an assessment boundary based on land ownership or management boundaries.

2.4.1 Core area

The core area of this assessment clearly includes the portion of the MTI Road where the moving targets drive, the off-road areas where they turn around, and the off-road area where a tank drove off road at a 5-to-30-degree angle to the MTI road during the test. The helicopter flight path and the missile trajectory should also be considered parts of the core area. Thus, the core area may be considered to comprise a series of vectors: the tank paths, the helicopter paths associated with the five shooting locations, and the five missile trajectories, projected onto the land. The coordinates of this core area are approximately defined by the area between the Chocolate and Middle Mountains and north of the IRCC and south of Prospect Square (i.e., bounded by coordinates of 749000 Easting and 747000 Easting and 3656000 Northing and 3670000 Northing (UTM Zone 11 coordinates in meters). As stated above, although some takeoffs occurred at Comanche Flats, this location west of the West Environmental Test Area on Laguna Range is not considered part of the test area in this demonstration of MERAF.

> The core assessment area is approximately 126 km^2.

2.4.2 Core time

The core time of the program is a three-week period, including fourteen days of activity, in August 2000. Because a similar test was conducted in October of 1998, one could assume that the program may occur for a few weeks of the year, every two years or so, but the frequency of the test program is highly dependent upon (1) the success of each test, (2) competing needs for this area of Cibola Range, and (3) competing needs for operations personnel.

> The core time is a three-week period.

The program has been conducted in the morning of each day, and it is not expected that additional tests would occur at night.

2.4.3 Influence Area

The influence area of the Apache Longbow–Hellfire missile test may be assumed to include the area along the helicopter path that is exposed to significant noise levels and the area across which drainages are receiving modified

> The influence area is the area along the helicopter flight path exposed to significant noise levels and the area of drainages receiving modified flows.

water flows. Unless the Hellfire detonation is much louder than the helicopter, the missile's influence area should not project beyond that of the helicopter, given the helicopter's much longer trajectory. The exact influence area can only be established with a high level of confidence after the exposure assessment has resulted in sound contours for the helicopter, and hydrological analysis has been performed. Prior to these analyses it was determined that the area of potentially significant hydrological changes associated with vehicle movement would be encompassed within the area of potentially significant helicopter noise, given the much longer trajectory of helicopters than of vehicles during the test. The influence area could include land area south of the IRCC, as helicopters taking off from that location could have an acoustic or behavioral impact south of that "core area" boundary. (Technically, any hydrological impact could be propagated all the way southwest to the Colorado River, but it is doubtful that this change in exposure would result in significant effects in high flow areas.) We estimate that the influence area would be on the order of hundreds of km^2.

2.4.4 Influence Time

The time influenced by a program is the time from the end of program activities to the recovery of all endpoint receptors. If mule deer populations (designated as assessment endpoint entities in Sect. 2.5) were adversely affected, then

> **The influence time must include the recovery period.**

recovery time would take a generation or more. The recovery of mule deer behavior from noise would be expected to be comparatively rapid (hours or days). On the other hand, much evidence suggests that vehicle tracks can affect surface soil microtopography and permeability, as well as vegetation composition or biomass for decades or perhaps centuries in semiarid and arid regions (Prose 1985, Lathrop 1993, Milchunas et al. 2000). Thus, if tanks turn around off-road, the influence time of the activity could take a century or more, even if the spatial scale of the effect is minimal. Similarly, many of the trees in the desert washes may be over 100 yrs old, so drought-induced mortality could have a long influence time.

2.5 ASSESSMENT ENDPOINT ENTITIES AND PROPERTIES

Assessment endpoints are explicit expressions of environmental values that are to be protected. The process of endpoint selection identifies which of the environmental entities are sufficiently valued to potentially change a management decision, are ecologically important and susceptible to the proposed activities, and are practical for assessment (EPA 1998). Susceptibility implies potential for a high level of exposure to stressors and/or a high degree of sensitivity to the stressors. In addition, state and federal regulations must be considered in the choice of endpoints.

An ecological assessment endpoint consists of an entity (population, community or ecosystem process), a property of that entity (abundance or production of a population, production or diversity of a community), and a level of potentially unacceptable adverse effects (e.g., 20%).

2.5.1 Potential Endpoint Entities and Properties

Numerous ecological endpoints could be chosen for this study. Almost all populations and communities in the area are susceptible to one or more of the component activities of the Apache-Hellfire test. Examples are provided in Table 2.2.

Table 2.2. Ecological endpoint entities susceptible to the Apache-Hellfire test at Yuma Proving Ground

Entity[a]	Example species	Species properties that would lead to increased exposure	Species properties that would lead to increased effects
populations of raptors	red-tailed hawk (*Buteo jamaicensis*) or American kestrel (*Falco sparverius*)	habitat in open area directly below or near overflight (e.g., red-tailed hawk nests), diurnal activity	behavioral sensitivity to low-altitude aircraft overflights
populations of ungulate mammals	desert mule deer (*Odocoileus hemionus crooki*), wild horses, wild burros	habitat in open area directly below or near overflight, diurnal activity	sensitivity to aircraft sound during rutting or while raising young, requirement for high-nutrient forage in washes that could be affected by altered hydrology if tanks disturb desert pavement
populations of carnivores	coyote (*Canis latrans*), kit fox (*Vulpes macrotis*), bobcat (*Felis rufus*), badger (*Taxidea taxus*)	habitat in open area directly below or near overflight, diurnal activity, found almost exclusively in washes	sensitivity to decreases in prey, reliance on auditory cues to detect prey or food
populations of small mammals	Harris' antelope squirrel (*Ammospermophilus harrisii*), round-tailed ground squirrel (*Spermophilus tereticaudus*)	dens located adjacent to road where tanks drive, burrowing under areas of tracked vehicle movement, diurnal activity of some species,	reliance on auditory cues to avoid predators
populations of reptiles	desert tortoise (*Gopherus agassizi*)[b], side-blotched lizard (*Uta stansburiana*), desert horned lizard *(Phrynosoma platyrhinos*), western whiptail (*Cnemidophorus tigris*)	habitat in open area directly below or near overflight, burrowing under areas of tracked vehicle movement, diurnal activity of some species	sensitivity of some populations to sound, but mostly unknown
desert shrub community	creosote bush (*Larrea tridentata*), bursages	habitat in location adjacent to vehicle movement	potentially exposed to vehicle movement, which is synonymous with sensitivity (ie, crushing) for this stressor
woody plant community in wash	blue palo verde (*Cercidium floridum*), desert ironwood (*Olneya tesota*), catclaw acacia	potentially exposed to changed in hydrology associated with vehicle movement	requires precipitation runoff from desert pavement that could be disturbed by tanks

Entity[a]	Example species	Species properties that would lead to increased exposure	Species properties that would lead to increased effects
	(*Acacia greggii*), western honey mesquite (*Prosopis glandulosa*)		

[a] If entity is a threatened or endangered species, then the relevant entity for a risk assessment should be an individual of the species rather than a population, and the property would be mortality, reduced fecundity, or loss of habitat (i.e., due to abandonment).

[b] Sonoran populations of desert tortoise are not threatened or endangered. The closest records of the tortoise are >10 km east and northeast of core study area. There is low potential for their presence in the study area, but it is possible in northern part of the area. Tortoises prefer rocky bajadas and steep slope.

Several valued species are not candidate assessment endpoint entities. Although desert bighorn sheep (*Ovis canadensis)* are known to use washes for cover, forage, and as migratory corridors, the sheep with habitat in the Chocolate and Middle Mountains have not been observed to migrate through the core area that is the subject of this study (Palmer 1986). Most small mammals such as pack rats and kangaroo rats are noctural and would probably be less exposed to sound and crushing by tanks than diurnal animals. The Mojave fringe-toed lizard (*Uma scoparia*) has only been observed in far northwest Cibola Range. Bats such as the California leaf-nosed bat (*Marcrotus californicus*) would be candidate endpoint species if the test occurred at night. Smoketree (*Dalea spinosa*), a valued tree species in desert washes of Yuma Proving Ground, was not observed in the core area of McAllister Wash during a field visit, but may be present.

Endpoint properties that are generally of regulatory concern include the abundance or production of vertebrate populations and the primary production, biomass or diversity of vegetation communities. In this study, animal behavior is sometimes considered to be an endpoint property because behavior is the response associated with noise exposure-response thresholds. However, it is not recommended to select endpoint properties based on the information that is available. They should be based on the goals of the assessment.

2.5.2 Need for Focus in this Study

The inclusion of numerous ecological assessment endpoints is not necessary for a demonstration of MERAF. To follow dozens of endpoints from the problem formulation to the analysis of exposure, the analysis of effects and

The potential assessment endpoints are reduced to two.

risk characterization could detract from the logical flow and focus of the assessment. In addition, funding limits the number of assessment endpoints. Thus, we have chosen the production and diversity of the woody desert wash community and the abundance and production of the desert mule deer (*Odocoileus hemionus crooki*) population as assessment endpoint entities and properties.

Because woody vegetation serves as cover and food for the mule deer, this choice of endpoints allows us to demonstrate the thought processes related to the consideration of indirect or contingent effects. That is, what if the biomass of particular desert wash species is reduced or a species is lost? How does that loss affect the abundance and production of the mule deer population? Other integrator species that utilize the washes (e.g., bobcats, neotropical migratory birds, raptors) would have served this purpose as well as desert mule deer.

In this risk assessment, a specific level of effects for the endpoints is not specified. That is, in many risk assessments, a 20% decrease in an endpoint entity such as abundance of mule deer, or a 20% decrease in vegetation cover may be considered significant (Suter et al. 2000). This is a management decision. However, where possible, we present information about 20%-level decrements in endpoint entities for demonstration purposes.

2.5.3 Vegetation in Washes

The biomass and/or diversity of woody vegetation in washes is an endpoint entity. Species that are found in desert washes include small trees, all of which are in the legume family, and all of which are aphyllous (no leaves) or microphyllous (small leaves), having a high proportion of their chlorophyll in or beneath the bark of stems (Turner and Brown 1994). Wash species include ironwood (*Olneya tesota*), blue palo verde (*Cercidium floridum*), western honey mesquite (*Prosopis glandulosa*), and catclaw acacia (*Acacia greggii*). Smoketree (*Psorothamnus spinosa*) is another wash species, which was not observed during a field visit to our study site.

> The biomass and/or diversity of woody vegetation in washes is an endpoint entity.

2.5.4 Mule Deer

Desert mule deer are a valued and susceptible species. The abundance and reproduction of mule deer are the population parameters that are of greatest interest. (Impacts to individual animals are typically of regulatory concern only if the population is threatened or endangered.) A challenge in this assessment will be to predict population parameters (for which there are no data) from estimated behavioral effects.

> Mule deer abundance and production is an endpoint entity.

2.6 EXPOSURE FACTORS

Exposure factors are quantities associated with assessment endpoint entities that help determine the spatial and temporal extent of exposure to stressors. These factors are presented here as they potentially apply to the assessment of risks from overflights (Chapter 3), missile firing (Chapter 4), and/or tank movement (Chapter 5). For mule deer factors such as habitat, home range, density, biomass, timing of reproduction, and timing of migration are presented here. A risk assessor may consider whether or not all of these exposure factors are useful for a risk assessment. They are only useful if they may be used to predict exposures that may be linked to effects. (In the case of this risk assessment for YPG, factors such as home range and timing of migration could not be linked quantitatively to responses of mule deer.)

2.6.1 Wash Vegetation

2.6.1.1 Delineation of washes

A map of desert washes in the study area is provided as Fig. 2.1. It should be noted that wash boundaries change with time (i.e., with voluminous storm events), and therefore Fig. 2.1 should be considered an approximation of the wash boundaries in August of 2000.

2.6.1.2 Species and biomass

U.S. Army installations collect some vegetation distribution data as part of the *Land Condition - Trend Analysis* (LCTA) Program. Data for the study site at Yuma Proving Ground are presented in Appendix A. From the base

Ironwood, paloverde, mesquite, and acacia are common woody wash plants in the area.

point of each LCTA plot, transects run for 100 meters at a known azimuth with a 6 meter width. Key components of the desert wash vegetation community include ironwood (*Olneya tesota*), western honey mesquite (*Prosopis glandulosa*), and catclaw acacia (*Acacia greggii*). Instances of *Cercidium microphyllum* (yellow paloverde) in the LCTA data may actually represent blue paloverde (pers. comm., S. Obregon, YPG, December 20, 2000). The two species have previously been confused by inexperienced surveyors.

2.6.2 Mule Deer

2.6.2.1 Habitat

Mule deer have been located in each of the seven plant associations found on YPG, including creosote flats (creosote/white bursage association), desert grassland (big galleta/mesquite association), dunes grassland

Mule deer use all habitat within the influence area, but washes are most heavily used.

(big galleta/foothill paloverde association), rolling hills (creosote/ocotillo association), mountain (foothill paloverde/saguaro association), bajada (foothill paloverde/ironwood association), and desert wash (blue paloverde/smoketree association) (Palmer 1986). Although some studies have shown that desert mule deer prefer mountainous vegetative associations (Ordway and Krausman 1986), the principal habitat used by deer for forage and cover at YPG is the blue paloverde/smoketree association of the washes (Palmer 1986). Smoketree is absent from these associations in the test site.

2.6.2.2 Home range

A change in home range or a change in distance from a water source are results that could lead to a change in abundance of mule deer. Therefore, typical home ranges in the region are discussed below. This discussion does not necessarily indicate that home range shifts were

A change in home range or a change in distance from a water source could lead to a change in abundance of mule deer.

associated with the Apache Longbow–Hellfire test. The text simply serves as background information in case home range shifts were found to result from the test activities in analyses in Chapters 3, 4 or 5.

Seasonal movement and watering

As temperatures at YPG increase in late spring and summer, desert mule deer occur much more consistently in washes within several kilometers of water sources (Palmer 1986). In

Some mule deer at YPG are migratory.

one study during the dry summer season in King Valley, AZ, which is approximately 35-40 km east of the study area, deer migrated to permanent water or remained in their home ranges at locations within 8 km of a water source (Rautenstrauch and Krausman 1989). Female mule deer visit water sources at least once each day in dry summer periods, usually around sunset, although up to 40% have been observed to

water during the day (Hervert and Krausman 1986). Female deer only drink once in a four-day period if temperatures are between 25E and 30EC (Hervert and Krausman 1986). The locations of the two watering points near the study area on Cibola Range are: 1) a tank located northeast of the study area: 749300 Easting and 3667700 Northing; 2) a tank located southeast of the study area: 749200 Easting and 3657600 Northing (UTM Zone 11 coordinates in meters) (S. Obregon, pers. comm, Dec. 18, 2000). These water point locations are depicted with others in Fig. 2.2.

Females that are denied access to usual water sources have been observed to leave their home ranges (Hervert and Krausman 1986). Some female deer in Cibola Range travel along washes to the Colorado River in the spring and return after the summer rains begin (Palmer 1986). They travel along washes with the densest and most diverse vegetation. Because a variety of travel routes are used, migration should not be impeded by the disturbance of one route. Also, it is assumed that the permanent water source northeast of our study site would deter some deer from migrating to the Colorado River.

During rainy periods, bucks often travel long distances (Palmer 1986). In a study in King Valley, all male deer were determined to be migratory (minimum-convex-polygon home ranges in winter and summer dry seasons do not overlap) (Rautenstrauch and Krausman 1989).

Home range size

Seasonal home ranges of migratory and nonmigratory desert mule deer in King Valley, AZ are presented in Table 2.3. 75% probability refers to the Fourier method used to calculate minimum area versus 75% probability estimates,

Home ranges of deer at YPG vary between about 7 and 99 km^2.

which requires no assumptions about the probability distribution of an animal's use distribution, has little sample-size bias, and excludes rarely used areas (Anderson 1982). These home ranges are much larger than those of other desert mule deer, except for those in the Belmont and Bighorn Mountains (Krausman and Etchberger 1995). For example, in a Chihuahuan Desert study, the average home range for males was 13.73 km^2 for males and for females, 5.67 km^2. It should be noted that King Valley has no dependable wildlife water source; thus, home ranges at Yuma Proving Ground may be expected to be smaller than areas presented in Table 2.3. Male deer in the Chihuahuan Desert of southwest Texas use larger home ranges than females at locations and during times when habitat productivity is low (Relyea et al. 2000). However, in King Valley, no differences in home ranges among different sexes of migratory deer were observed (Table 2.3, Rautenstrauch and Krausman 1989).

In the study in King Valley, AZ, six of 15 deer monitored had summer, dry-season home ranges that did not overlap with the home ranges used in the summer wet season through the spring (Rautenstrauch and Krausman 1989). Ten of fifteen deer that were monitored were migratory and traveled a mean of 14.2 km between seasonal ranges (range 8.8 to 23.5).

Based on deer densities in Sect. 2.6.2.3, there may be some overlap between home ranges in Cibola Range or, as stated above, home ranges in Cibola Range may be smaller than those in King Valley.

2.6.2.3 Density of mule deer

The average density of mule deer in the area of interest at YPG has varied from about 0.5 to 1.5 deer per square mile (0.19 to 0.58 per

The density of mule deer is 0.56/km^2.

Table 2.3. The mean seasonal 75% probability and minimum-convex-polygon home-range size (km^2) of desert mule deer and the mean distance (km) from deer to the closest permanent water source in King Valley, AZ (Rautenstrauch and Krausman 1989). Reproduced with permission from Paul R. Krausman, the Society of Mammalogists, and Allen Press

	Season											
	Winter			Spring			Summer dry			Summer wet		
	O	SE	*n*	O	SE	*n*	O	SE	*n*	O	SE	*n*
Migratory females												
75% probability	30.3A[a]	2.6	9[b]	62.3A	3.9	9	47.8A	5.6	10	29.7A	2.5	8
Minimum convex polygon	36.7	2.5	9	72.9	4.2	9	78.5	8.7	10	63.3	5.8	8
Distance	12.2A	0.1	86[c]	11.0B	0.1	101	4.2C	0.1	76	9.7B	0.1	69
Migratory males												
75% probability	48.5A	4.0	6	57.0A	9.7	6	32.0A	2.9	6	30.5A	3.0	6
Minimum convex polygon	90.7	8.6	6	99.0	8.9	6	33.7	4.3	6	38.0	3.9	6
Distance	10.7A	0.1	65	9.0B	0.1	78	5.1C	0.1	52	10.3B	0.1	49
Nonmigratory females												
75% probability	41.0A	4.4	8	50.8	4.8	8	22.3AB	1.9	9	10.7B	1.5	9
Minimum convex polygon	29.7	1.8	8	43.9	3.5	8	25.5	2.3	9	7.0	0.5	9
Distance	8.2A	0.0	102	6.9B	0.0	117	4.5C	0.1	92	7.6B	0.0	82

[a] Means within rows with the same capital letters are not different (P > 0.05).
[b] Number home ranges.
[c] Number locations.

square km) in the last ten years (Bob Henry, Arizona Game and Fish Department, pers. communication to Sergio Obregon, Dec. 20, 2000). The number present at any given time or place varies considerably but not in any predictable way. However, densities of deer are probably higher in the northern areas of Cibola Range than at our test site (Palmer 1986). The Arizona Game and Fish Department has counted up to eighteen deer on survey transects in the valley between the Chocolate and Middle Mountains, which translates to approximately 70 to 80 deer in 1994 (Bob Henry, pers. comm. to Sergio Obregon, Dec. 20, 2000). Vegetation condition and water availability probably are the most important factors, but overall numbers of deer change with fluctuations in precipitation. Current densities are likely lower than these

surveys indicate, as overall deer numbers have declined (Bob Henry, pers. communication to Sergio Obregon, Dec. 20, 2000).

It is unknown whether the 126 km² area between the Chocolate and Middle Mountains would delineate a "reproducing population." Such a population would probably have a larger range than that area. However, it is noteworthy that there is a precedent for vaguely defining a "local population" endpoint entity for Superfund ecological risk assessments (EPA 1999).

Therefore, for the purpose of this assessment, it is assumed that about 70 deer occupy the 126-km² study site. This gives a figure of 0.56 deer/km² or 1.4 deer/sq mi, which is consistent with the upper end of the range of 0.5 to 1.5 deer/sq mi cited above.

2.6.2.4 Forage behavior and dietary composition

Krausman et al. (1997) measured the relative density of plant species in seasonal diets of desert mule deer in the King Valley, AZ, region of the Sonoran Desert (Table 2.4). King Valley is located 80 km northeast of Yuma, AZ

Ironwood is a dominant browse species and has high nutrient content for mule deer.

within the boundary of Kofa National Wildlife Refuge. In that study ironwood was the dominant forage species of mule deer. Anderson et al. (1965) have observed that browse is dominant in mule deer diets during dry years.

Table 2.4. Relative density of plant species in seasonal diets of desert mule deer in King Valley, AZ, as determined by analysis of feces, September 1983-June 1984, adapted from Krausman et al. (1997)

Species[1]	Latin name	Jan-Mar	Apr-Jun	Jul-Sept	Oct-Dec
				%	
Ironwood	*Olneya tesota*	40.8	35.9	49.0	44.1
Smoketree[2]	*Dalea spinosa*	18.9	3.2	14.0	31.5
Paloverde species	*Cercidium*	0.1	4.5	8.0	2.6
Mesquite	*Prosopis juliflora*	0.4	1.6	8.5	1.2
Browse[3] total		64.6	66.1	87.0	84.2
Forb total		34.8	33.5	6.0	14.2
Grass total		0.1	0.4	3.0	0.4

[1]Mesquite was not listed as a significant fraction of the mule deer diet.
[2]Found in many washes in Cibola Range, but not in specific test area.
[3]Perennial shrub

Rautenstrauch et al. (1988) measured the nutritional quality of desert mule deer forage in the King Valley. Factors that were measured included: dry matter, protein, ash, fiber, cellulose, hemicellulose and lignin. Blue paloverde, mesquite, ironwood and catclaw acacia, woody trees of desert washes, had among the highest protein contents (Rautenstrauch et al. 1988). Bobek et al. (1984)

developed an index of nutritional content of forage that is calculated as (% protein × % ash) divided by (% ether extract × % acid detergent fiber). This index is presented for several plant species in Table 2.5. Ironwood is among the most nutritious species to mule deer (Table 2.5) as well as comprising a large fraction of the deer's diet (Table 2.4).

Table 2.5. Index of nutritional content of mule deer forage, calculated from data in Rautenstrauch et al. (1988) using formula of Bobek et al. (1984)

Species[1]	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec
Ironwood	2.06	2.37	2.45	3.00	1.69	2.34
Blue palo verde	1.83	1.57	0.79	2.66	1.66	1.21
Acacia	1.33	0.81	1.77	2.49	1.09	0.97
Brittlebush	0.95	0.69	0.43	1.03	1.69	1.10
Desert lavender	0.23	0.15	0.19	0.39	0.33	0.28
Ratany	0.68	0.81	1.46	1.14	1.21	0.61
Wolf-berry	3.99	1.32	0.45	0.13	NA	1.00
Jojoba	2.14	1.14	2.10	1.10	1.57	1.16

[1] Species include those found near the core study area in LCTA plots 95, 99, 106, 108, 96, 98, 101, 103

2.6.2.5 Timing of critical reproductive activities

Desert mule deer fawning at YPG occurs in May and June, and the rutting period takes place in November and December months (Sergio Obregon, YPG, personal communication, December 2000). Elsewhere in the Mojave-Sonoran Desert province, fawning has been observed to occur in August and September (Fox and Krausman 1994).

Critical times for mule deer are May-June and November-December.

2.6.2.6 Predation on mule deer

Mule deer constitute about 10% to 13% of the coyote diet, post-fawning, and 0% pre-fawning in the Belmont and Bighorn Mountains, Arizona (Fox and Krausman 1994). Thus fawns are susceptible to predation. However, the impact of the Apache Longbow–Hellfire test on coyote, and thus on mule deer is beyond the scope of this study.

2.7 CONCEPTUAL MODEL FOR APACHE-HELLFIRE TEST

Conceptual models are representations of the hypotheses about how effects may be induced as a result of an activity or set of activities, e.g., the Apache-Hellfire test. They summarize the results of the problem formulation in terms of cause and effect relationships. The conceptual model for a test program consists of the

Programmatic conceptual models link stressors from all activities to potential effects.

integration of three types of conceptual models, if all are relevant to the study: (1) a set of generic, activity-specific conceptual models for each of the three activities, (2) a conceptual model for the site of interest, and (3) conceptual models for the assessment endpoint entities (Suter 1999b). A conceptual model for the site is not really necessary unless the stressor has complex interactions with the environment (as with a chemical toxicant that is propagated among multiple media such as soil, water and air). Noise is assumed to propagate in a simple manner, at least in the available sound contour models. A digital elevation model (Fig. 2.2) can serve the same role as a conceptual model for site hydrology; thus a site hydrological model is not needed for this study. A conceptual model for the assessment endpoint (ecological receptor) would include factors such as habitat and availability of cover, prey or other food, predators, natural stressors, etc. These relationships are described in Sect. 2.6.

A skeletal conceptual model for the Apache-Hellfire test is presented below (Fig. 2.4). This model includes the three activities, potential stressors, and the two assessment endpoint entities, woody vegetation communities in washes and mule deer populations. The link between wash plant production and mule deer abundance and production is shown, and the elucidation of this link becomes a demonstration of how MERAF may be used to address indirect effects of stressors (e.g., disturbance effects hydrological change, which potentially affects vegetation, which potentially affects mule deer. Also, the ability of MERAF to integrate risks from different activities is evident from the three potential sources of sound (aircraft, missiles, and tanks), and the two potential sources of hydrological change (vehicle movement and missile explosions).

Insignificant stressors are eliminated over the course of the risk assessment. The assessor has the flexibility to eliminate insignificant stressors at the beginning of the assessment (and not even include them in the conceptual model) or to carry them through the characterization of exposure, characterization of effects and risk characterization if there is reason to definitively demonstrate their lack of importance. In this demonstration of MERAF, some of these insignificant stressors are eliminated immediately (e.g., risks from chemicals in Hellfire explosions, risks from air movement associated with helicopters, risks from oil leaks associated with tank movement), and others are discussed at length to illustrate their lack of importance (risks from shrapnel associated with Hellfire explosions, risks from erosion associated with tank movement). No information was available to assess risks from noise associated with tanks, though this stressor could be locally significant.

Activity-specific conceptual models, which provide more details about the interactions among the stressors and desert wash vegetation or mule deer are presented in Sect. 3.1.2 (aircraft overflights), Sect. 4.1.2 (missile firing), and Sect. 5.1.2 (vehicle movement). In these conceptual models, rectangles are states, hexagons are processes, and circles are links to something outside of the model.
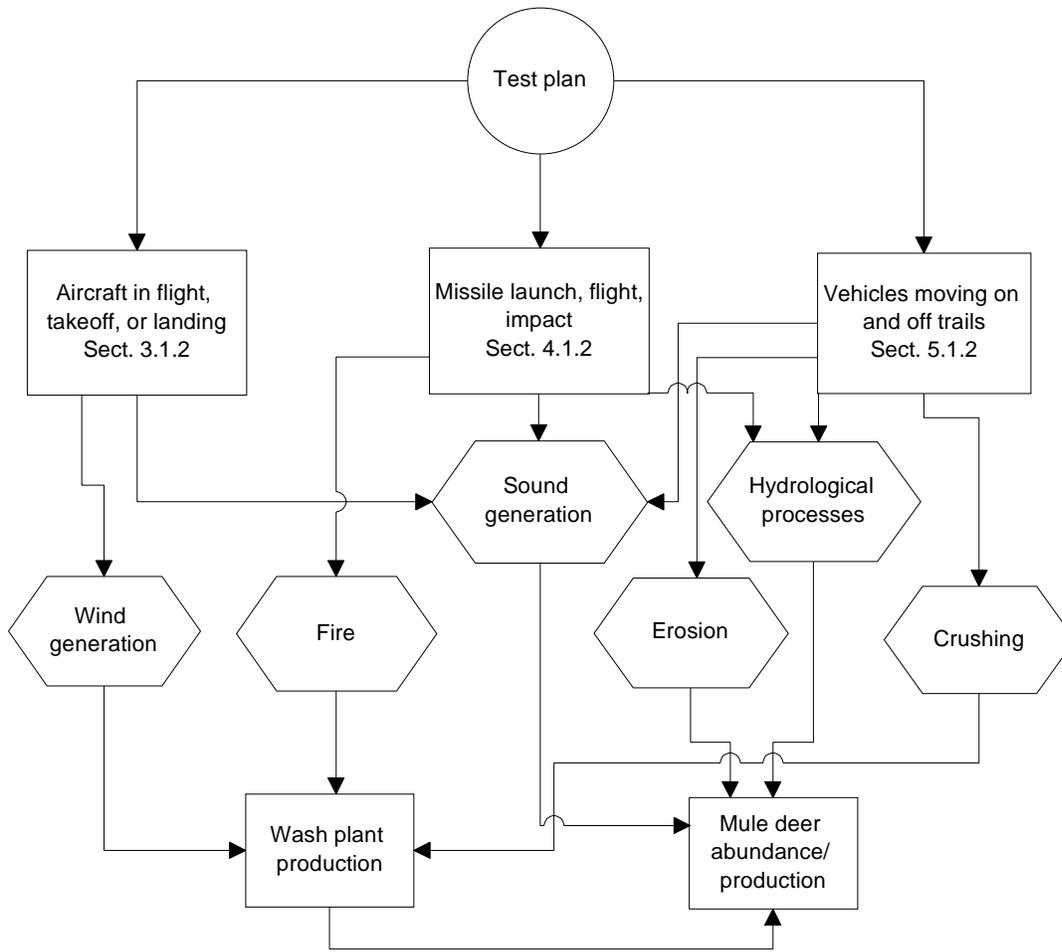
Fig. 2.4. Conceptual model for the Apache Longbow–Hellfire missile program at Yuma Proving Ground.

3. RISK ASSESSMENT FOR APACHE LONGBOW

3.1 ACTIVITY-SPECIFIC PROBLEM FORMULATION

3.1.1 Potential Stressors and Modes of Action

Candidate stressors associated with helicopter overflights are presented in Table 3.1, which is modified from *Ecological risk assessment framework for low-altitude overflights by fixed-wing and rotary-wing military aircraft* (Efroymson et al. 2000).

Sound is a key stressor associated with aircraft overflights.

Stressors are categorized broadly and may arise from several specific sources. For example, noise from helicopters consists of rotor noise, engine noise, gear box noise, and sometimes blade slap (Molino 1982). However, it is impossible to separate the intensity and frequency range of sound arising from each source during the activity. Sound pressure is treated as a single stressor, even though different frequencies of sound could be associated with different effects. Certain stressors were included in the generic risk assessment framework for overflights but were deleted in this particular assessment because of the test description: physical aircraft (birdstrikes by helicopters are rare and birds are not assessment endpoint entities in this study), vibration (potential modes of action are unknown), and heat (helicopters land on helipads, rather than on soil). In addition, some of the modes of action in the generic risk assessment framework for overflights are irrelevant because YPG does not have snow, ice or permafrost, and assessment endpoint entities in this study do not practice echolocation.

Table 3.1. Stressors and modes of action associated with overflights by rotary wing aircraft

Stressor	Potential mode of action
sound	behavioral response of wildlife, auditory damage to wildlife, interference with foraging or predation, interference with mating
sound level at a particular frequency	interference with signaling among wildlife, interference with echolocation
visual image or shadow of aircraft	behavioral response
air movement (rotor wash)	erosion and associated effects on plant community, stem breakage

3.1.2 Conceptual Model

The conceptual model for helicopter overflights is depicted in Fig. 3.1. The model represents the combination of overflight stressors in the Apache Longbow–Hellfire missile test, without making an assessment of importance of each stressor. The original

The conceptual model shows pathways between potential stressors (sound, view of aircraft, rotor wash) and potential effects.

conceptual model in Efroymson et al. (2000) included collision as a stressor, but that stressor only applies to birds, which are not assessment endpoint entities here. In this particular assessment there is no pathway from helicopter rotor wash to vegetation in washes, but this pathway is shown in Fig. 3.1

because an assessor unfamiliar with the location of the Apache Longbow–Hellfire test would have to consider air movement from the helicopter as a potential, direct stressor.
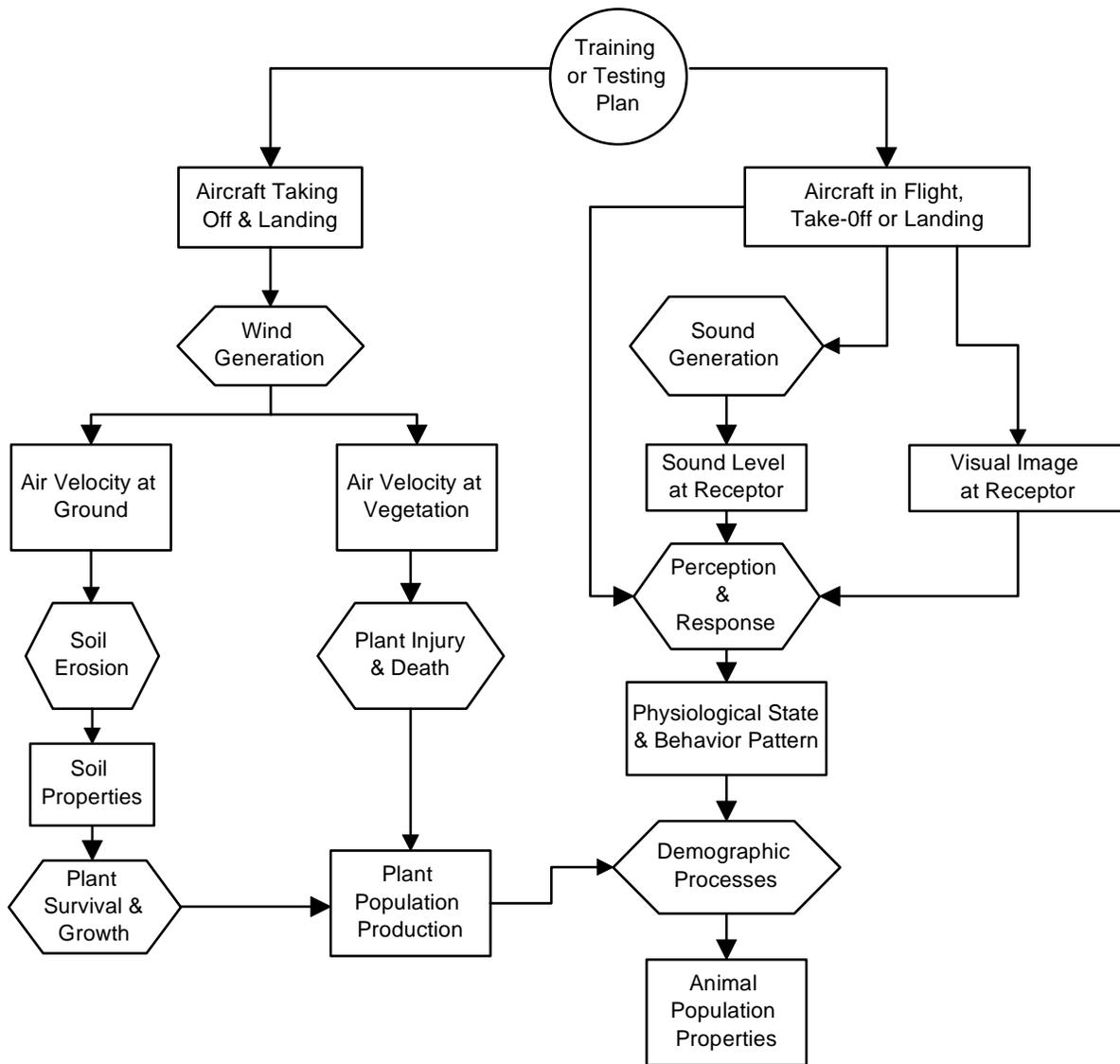
Fig. 3.1. Conceptual model for helicopter overflights in the Apache Longbow–Hellfire test at Yuma Proving Ground.

3.1.3 Selection of Activity-specific Measures of Exposure

3.1.3.1 Intensity measures

Sound

The principal two measures of exposure to sound that provide a description of a single overflight event and are related to responses in wildlife are the sound exposure level (SEL) and

Two principal sound metrics are A-weighted sound exposure level (SEL) and maximum sound level (Lmax).

26

maximum sound level (L_{max}). The SEL combines the maximum noise level of an overflight and its duration; all of the acoustic energy of an event is normalized into one second (USAF 1998). No information is available to determine whether the SEL or the maximum sound level is a better predictor of effects on wildlife, and limited effects data are available for each sound metric. Therefore, we use both SEL and L_{max}, as they are both optional output metrics of the MR_NMAP (Air Force noise contour) model, and as the former metric can be calculated from the day-night average sound level output of NOISEMAP, another noise contour model. The day-night average sound level (DNL), the primary noise metric used by DoD (especially the Army) (USACHPPM 1998), is not as appropriate for ecological risk assessment. The level is commonly associated with human community effects and often presented as a value that has been adjusted upward by 10 dB for sleeping hours or the "surprise" reaction to some overflights (USAF 1998).

Decibels (except for blast noise, Chapter 4) are most often expressed on an A-weighted basis (i.e., adjusted to represent the way the average human ear responds to various frequencies of sound), because sound monitoring devices are adjusted to this default and because the appropriate sound frequency weightings for few non-human species are known.   A-weighting leads to uncertainty when exposures are extrapolated from species to species or aircraft to aircraft to estimate exposure-response relationships (Efroymson et al. 2000). P. R. Krausman of the University of Arizona has developed a weighted sound metric for ungulates and tested the hearing levels for pronghorn (personal communication, Mara Weisenberger, Wildlife Biologist, USFWS San Andres NWR, Las Cruces, NM, 5/01/01); however, this metric cannot be used to clarify older exposure-response models or thresholds for ungulate behavior or production.

As stated in the risk assessment framework for aircraft overflights, background sound is not usually a significant contributor to the total sound, given the logarithmic scale of decibels (Efroymson et al. 2000). Thus, in rural areas such as the study area in Cibola Range, the background contribution to a sound exposure level can be ignored unless noise from natural sources (e.g., insects, amphibians, flowing water, or wind) or noise from other military tests is high.

Distance

The distance from an aircraft to an animal, sometimes called the "slant distance," as it is the hypotenuse of the right triangle that includes above-ground altitude and lateral distance, is the exposure metric in some exposure-response models for aircraft overflights (Efroymson et al. 2000).

> Distance from aircraft to receptor is a metric that represents sound and visual exposure.

3.1.3.2 Temporal measures

Temporal aspects of exposure include duration, frequency, and timing. The duration of an overflight may influence the magnitude of effect, but almost no information is available on this factor. An exception is the SEL metric above, which normalizes the sound level based on flight duration. Exposure-response models for overflights do not use frequency of overflight (number per day) as a temporal measure of exposure. However, this frequency may be related qualitatively to the likelihood of habituation (Sect. 3.3.1.5). The timing of overflights is critical, particularly as it relates to reproductive behavior, home range locations, and the diurnal or nocturnal activity of candidate assessment endpoint populations.

3.1.3.3 Spatial measures

Spatial measures of exposure include the spatial extent of overflights; the habitats, home ranges, forage and water locations of mule deer; and the area where mule deer potentially receive a critical level

of exposure to sound or to the sound and view of the aircraft combined. Many of these exposure factors are described in Chapter 2.

3.1.4 Selection of Measures of Effects

Measures of effects are identified in the problem formulation. With knowledge of these measures, the assessor can determine the types of data that may be obtained or generated and the models that must be generated in order to perform the analysis of effects. The measures of effects may be obtained from field studies, from the laboratory, or from observations at the specific site of concern.

Measures of behavioral effects include SEL, Lmax, and distance. These are not direct measures of the population-level assessment endpoint for mule deer.

The primary measures of effect are observed behavioral responses of ungulates to aircraft noise, including movement to a new home range and disruption of foraging, rutting, or calving. Changes in heart rate were used as supporting measures of effect. Thus, the measures of effect that are available or that can be simulated in this study are not direct measures of the assessment endpoint entity (mule deer abundance and reproduction).

3.2 CHARACTERIZATION OF EXPOSURE

3.2.1 Wash Vegetation

Vegetation in washes was not exposed to rotor wash (air movement) from the helicopter. Takeoffs and landings did not occur in the washes.

3.2.2 Mule Deer

3.2.2.1 Sound contours calculated using MR-NMAP

Sound levels experienced by mule deer were not measured as a part of this study. Therefore, sound levels on the ground were estimated using U.S. Air Force software, MR-NMAP and NOISEMAP. As described below, the use of both programs resulted in estimates of noise contours for the Apache Hellfire test.

Air Force programs NOISEMAP and MR_NMAP are used to estimate sound exposures of mule deer, even though these programs are not designed for helicopters.

However, it should be noted that neither of the two officially-sanctioned Air Force noise generation programs is ideally suited for noise simulation of a helicopter test.

Program structure

MR_NMAP (MOA Range NOISEMAP) v2.1 was obtained from the Air Force Center For Environmental Excellence (AFCEE) website, http://www.afcee.brooks.af.mil/ec/noise/noisemodels.htm. The program is intended to be run under the DOS operating system but can be run under Windows. This program is designed to simulate noise contours inside MOAs and MTRs, but will also simulate noise from bombing tracks. A bombing track is a flight path that is composed of straight segments and turns (Lucas and Calamia 1996). The track algorithms in MR_NMAP are similar to algorithms in the NOISEMAP program (Sect. 3.2.2.2). MR_NMAP is not designed for low-level flights by rotary-wing aircraft, even though it is used for that purpose. In MTR or bombing track mode, the program can only

consider one helicopter overflight at a time, which is a reasonable assumption for this test but not for many training activities. Training activities can be specified as operations in MOAs, with the number of daily, monthly or yearly values. The program interface was written by Wyle Labs, a contractor to the Air Force. Wyle Labs has completed MR_NMap v2.2, but this version has not yet been officially released by the Air Force, and so is unavailable. MR_NMAP v2.1 was used to generate noise contours for the AH-64 at YPG.[2]

MR_NMAP consists of 3 parts: a front-end to generate the situation input file, the noise simulation itself, and a back-end plotting program (Lucas and Calamia 1996). For MR_NMap, the front-end program is MR_OPS v1.60. MR_NMAP uses NMPlot v 4.5 as the back-end plotting package.

Within MR_NMAP, the user does not specify altitude at each point along the track. Rather, one specifies the percentage of time that the aircraft is between a series of altitude pairs. A maximum of 10 altitude pairs can be entered for each mission, and the altitude profile must begin at the lowest altitude and be contiguous from one altitude pair to the next.

Thus, instead of MR_NMAP calculating noise contours for different altitudes, it first calculates an Equivalent Acoustical Altitude (EAA), the constant altitude at which the aircraft must fly to produce the same average noise level for a distributed altitude profile. The EAA replaces the altitude distribution in all subsequent calculations. Using the EAA in place of the altitude profile significantly increases the computational speed of MR_NMAP during noise calculations and is intended to emulate the fact that aircraft do not always fly at the exact altitudes in the flight plans. However, the EAA prevents the user from specifying actual altitude changes within a single track. All noise contours produced by MR_NMAP are symmetrical because of this, regardless of altitude changes made by the aircraft as it moves over the track. The use of EAA in low-level operation may overestimate the noise contours which are produced (pers. comm., Kevin Bradley, Wyle Labs).

Contours and gridded data in UTM projections may be exported as shapefiles to ArcView.

Implementation for Apache-Hellfire test at YPG

Five attack runs for Apache Longbow AH-64 Hellfire testing were simulated. All attack runs begin with a takeoff at the IRCC, after fitting with Hellfire missiles. The five runs differ in the spatial location where the Hellfire is launched at

> The highest sound exposures predicted by MR_NMAP are 89 dB SEL and 102 dB Lmax.

armored targets traveling along the MTI Road. The launch points, provided by Bert Evans of Yuma Proving Ground, are cited in Sect. 2.2.2.2.

The MR_NMAP simulations assume that the Apaches fly directly from IRCC to one of the above firing points, fire, fly to the Pinkrock IP (w48) to assess the success of the mission, then fly directly back to the IRCC. Because the Apaches fly precision attack patterns during the Hellfire tests, we have simulated their paths as bombing tracks within MR_NMAP. Simulation of the paths as MTRs would have permitted more variance in course along the specified path, and may have resulted in inaccurately broad or narrow noise contour patterns.

Because there is no provision inside MR_NMAP for changing airspeed along a single track, the noise is simulated by assuming that the Apaches fly at 40 knots airspeed throughout the mission. (An average velocity of 20 knots was recommended by Bert Evans of YPG, but this low value is not an option

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[2] MR_NMAP had to be modified before it could be used. When we tried to generate examples of noise contours from AH-64 with MR_NMap, the program inappropriately generated noise from an F-16 aircraft. We contacted Kevin Bradley at Wyle Labs, and, upon examining our files, Mr. Bradley realized that the version of AIRCRAFT.DAT, the aircraft database, did not match the version of NOISE, the noise database. Thus, the version of MR_NMAP that has been recently distributed by AFCEE from their web page provides erroneous results for AH-64. Mr. Bradley advised us how to directly edit the situation input file, thus bypassing the front-end program to specify the AH-64 aircraft as the noise source. Mr. Bradley also provided a User's Manual for the MR_NMAP program.

in the program.) With rotary-wing aircraft in MR_NMAP, the airspeed setting determines the power setting as well. It is possible to select another "average" speed (of 6 available, 40 knots is the slowest), or to break the track into multiple individual tracks, which can then have different "average" speeds. This technique has not been used for the noise simulation of the Apache Longbow–Hellfire test.

In the simulation we assume equal distributions of missions across the five ground tracks and assume that a total of 14 daylight missions occur each year.

For these simulations, we have assumed an altitude profile in which the Apache spends 5% of mission time between 0 and 50 feet AGL, 5% between 50 and 100 feet, 5% between 100 and 150 feet, 5% between 150 and 200 feet AGL, 20% between 200 and 250 feet AGL, 30% between 250 and 300 feet AGL, and 30% between 300 and 350 feet AGL. This altitude profile distribution was recommended by Mr. Bert W. Evans at YPG as closely reflecting the Apache Longbow altitudes during Hellfire testing. This altitude-time distribution can readily be adjusted within MR_NMAP. The input file which specifies these noise simulations is included as Appendix B.

The output sound metrics that were utilized include Sound Exposure Level, or SEL, and Maximum A-weighted Sound Level, or Lmax. Contours were exported as shapefiles to ArcView. The noise contour output maps, draped on Landsat images, are presented as Figs. 3.2 (SEL) and 3.3 (Lmax). These maps depict the extent of above-ambient sound simulated from the Apache Hellfire test. The highest sound levels are 89 dB SEL and 102 dB Lmax. Contours going outward from the center indicate noise levels across the map. The default ambient sound level is 35 dB SEL in MR_NMAP. The default value was not changed because of the insignificance of background sound in most overflight sound exposure estimates (Efroymson et al. 2000) and the programming that would be required to change the default value.

3.2.2.2 Sound contours calculated using NOISEMAP

Program structure

NOISEMAP 6.5 is another official Air Force noise contour program. A copy was obtained from the Air Force Center For Environmental Excellence (AFCEE) website, http://www.afcee.brooks.af.mil/ec/noise/noisemodels.htm. Version 7.0 has been developed but is not publicly available. The program is intended to be run under the DOS operating system but can be run under Windows. NOISEMAP is designed to simulate noise contours at airbase runways or engine power run-up areas, and requires the entry of runway locations, takeoff directions, and approach and departure patterns. Because the YPG Hellfire tests do not involve airports and runways, MR_NMAP (above) was investigated first. However, an advantage of NOISEMAP compared to MR_NMAP is that NOISEMAP allows the input of a flight altitude profile along the aircraft track. NOISEMAP 6.5 includes parameters for the AH-64 and other rotary-wing aircraft.

Just like MR_NMAP, NOISEMAP consists of 3 parts: a front-end to generate the situation input file, the noise simulation itself, and a back-end plotting program (Moulton 1990). For NOISEMAP, the front-end program is BASEOPS. NOISEMAP uses NMPlot v3.05 as the back-end plotting package. Example files which are generated from NOISEMAP were successfully installed and regenerated.

The following text provides detail about the NOISEMAP structure and how to run the program. This detail is provided to guide other users through the use of this complicated program. The input data files for NOISEMAP consist of a root file name with several extensions: *.air, *.fac, *.id, *.pad, *.run, *.flt and *.pow files, with the latter two files the most important. The BASEOPS utility produces these separate files based on a cumbersome user-interface. In practice, it is often easier to edit the individual files directly, rather than to depend on the BASEOPS interface. However, the programs are highly dependent on column-specific input, and placement and retention of white space and carriage returns is critical to proper program function.

Fig. 3.2. A-weighted decibel sound contours in Sound Exposure Level (SEL) metric, produced using MR_NMAP software, draped over Landsat 7 image of study site.

31
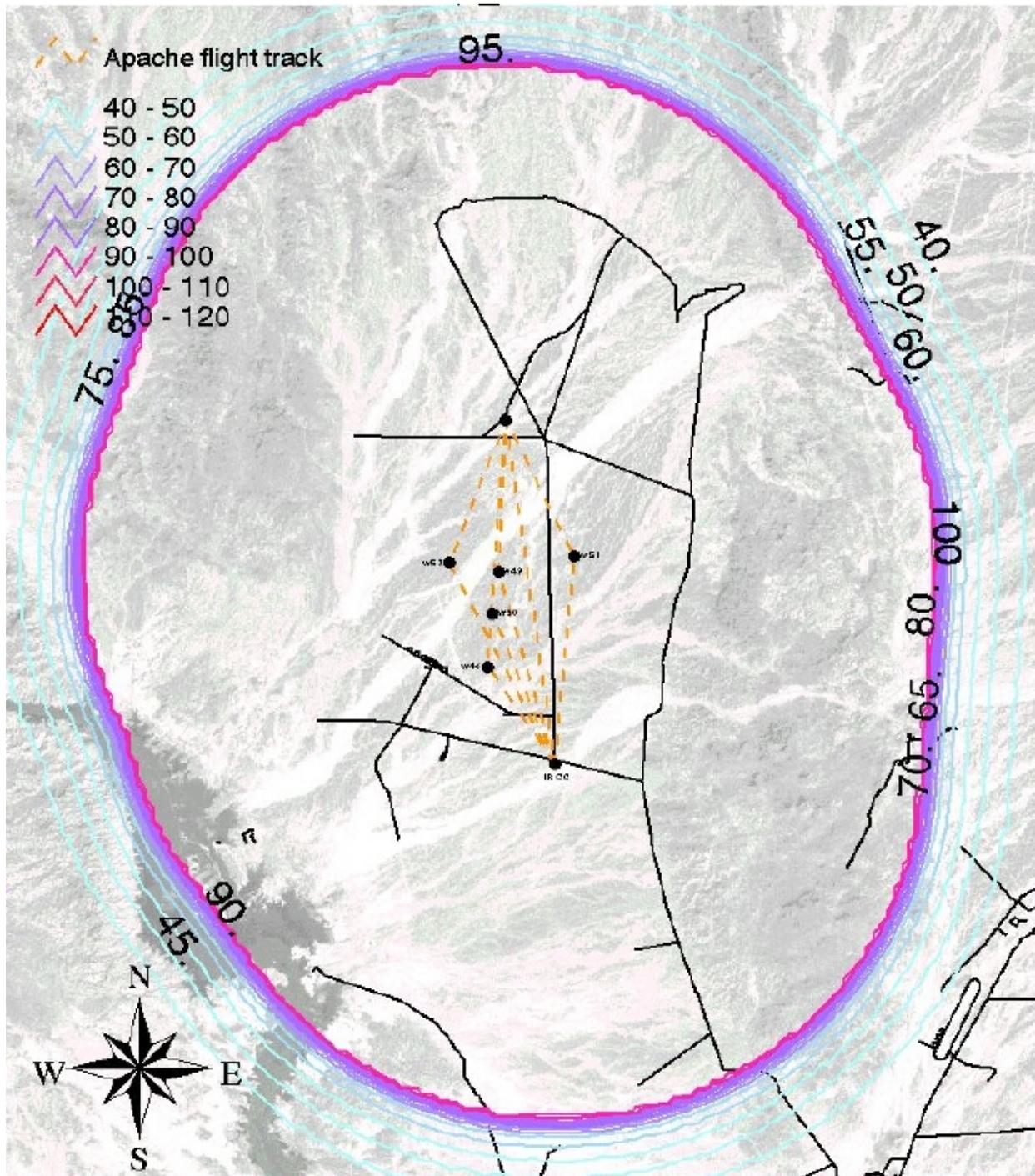
Fig. 3.3. A-weighted decibel sound contours in Lmax metric, produced using MR_NMAP software, draped over Landsat 7 image of study site.

When finished with the set-up, the user specifies that BASEOPS create Master Control Module (MCM) files. The user is prompted for a short text descriptor for the case. This creates a *.bps (acronym for "baseops source") file under the SOURCES subdirectory. This file will have the root file name followed by an accession number, then the .bps extension. The user must check the *.log file to determine the full *.bps file name which was created.

The next step is to run the baseops source (*.bps) from within MCM64 (named Master Control Module 6.4, but really version 6.5). The baseops source is identified using the same text case descriptor given in the MCM step to generate the baseops source file. The Run Options Grid Spacing was changed to 700 for best resolution of the Apache-Hellfire noise simulations. After the baseops source file is loaded, the case must be saved. Note the new file name for the saved case; it will be the same root file name as before, but with a *new* accession number, and the extension *.cas (acronym for "case"). Cases are stored under the CASES subdirectory.

Then the user executes the NOISEMAP Full Case under the Run option of the MCM. Often the MCM hangs and never returns from NOISEMAP, even though NOISEMAP has run successfully. The Windows Task Manager can be used to regain control. At other times control is successfully returned, and MCM can be ended using the Quit End options. While there is an option to execute NMPlot from MCM, the accompanying instructions strongly encourage quitting MCM before executing NMPlot as a standalone program.

NOISEMAP creates a subdirectory under nmap64 of the same name as the saved case file (without the *.cas extension). All products from the NOISEMAP run are stored under this subdirectory, along with a copy of the saved case file, the resultant noise grid file (*.grd), and Omega10 and other ancillary outputs. The Omega10 chronicle files are also located in this subdirectory.

The user invokes NMPlot, and then reads the noise grid file (*.grd) from the proper subdirectory. The "Grid Add constant to data points" option can be used to add 49.5 dB to convert the noise metric from Day-night average sound level (DNL), a human annoyance metric, to SEL in this test case where there is only one flight per day and no nighttime flights. (The equation for DNL is: DNL = SEL + 10log(numberflightsperday + 10.0 * numberflightspernight) - 49.37.) Then Grid--Display Plot of this Grid is chosen to read and convert the grid to a plot (*.nmp) format file. Plot Options can be used to make flight tracks visible and to generate custom contours. Finally, the plot file can be saved as a *.nmp file, with the same root name as the saved case file. Contours and a grid can be exported as shapefiles to ArcView.

Implementation for Apache-Hellfire test at YPG

Because NOISEMAP is designed for fixed-wing aircraft noise simulation, particularly when operating around airports and bases, it expects operations to be centered on one or more runways. For this reason, it was necessary to

> The highest sound exposure predicted by NOISEMAP is 104.6 dB, SEL, over the IRCC takeoff/landing zone.

create a "virtual" runway which does not really exist at YPG. We created this virtual runway from w48, the Pinkrock IP, to the IRCC, since this return track was shared by all 5 practice Hellfire attack patterns.

Each of the 5 attack patterns is simulated as a closed loop. Since the common "return" direction was toward the IRCC, this was the direction of "takeoff" along the virtual runway. Thus, for the purposes of the NOISEMAP noise simulation, the Apaches "begin" a "takeoff" over the target at the Pinkrock IP, already at an altitude of 200 feet AGL, fly to the IRCC, land, takeoff, fly to one of the five launch points, and then "end" the closed loop back over the target at the Pinkrock IP. These simulation tricks are not expected to have any effect on the simulated noise contour outputs. The altitude assumptions are identical to those for the MR_NMAP simulations.

Only the location of the launch point (w52, w51, w49, w50, or w46) changes for each closed test attack loop. The coordinates of each launch point (and thus the flight distance for each leg of each attack triangle) are known. However, unlike MR_NMAP, NOISEMAP expects track course inputs in the form

of headings and flight distances, as a series of turns. The Law of Cosines and Law of Sines for triangles were used to convert the lengths of the sides of each of the 5 triangles into flight distances and angles, which were then converted into heading changes for input into NOISEMAP. Because a short flight distance is required to make each heading change, exact solutions for the triangular course were adjusted to achieve best track closure.

Humidity was specified as 32%, and temperature was set to 95E F for the noise simulations. All 5 attack triangles shared the same altitude profiles: 200 ft AGL over w48 Pinkrock IP, 350 ft AGL over IRCC, land at IRCC, takeoff from IRCC, climb to 300 ft AGL, 300 ft AGL over the launch point, fly to w48 Pinkrock IP at 300 ft AGL. The Apaches are simulated as flying at 40 knots LFO (Low Flight Operations) power and speed settings throughout, except for takeoff and landing power where appropriate. These altitudes and power settings were recommended by Bert Evans of YPG [3], and their percentage distribution matches the altitude distribution profile specified for MR_NMAP simulations. The input file which specifies these noise simulations is included as Appendix C.

Initial simulations at the default resolution of 1000 ft produced unrealistic noise contours, with diagonal legs of flight tracks not represented by sound contours. We eventually realized that these "silent" legs were caused by a resolution effect; the coarse resolution caused these legs to disappear from the output sound contours. Experimentation with resolution changes indicated that a resolution of 700 ft would still cover the entire extent of the Yuma test area, while at the same time being fine enough to resolve the diagonal flight tracks.

Sound contours simulated by NOISEMAP are depicted in Fig. 3.4. A maximum SEL of 104.6 dB is reached over the IRCC takeoff/landing zone in the NOISEMAP prediction.

Model uncertainty

The term "model uncertainty" refers to the accuracy of the model used to simulate noise contours. Model uncertainty can be discussed qualitatively by considering the following factors: (1) the extent to which NOISEMAP and MR_NMAP outputs agree, (2) the extent to which these programs that were designed for fixed-wing overflights may be used for simulating rotary wing flights, and (3) environmental features that are missing from the simulations.

Despite an attempt to specify as uniformly as possible an identical implementation of the YPG Apache Hellfire missile training in both NOISEMAP and MR_NMAP, considerable differences exist between the simulated output noise contours which are produced from each tool, even for the same noise metric. Although the maximum SEL values obtained by both programs are quite similar, the SEL contours predicted from NOISEMAP are much more spatially localized than the generalized concentric oval contours predicted from MR_NMAP. A maximum SEL of 104.6 dB is reached over the IRCC takeoff/landing zone in the NOISEMAP prediction, while a maximum SEL of 89 is obtained from MR_NMAP (with the elliptical contour of 85 dB depicted in Fig. 3.2). Similarly, whereas the area exceeding 100 dB SEL in MR_NMAP is 0, the area is 0.3 km in NOISEMAP. A maximum Lmax of 102 dB is predicted within a much larger oval area when using MR_NMAP.

The differences in spatial noise predictions probably relate to the very different ways that the two models treat aircraft altitude. Whereas NOISEMAP allows the specification of starting and ending altitudes along each flight path, MR_NMAP allows only a percentage breakdown of proportion of time spent at each altitude across the entire flight track, specifying altitude in a non-spatial way. As explained earlier, MR_NMAP uses the concept of Equivalent Acoustical Altitude (EAA). MR_NMAP sums the total noise level under the aircraft, and then uses this noise level to look up the equivalent altitude from the SEL tables. This EAA then replaces the altitude distribution in all subsequent calculations. It is likely that the use of the EAA in MR_NMAP results in the generalization of the projected noise contours into smooth ovals. MR_NMAP loses some of its credibility by depicting noise contours that are

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[3] Actually, Bert Evans recommended an average velocity of 20 knots, but the program does not permit such a slow speed.
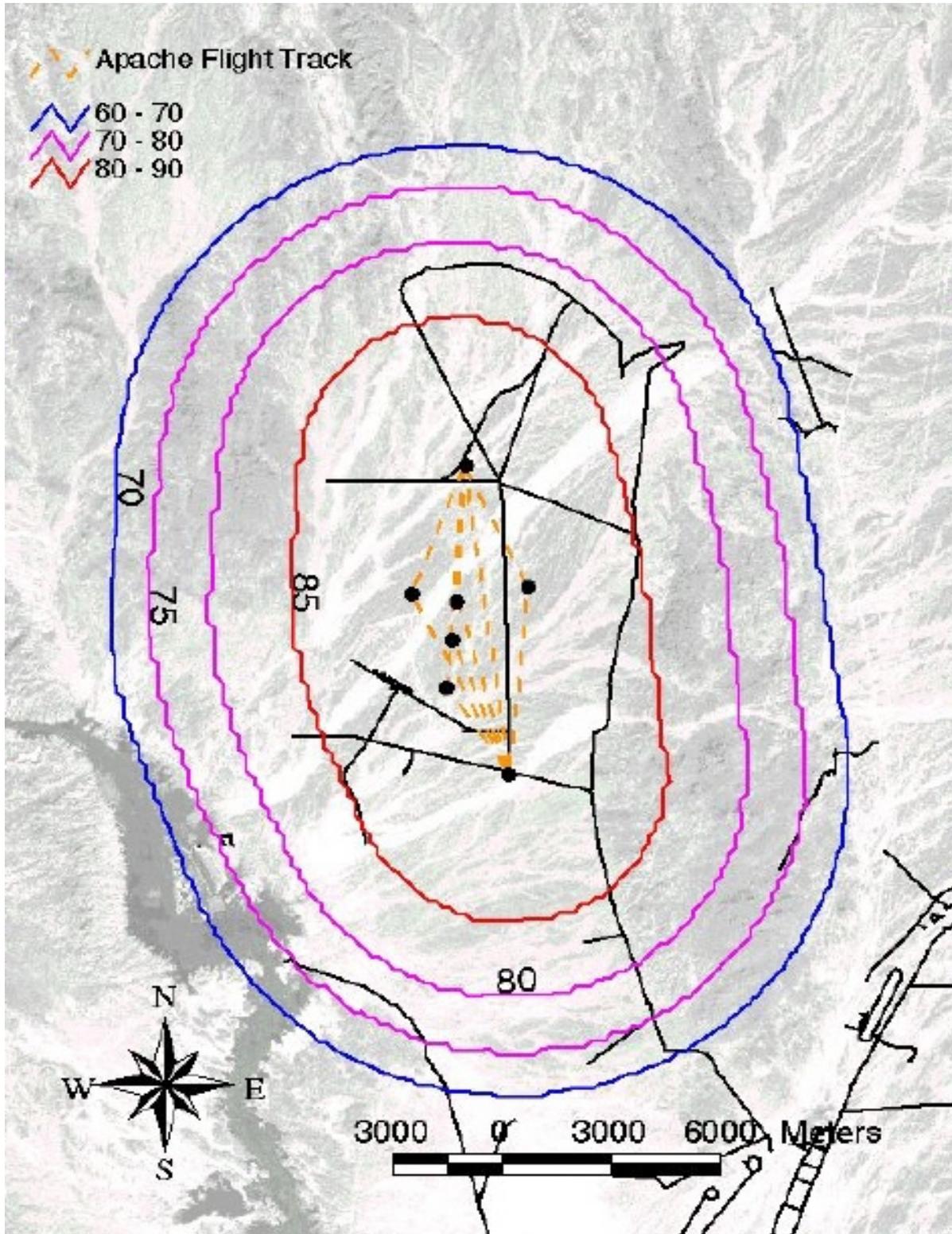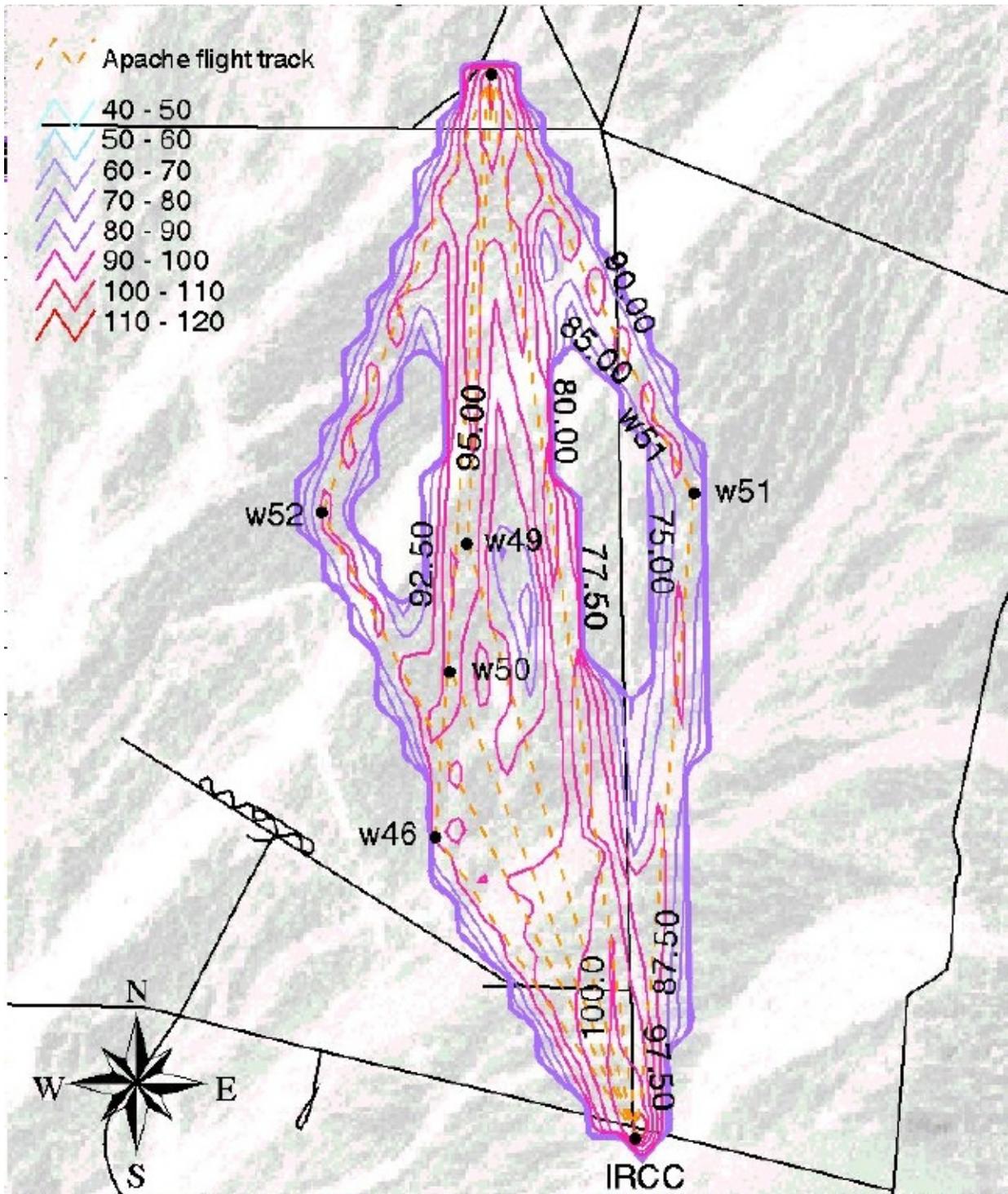
Fig. 3.4. A-weighted decibel sound contours in Sound Exposure Level (SEL) metric, produced using NOISEMAP software, draped over Landsat 7 image of study site.

unrelated to the location of takeoff or landing, where sound on the ground should be maximized. This uncertainty should be considered in the weight of evidence for the risk assessment.

NOISEMAP and related programs "can be and have been used for helicopter operations but are not well suited to this use in their present form" (Lee et al. 1996). Vertical takeoff and landing (VTOL) is not explicitly considered in NOISEMAP or MR_NMAP. Also, "helicopter noise is somewhat unique in that it has different directional characteristics on the left, center and right sidelines due to main and tail rotor noise asymmetries, relative to the flight path" (Lee et al. 1996). Levels typically vary 3 to 5 dB in SEL between the left, center and right sides of the aircraft. Lateral attenuation of sound may differ between fixed-wing and rotary-wing aircraft due to the harmonic content of helicopter noise, a sometimes impulsive nature of helicopter noise, and the open rotors of helicopters (Lee et al. 1996). And sharp lateral or vertical maneuvers of helicopters are not simulated in the current programs. A model for helicopter noise called Rotocraft Noise Model (RNM) is under development by NASA-Langley, but the source database does not yet include Army helicopters.

Uncertainties associated with the output of NOISEMAP and MR_NMAP include all of the variables that affect sound propagation that are not included in the model. For example, MR_NMAP does not include wind, ground topography, or day-to-day variations in meteorological conditions (USAF 1998). Some of the errors are quantified; for example, topographic features can sometimes cause momentary increases in sound levels (reflections) of up to 3 dB for brief periods and can sometimes decrease sound substantially (shielding) often more than 20 dB (USAF 1998). Also, because altitude is calculated relative to the highest local ground elevation, the altitude relative to a canyon bottom is underpredicted. When sound is propagated in the model through distances greater than one or two km, atmospheric absorption and lateral attenuation can lead to large uncertainties (USAF 1998).

Uncertainty in the exposure results could be minimized by a field study using radiocollared deer with acoustic monitors. Such a study could be a means of evaluating the two noise models, as well as more accurately determining Lmax and SEL of exposed mule deer.

3.2.2.3 Estimates of exposure based on slant distance from aircraft

The distance from an aircraft to an animal is an exposure metric that is related to behavioral effects on ungulates (hoofed mammals) in the *Ecological risk assessment framework for low-altitude overflights by fixed-wing and rotary-wing military aircraft* (Efroymson et al. 2000). As stated above, this exposure metric typically incorporates two stressors: sound and view of the aircraft.

For the distance exposure metric, the flight activity description (altitude, lateral trajectory) serves to characterize exposure. The calculation of minimum distances to all deer is not possible.

Sound contour models such as NOISEMAP and MR_NMAP typically calculate areas of contours for an entire test activity. That is, areas exposed to the five helicopter trajectories are considered simultaneously. In the calculation of slant distances, a single helicopter trajectory is considered. The total distance of each of the five trajectories is calculated in Table 3.2, using segments determined in the GIS.

The longest of the five trajectories is the path through waypoint w52, although all distances are close. In this exposure analysis, the longest of the five trajectories is used because it results in the largest exposed area (Table 3.2). As stated above, the aircraft takes off at IRCC, quickly ascends to 300 ft (91 m), flies to the waypoint w52, shoots, descends to 200 ft (61 m) at the Pinkrock IP, ascends to 350 ft (107 m) just before returning to the IRCC and lands. For the purpose of this assessment, it is assumed that the Apache's altitude for each segment corresponds to the average of the lowest altitude at each end of each segment. (Thus, the helicopter's ascent to 350 ft (107 m) immediately before landing is ignored to

Table 3.2. Distances of five helicopter trajectories in the Apache Longbow–Hellfire test

Trajectory	Distance (km)			
	IRCC to waypoint	Waypoint to Pinkrock IP	Pinkrock IP to IRCC	Total
1, through w52	5.91	3.93	8.99	18.83
2, through w46	3.07	6.39	8.99	18.45
3, through w50	4.24	4.99	8.99	18.22
4, through w49	5.20	3.92	8.99	18.11
5, through w51	5.45	3.87	8.99	18.31

maximize the assumed, exposed area.). Therefore, the first segment is assumed to be flown at 150 ft (46 m) AGL, the second segment at 250 ft (76 m) AGL, and the third at 100 ft (31m) AGL.

This activity description serves as the exposure determination for the slant distance-response relationship. It is not possible to calculate the minimum distance to each deer. Affected areas are calculated in the Risk Characterization (Sect. 3.4) using effects thresholds presented in Sect. 3.3.1.4. Slant distances associated with effects are described below.

The principal uncertainty associated with this activity description is the averaging of altitudes along a segment. In addition, aircraft do not always fly to planned altitudes and waypoints.

3.3 CHARACTERIZATION OF EFFECTS

Exposure-response relationships are models of the induction of effects by exposure to a particular stressor or set of stressors associated with an activity. That is, the level of expected effect increases with increasing exposure to the stressor. For many stressors and receptors there is a threshold exposure level below which no consequential effects occur, an increasing level of effects with increasing exposure, and a level at which the maximum effects occur (e.g., extinction or complete vegetation loss). The characterization of effects is not intended to be site-specific; most relationships are derived at sites other than YPG or for a general case. The specific estimate of risk is provided in the Risk Characterization section of this chapter (Sect. 3.4).

3.3.1 Mule Deer

3.3.1.1 Assessment endpoint property

Desert mule deer are not threatened or endangered. Thus, the behavior or survival of individuals is not of regulatory interest, and is probably not of broad, societal interest. Therefore, the assessment endpoint property was chosen to be a population-level property, i.e., the abundance or production of desert mule deer (Sect. 2.5.2). However, the exposure-response models that relate noise or the view of aircraft to effects on ungulates focus mostly on behavior and occasionally on heart rate. Thus, the extrapolation from behavioral to population-level effects will be qualitative if behavioral effects are expected (and the quantitative potential of risk assessment methodology may not be demonstrated with

this example). On the other hand, if no behavioral effects are observed, there is quantitative certainty that reproductive effects will not occur.

3.3.1.2 Necessary extrapolations

As stated above, a major extrapolation (and major source of uncertainty) in this assessment is the extrapolation from behavior to population-level effects. The mechanisms by which these extrapolations can occur are depicted in Fig. 3.5. Few studies relate behavior

> Twelve mechanisms are identified for behavior to affect reproduction and abundance of mule deer.

to population-level effects. In one study in which jets flew over captive sheep, the number of females bred and young produced was higher than in reference areas (P. R. Krausman, University of Arizona, personal communication, May 15, 2001).

It should also be noted that the characterization of effects also involves extrapolations among aircraft (see discussion of expected, relative effects of rotary-wing and fixed-wing aircraft below in Sect. 3.3.1.3) and among ungulates; no data on impacts of the Apache Longbow helicopter on desert mule deer exist. Similarly, the characterization of effects must rely on studies carried out at different sites from YPG. Some of these study sites include penned areas with exposure to recorded sound.

As stated above, the mechanisms depicted in Fig. 3.5 don't need to be known if behavioral or acoustic effects are zero. Then, population-level effects (abundance and reproduction) are zero also.

3.3.1.3 Sound level effects thresholds

Movement and other behavior

Weisenberger et al. (1996) observed changes in activities of penned two-to-six-year-old desert mule deer when deer were exposed to simulated low-altitude noise of B1-B and F4-D aircraft. Maximum sound levels for B1-B jets ranged from 101.0 to 112.2 dB. Maximum sound levels for F4-D jets ranged from 92.5 to 109.3 dB. During 112 overflight simulations

> The behavioral effects threshold for mule deer may be assumed to be 92.5dB Lmax (conservative) or 100 dB Lmax (less conservative) or 112.2 dB SEL (less conservative).

each in the summer (May 12-Aug 9), late summer (Aug 13-Oct 12), and spring (Feb 4-Apr 5), deer responded with "alarm" to 33, 6 and 6 simulations, respectively. (The Apache Longbow–Hellfire missile test occurred in August of 2000, so "summer" and "late summer" impacts are most relevant.) The term "alarm" indicated startle, a look toward the speaker, and an alteration of activity. The time to return to original behavior averaged 21.6 sec in late summer, 114.5 sec in summer, and 252.3 sec in spring. The researchers did not relate sound exposures to effects; all simulated overflights were treated equally. Thus, the exact threshold for the effect is unclear, and the data cannot be easily reexamined to determine a threshold (M. E. Weisenberger, U.S. Fish and Wildlife Service, personal communication, May 1, 2001). The authors of the study concluded that "the exposures [to] aircraft noise were of such short duration in this study that noise created from low-flying jet aircraft probably could not be considered detrimental (i.e., inhibiting reproductive mechanisms) to desert mule deer . . . . However, there may be additional, or interactive effects from the visual stimulus of actual aircraft" (Weisenberger et al. 1996).

P. R. Krausman of the University of Arizona suggests that deer would be likelier to move in the presence of a helicopter than in the presence of fixed-wing aircraft at the same sound level; the helicopter is overhead longer because of its slower speed (personal communication, May 15, 2001).
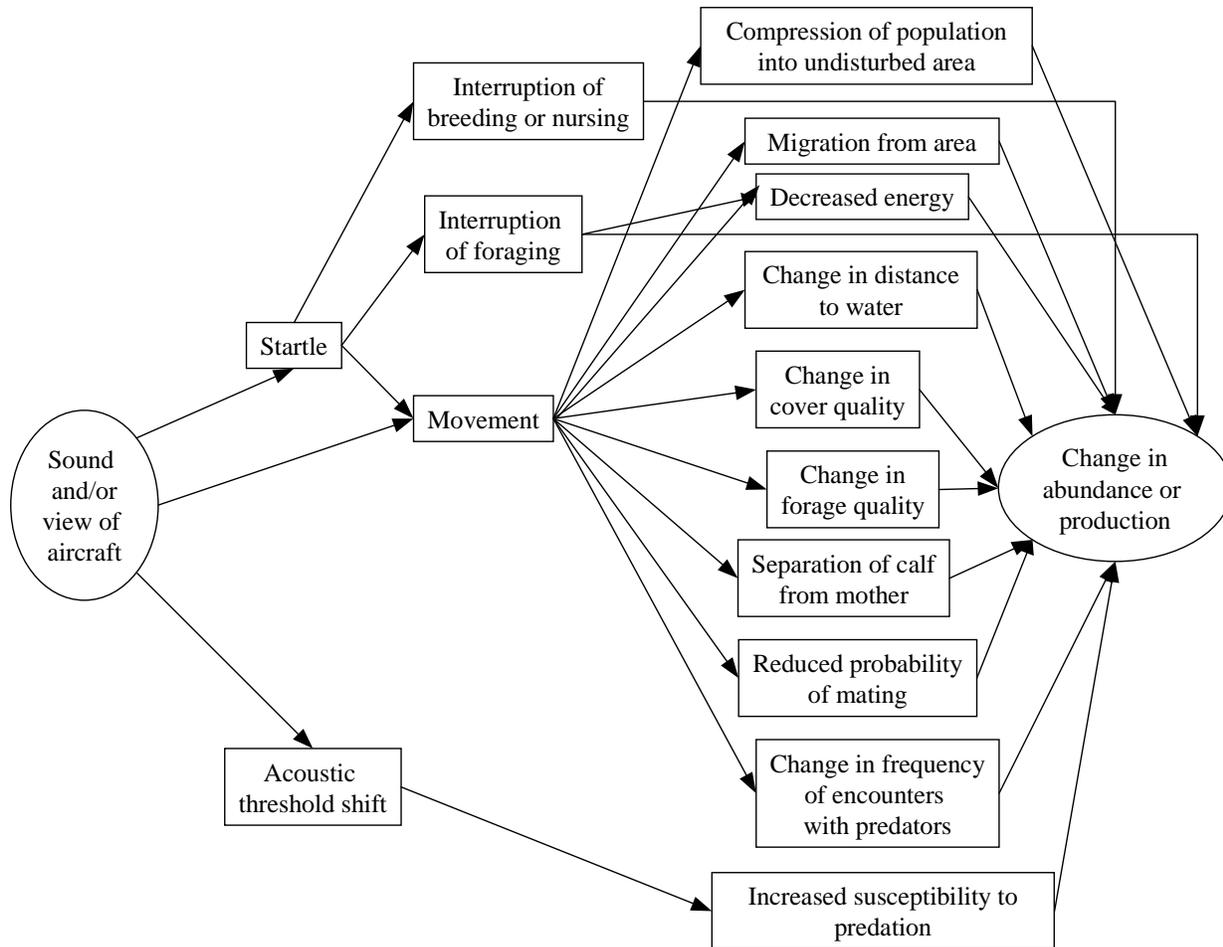
Fig 3.5. Mechanisms by which sound may affect abundance or production of ungulates. Most involve movement of animals that alter habitat or reproductive activities. Adapted from Efroymson et al. (2000).

LeBlanc et al. (1991) simulated noise from F4 aircraft. Pregnant mares were exposed to 4 exposures per day of 113.4 dB (Lmax) or 112.2 SEL. All non-habituated horses exhibited flight posture (highly elevated head, wide open eye lids, dilated nostrils, quick forward or sideways movement), and movement of horses was significantly higher in the treatment group than in a control group. Habituated horses did not show this response.

For the purpose of this assessment, the following assumptions are made:

- 92.5 dB, Lmax, is a conservative estimate of a behavioral effects threshold for mule deer
- 100 dB, Lmax, is a reasonable, less conservative estimate of a behavioral effects threshold for mule deer
- 112.2 dB, SEL, is probably a non-conservative estimate of a behavioral effects threshold for mule deer, based on responses of horses.

Heart rate changes

Weisenberger et al. (1996) observed changes in heart rates of penned desert mule deer when deer were exposed to simulated low-altitude noise of B1-B and F4-D aircraft.

A threshold for temporary heart rate changes in mule deer may be assumed to be 92.5dB Lmax (conservative) or 100 dB Lmax (less conservative).

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Maximum sound levels for B1-B jets ranged from 101.0 to 112.2 dB. Maximum sound levels for F4-D jets ranged from 92.5 to 109.3 dB. The mean heart rates of desert mule deer increased during overflight simulations during two summer and one spring period and remained at a high level for at least three minutes in the spring period. The spring response may have been due to the naive deer added in the spring (see Sect. 3.3.1.5 on habituation). Heart rates did not exceed the maximum values that were observed during the 25 to 30-day period prior to the overflight noise simulation. The increase in heart rates was highest for animals in pens exposed to the loudest overflights.

LeBlanc et al. (1991) simulated noise from F4 aircraft. Pregnant mares were exposed to 4 exposures per day of 113.4 dB (Lmax) or 112.2 SEL. Thirty-eight percent of non-habituated, exposed horses had mild heart rate increases sustained for 20 sec.

Acoustic threshold shift

Temporary or permanent acoustic threshold shift is hearing loss associated with loud sounds. Such hearing loss can make an animal more susceptible to predation and less likely to hear mating signals or a lost calf. No exposure-response relationship is available for the relationship between sound level from low-altitude helicopter or fixed-wing overflights and acoustic threshold shift in ungulates. Therefore this effect is not considered further in this Chapter.[4]

3.3.1.4 Slant distance effects thresholds

Most of the exposure-response models for effects of aircraft overflights on ungulates are slant distance thresholds. A distribution of slant distance thresholds for effects of helicopters on ungulates is presented in Fig. 3.6. This figure represents a distribution of combinations of species (included habituated and unhabituated, Sect. 3.3.1.5), helicopter types, and environmental conditions. The data are a subset of a distribution of thresholds for fixed-wing and rotary wing aircraft from Efroymson et al. (2000). More detailed descriptions of these thresholds is provided as Appendix D. The distances associated with a 10%, 20% and 50% probability of effects on a randomly drawn combination of ungulates, helicopters and environmental conditions are 445, 400, and 175 m, respectively (Fig 3.6). Therefore, at a 400 m slant distance there is a 20% chance that the mule deer exposed to an Apache helicopter during the Apache–Hellfire test would be affected.

The distances associated with 10%, 20% and 50% probability of effects on a randomly drawn combination of ungulates, helicopters and environmental conditions are 445, 400, and 175 m.

The justification for splitting response distances for rotary wing aircraft from those for fixed-wing aircraft is the following. Desert ungulates tend to respond differently to helicopters than to fixed wing aircraft with respect to visual stimuli, regardless of the decibel level (pers. comm., Mara Weisenberger, U.S. Fish and Wildlife Service, May 1, 2001). Indeed, if desert mule deer were exposed to two overflights at equivalent distances, one a rotary-wing flight and the other a fixed-wing flight, P. R. Krausman of the University of Arizona believes (based on professional judgment) that a mule deer would be likely to run farther in response to a helicopter than a fixed-wing aircraft, because of 1) the greater noise of the former aircraft, 2) the slower speed (and longer exposure to) the former aircraft, and 3) possibly a visual image of the former aircraft that creates a greater response (pers. comm., P. R. Krausman, University of Arizona, May 15, 2001). For example, mule deer exposed to fixed-wing aircraft at 300 ft (91 m) or greater lateral distance do not usually exhibit a behavioral response, whereas deer

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[4] Acoustic threshold shift is considered in Chapter 4, even though data are available only for humans and not for mule deer. These data are utilized for the purpose of demonstrating MERAF, because they are the only effects data available for blast noise.

exposed to helicopters at greater distances often do (pers. comm., P. R. Krausman, University of Arizona, May 15, 2001). (This observation is consistent with the assumed sensitivities above.)
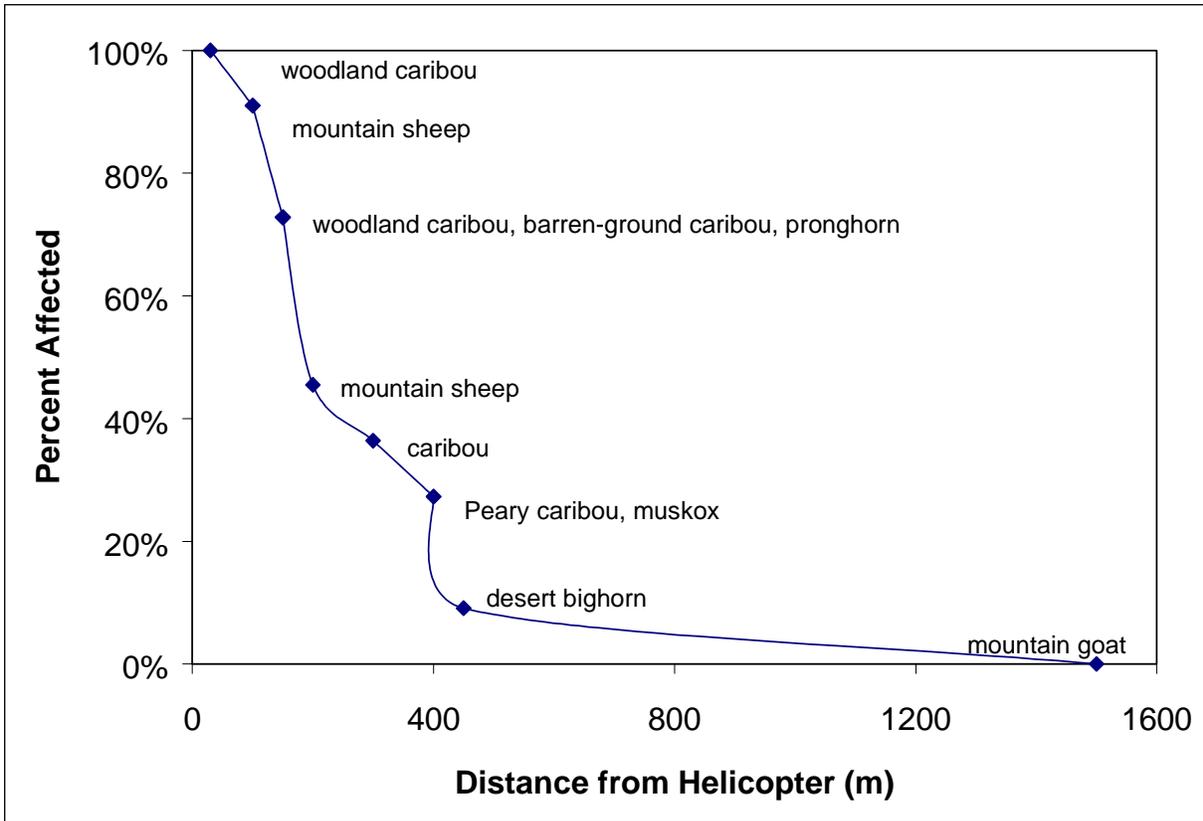
Fig. 3.6. Slant distance thresholds for behavioral effects associated with ungulate exposure to helicopter overflights. Behavioral effects include movement (e.g., escape response), change in habitat, or change in activity (e.g., reduction in foraging).

Picacho Mountains in south-central Arizona

One study of mule deer is not included in the slant distance threshold distribution because it relates to fixed-wing rather than rotary-wing aircraft. However, it may be relevant to the case study because it directly concerns desert mule deer.

The lowest observed adverse effects level for light, fixed-wing aircraft and mule deer in an Arizona study is less than a 50 m altitude.

Light, fixed-wing aircraft were flown over desert mule deer in the Picacho Mountains to determine whether or not the deer shift their home ranges in the presence of survey aircraft (Krausman et al. 1986). Seven female and nine male deer were observed from the ground and were also radio-collared. Seventy responses of deer to aircraft (i.e., multiple responses of deer to different overflights) were recorded in 17 days. Results are presented in Table 3.3. Interestingly, whether a deer changed habitats was independent of the above-ground height of the aircraft, though this lack of a relationship could have been due to the small number of animals or the large number of variables. Three of 16 radio-collared deer moved to adjacent habitats during one overflight each, out of 70 possible positive responses. If all exposures are considered, the positive response rate is 4 percent. If only non-habituated deer are considered, the positive response rate is 19 percent. (See discussion of habituation in Sect. 3.3.1.5). For

the purpose of this demonstration, a threshold response may be assumed to have a 20 percent probability of occurrence. Thus, the No-Observed-Adverse Effects Level (NOAEL) is below a 50-m altitude, and the Lowest-Observed-Adverse-Effects Level (LOAEL) would be expected to be substantially below a 50-m altitude, as none of the flights below 50 m had a behavioral effect on the deer.

Table 3.3. Desert mule deer responses to aircraft overflights between 0600-1200 hours at various elevations above ground in the Picacho Mountains, AZ, May-September 1984 (Krausman et al. 1986). Reprinted from the *Wildlife Society Bulletin* with permission from The Wildlife Society, the copyright-holder.

	Aircraft altitude (m)				
Deer response	<50	50-100	100-150	>150	total
Changed habitats	0	1	2	0	3
Did not change habitats	10	29	20	8	67

3.3.1.5 Magnitude of movement effects

No information is available regarding the distances that mule deer that react to helicopter overflights (sound or distance) move. Limited data on movement distances are available for other ungulates, including mountain goats (*Oreamnos americanus*) (Côté 1996) and mountain sheep (*Ovis canadensis*) (Bleich et al. 1994, Bleich et al. 1990). Barren-ground caribou

> Limited data are available on movement distances and home range shifts of ungulates during overflights. No exposure-response relationship is available for particular movement distances.

(*Rangifer tarandus*) movement distances in response to military jets are described in Harrington and Veitch (1991) and Maier et al. (1998). None of these studies estimate home range shifts, based on movement distances. Because of the difference in these species and habitats from mule deer, movement distances and potential home range changes associated with helicopter overflights are not estimated. To determine a home range shift, an assessor would probably have to utilize species-specific and habitat-relevant data (as in the Picacho Mountains study above, though that study relates more closely to fixed-wing rather than rotary-wing flights) or perform a site-specific field study.

3.3.1.6 Extrapolation of effects from multiple-activity training programs

During a training activity at Piñon Canyon Maneuver Site in southeastern Colorado, mule deer increased their home range size, either by moving out of their normal home ranges during maneuvers or by increasing their home ranges within maneuver areas (Stephenson et

> Training activities at another site, which involved a much higher level of disturbance, caused changes in mule deer habitat use.

al.1996). The ratio of maneuver to non-maneuver home range size for female deer ranged from about two to four. In addition, female deer in areas exposed to previous maneuvers used larger home ranges than females in non-maneuver areas. One explanation is that habitat, including vegetation density and area of bare ground was altered. Another is that the training program directly disturbed the deer. It

should be noted that the training activity, which was conducted for a 2 to 3-week period for three years in August, involved 2624 to 6619 troops per 2 to 3-week exercise, 30 to 50 helicopters on site at one time, and 584 to 2397 vehicles on site at one time (Stephenson et al.1996). Battlefield simulations included machine gun fire and cannon fire (without live ammunition). Traffic included jeeps, trucks, armored personnel carriers, tanks, helicopters, and jet fighter overflights. Thus, the intensity and scale of this activity were substantially higher than those at Yuma Proving Ground, effects cannot be linked to particular exposures, and extrapolation of results to the Apache Longbow–Hellfire missile test is not appropriate.

In another study at Piñon Canyon Maneuver Site (Gerlach et al. 1986), mule deer that were pursued by low-flying helicopters to be netted often moved to pinyon-juniper cover, where they remained during the overflights.

If data on deer movements associated with the test at Yuma Proving Ground were available, an assessor would consider whether the habitat (i.e., cover, forage, water availability) to which deer are being chased is equivalent to or worse than that from which they are being chased. Reproductive effects would probably not result if habitat were equivalent and unoccupied, and if substantial energy resources had not been used in movement.

3.3.1.7 Factors that modify magnitude of effects

Habituation

Krausman et al. (1986) observed that desert mule deer in south-central Arizona seemed to habituate to low-altitude, fixed-wing overflights. Of the three deer that changed habitats during overflights, the two adults only

> Mule deer habituate to low-altitude aircraft overflights.

did so during the first overflight (a yearling male moved during the eighth overflight). In a study of heart rate changes in desert mule deer exposed to simulated noise from fixed-wing, jet aircraft overflights, Weisenberger et al. (1996) observed that mule deer habituated to the sound with each season of exposure (mid-summer, late summer, and the following spring). Habituation meant fewer alarmed responses and decreased response times with increased exposure. It is notable that this study did not include the visual stressor that is present in the Apache-Hellfire test.

Mule deer at Yuma Proving Ground would probably habituate to overflights during the three-week test period. In the absence of other helicopter overflights, it is unlikely that they would still be habituated to the activity in the three years between similar tests. However, helicopter overflights are associated with numerous test programs in the area. Thus, the time period without helicopters probably determines whether deer are going to move sufficient distances to change their home ranges during the Apache Longbow–Hellfire missile test.

P. R. Krausman of the University of Arizona would expect desert mule deer to acclimate to daily helicopter overflights during the Apache Longbow–Hellfire missile test, but no studies have been undertaken to determine the frequency or duration of exposure that would be required for habituation (personal communication, May 15, 2001). Krausman also notes that if deer move, they may not return for a period of time, and habituation of those deer would not be relevant.

Several other ungulate species have been observed to habituate to overflight exposure. Bighorn sheep (Weisenberger et al. 1996) and barren-ground caribou of the Delta herd in interior Alaska are have habituated to aircraft overflights (Valkenburg and Davis 1985). Horses have habituated to simulated aircraft sound (LeBlanc et al. 1991).

Previous activity

The response of ungulates to overflights is dependent on the activity that the animals are

> Mule deer responses to overflights may be dependent on previous activities.

engaged in at the time, though few data are available for desert mule deer, specifically. Barren-ground caribou at river crossings were most reactive to overflights, followed by traveling and feeding animals, and followed by resting animals (Calef et al. 1976). Woodland caribou ran farther and for longer periods of time if they were initially walking, compared to animals that were resting, standing, or feeding (Harrington and Veitch 1991). Similarly, responses of muskoxen were dependent on the previous activity of the animals (Miller and Gunn 1979).

Season

Season is also an important determinant of effects of overflights on ungulates. Behavioral responses of female barren-ground caribou to military jets were strongest during postcalving, intermediate during the insect season, and lowest in the late winter (Maier et al. 1998). Mountain sheep move greater distances following helicopter disturbances in the spring than in other seasons (Bleich et al. 1994). During spring and fall migration periods, barren-ground caribou responses are greater than during calving (Calef et al. 1976).

> **Effects of overflights on ungulates are associated with particular seasons.**

Habitat

Vegetation type did not affect response of barren-ground caribou (Calef et al. 1976) but did determine distances that mountain sheep moved following overflights (Bleich et al. 1994).

3.3.1.8 Biological survey

An ideal study of desert mule deer that would support this risk assessment or a larger scale assessment for a training program would be conducted with helicopters (noise and visual stressor) and free-ranging desert mule deer and would examine behavioral effects on all age and sex classes, especially during reproductively sensitive times, and more direct measures of reproduction (e.g., calving success).

> **A controlled field study at YPG would be an ideal line of evidence for this risk assessment.**

3.4 RISK CHARACTERIZATION

3.4.1 Mule Deer

3.4.1.1 Expected behavioral impact area, based on sound

In a previous study desert mule deer behavior was impacted by simulations of fixed-wing overflight noise at sound levels somewhere between 92.5 and 112.2 dB, Lmax (Weisenberger et al. 1996), with thresholds estimated to be between 92.5 dB (conservative) and 100 dB (less conservative) (Sect. 3.3.1.3). Horses were impacted at sound levels of 112.2 SEL (LeBlanc et al. 1991). The areas of land and number of deer exposed to these sound levels are presented in Table 3.4. The core assessment area is 126 km^2 (Sect. 2.4.1), and the approximate number of deer in that area is 70 (Sect. 2.6.2.3). The range of deer that

> **Between 0 and 70 deer in the 126 km^2 core study area (plus 190 possible additional deer in the influence area) may be behaviorally affected by Apache overflights.**

are expected to be behaviorally impacted range from 0 to all 70 deer in the core assessment area, plus about 190 additional deer in the influence area (about 260 deer total, Table 3.4).

Table 3.4. Number of deer and areas exposed to sound levels of potential concern for behavior

Simulation	Sound level	Reference	Area[1], km[2]	Number of deer
MR_NMAP	92.5 dB, Lmax	conservative threshold estimate, Weisenberger et al. (1996)	470	263
	100 dB, Lmax	reasonable threshold estimate, Weisenberger et al. (1996)	460	258
	113.4 dB, Lmax[2]	threshold estimate, LeBlanc et al. (1991)	0	0
	112.2 dB, SEL	threshold estimate, LeBlanc et al. (1991)	0	0
NOISEMAP	92.5 dB, SEL	conservative threshold estimate based on Weisenberger et al. (1996); inappropriate noise metric but improved altitude profile over MR_NMAP	10	6
	100 dB, SEL	reasonable threshold estimate based on Weisenberger et al. (1996); inappropriate noise metric but improved altitude profile over MR_NMAP	0.3	0
	112.2 dB, SEL	threshold estimate, LeBlanc et al. (1991)	0	0

[1] core area and influence area, combined
[2] low confidence in MR_NMAP Lmax (based on response of horses) compared to other Lmax values (based on response of mule deer)

3.4.1.2 Expected behavioral impact area, based on distance

As stated in Sect. 3.3.1.4, the slant distances associated with a 10%, 20% and 50% probability of effects on an individual or group of ungulates are 445, 400, and 175 m, respectively. For the longest helicopter trajectory, these slant distances correspond to areas of 8.33, 7.48, and 3.19 km[2], which are associated with 5, 4, and 2 deer, respectively.

These area estimates and deer density estimates are rather uncertain, as the variability in sensitivity among species is uncertain. Also, the

Based on distance from receptor to aircraft, and effects thresholds for various ungulates, there is a 10%, 20% and 50% probability that 5, 4, or 2 deer will alter their behavior, due to the Apache-Hellfire test. Based on an effects threshold for altitude of light, fixed-wing aircraft and mule deer, no deer will alter their behavior, due to the Apache-Hellfire test.

areas only approximately correspond to the slant distances, given that the exact locations of altitude shifts (and the altitudes themselves) are unknown.

As stated in Sect. 3.3.1.4, the LOAEL for behavioral effects on mule deer exposed to overflights by light, fixed-wing aircraft at the Picacho Mountains in south-central Arizona would be expected to be well below 50 m. For the purpose of calculating slant distance, the first segment of the flight is assumed to be flown at 150 ft (46 m) AGL, the second segment at 250 ft (76 m) AGL, and the third at 100 ft (31 m) AGL (Sect. 3.2.2.3). However, in reality, the only parts of the flights that occur below 50 m are the takeoff and landing, because the Apache quickly ascends after taking off (Sect. 3.2.2.3). The IRCC is essentially a parking lot for helicopters and other vehicles. Therefore, the number of deer that would be exposed to altitude below 50 m would be expected to be negligible. In addition, deer inhabiting nearby areas would be expected to be habituated to the sound from helicopter takeoffs for other tests and training activities.

3.4.1.3 Potential change in heart rate, based on sound

A conservative threshold estimate for changes in heart rates of deer is 92.5 dB, Lmax (Sect. 3.3.1.3). A reasonable threshold estimate is 100 dB, Lmax. As in Table 3.4, the number of deer that would be expected to be affected in the study area would be 70 (all of the deer), with an additional 193 deer outside of that area. There is less confidence in the threshold value for horses, 112.2 dB SEL, which is a value associated with horses. As in Table 3.4, the number of deer affected would be expected to be zero.

3.4.1.4 Acoustic threshold shift

No evidence of hearing loss by ungulates due to these overflights or others has been obtained.

3.4.1.5 Population issues

The reduction of reproduction and abundance of ungulates due to aircraft overflights has probably not been observed. Most of the exposure-response relationships signified by arrows in Fig. 3.5 cannot be quantified with data from Yuma Proving Ground, data from other sites, or existing mechanistic models. Factors such as home range for desert mule deer, watering point locations, timing and prevalence of migration, and timing of key reproductive activities were included in Chapter 2 to support the development of a mechanistic model, but the development of that model is beyond the scope of this risk assessment.

If we were confident that there were no behavioral effects on mule deer, we could be confident that there would be no population-level effects. Given that the likelihood of movement, the average distance of movement, the direction of movement, the time of displacement, and the habituation period are all unknown, then one cannot quantitatively assess risks to abundance or reproduction unless behavioral effects are estimated to be low or negligible.

The population of mule deer would not be expected to be affected appreciably by short-term changes in heart rate. Herbivores such as mule deer would be expected to have evolved tolerance for frightening stimuli, such as predators that were once present in the area. Similarly, it is unlikely that frightened movements of mule deer would lead to the physiological inhibition of reproduction or death. Therefore, risks to mule deer populations are inferred from overt behaviors rather than from heart rates or other evidence of transient stress.

3.4.1.6 Weight of evidence

In most predictive assessments such as NEPA documents, only one line of evidence is available for risk characterization (Suter et al. 2001). However, in this case there are multiple defensible methods to derive the sound exposure estimates and different behavioral effects thresholds associated with the different exposure metrics. Therefore, risks should be estimated by each method and the relative merits of the results should be weighed.

The weight of evidence indicates that some deer may experience behavioral effects from noise and/or visual stressors associated with Apache overflights, but that the deer population is unlikely to exhibit changes in abundance or reproduction.

The following criteria may be used to weigh evidence: (1) data relevance (whether or not the estimated effect is a direct estimate of the assessment endpoint); (2) credibility of exposure-response relationship; (3) relevance of temporal scope of effect; (4) relevance of spatial scope of effect; (5) quality of exposure and effects data; (6) quantity of observations, especially related to variance and biases in sampling; and (7) relevance to a requirement to integrate risks from multiple activities (Suter et al. 2000, Suter et al. 2001). In addition, the importance of multiple modes of action should be considered.

The weight of evidence for risks to mule deer that are associated with Apache overflights is presented in Table 3.5. The predictions of exposure, and therefore the predictions of behavioral and potential reproductive effects on mule deer, conflict.

Outputs of NOISEMAP (suggesting no behavioral risk) may be slightly more reliable than outputs of MR_NMAP (suggesting some behavioral risk), because NOISEMAP does not do any altitude-averaging for overflight missions. However, the output of MR-NMAP feeds more reliably into a credible exposure-response relationship for mule deer (L_{max} sound threshold). Distance exposure estimates are highly reliable, and both the slant distance metric (combined with a distribution of response thresholds for ungulates and helicopters) and the altitude metric (combined with a threshold for effects on mule deer) lead to a conclusion of no or low risk to mule deer behavior. The weight of evidence result is an uncertain risk to mule deer behavior.

However, the conclusion is that there is no risk to mule deer abundance or reproduction for the following reasons:
• Most lines of evidence point to no behavioral effects.
• If a threshold of 103 dB L_{max} instead of 100 dB L_{max} were chosen as the likely LOAEL (very possible using data in Sect. 3.3.1.3), the conclusion would be that no deer are behaviorally affected by the sound. (102 dB L_{max} is the highest sound contour produced by MR-NMAP (Fig. 3.3).
• Critical reproductive time periods for mule deer are May-June (fawning) and November-December (rutting). If behavioral effects were to influence reproduction, they would likely occur in these months. The test did not occur in these months.
• Most of the effects data are for unhabituated deer. Most deer in the test area would be expected to be habituated to helicopter noise following the first day of the test if not before.
• Helicopter movement would not be expected to cause deer to move away from water sources. In fact, deer running from a north-oriented flight might be expected to move toward a tank located northeast of the study area at 749300 Easting and 3667700 Northing (UTM Zone 11 coordinates in meters) (Sect. 2.6.2.2).
• As stated in Sect. 3.4.1.5, frightening a fraction of a population of deer would not be expected to lead to population-level effects, because deer would be expected to have evolved tolerance for moderately frightening stimuli.

Table 3.5. Summary of the risk characterization for the desert mule deer population exposed to Apache Longbow helicopter overflight in the 126-km study area in Cibola Range, Yuma Proving Ground

Evidence	Behavioral Effect Result[1]	Population-level Effect[2] Result	Explanation
Slant-distance /ungulate behavior relationship	−	−	Approximately 4 deer in a 7.48 km^2 area are exposed to a distance from the helicopter which has been associated with behavioral effects in 20% of ungulate groups exposed to helicopter overflights. This quantity represents about 6% of the 70 deer presumed to inhabit the valley between the Chocolate and Middle Mountains.
Altitude/deer behavior relationship	−	−	No deer are expected to be exposed to an altitude of well under 50 m, the LOAEL for mule deer exposed to light, fixed-wing aircraft.
Sound level/ungulate behavior relationship	+	±	The maximum sound levels at ground level that are predicted by MR NMAP software are higher than the threshold sound level from overflights which is associated with behavioral effects on mule deer. All deer (70) in the 126 km^2 area are exposed, and about 2.7 times as many deer (190) in outlying areas are predicted to be exposed.
	−	−	The sound exposure levels at ground level which are predicted by NOISEMAP software are lower than the minimum threshold sound level from overflights which is associated with behavioral effects on horses. Therefore, no behavioral effects on mule deer are expected.
Weight of evidence	±	−	The weight of evidence suggests that the helicopter overflight component of the Apache Longbow test program may affect behavior of mule deer, but effects on abundance or reproduction of the population are unlikely.

[1]An effect is presumed to be negative if fewer than 20% of the mule deer are affected.

[2]Population-level effects may occur (±) if behavioral effects are significant, but would be predicted to occur (+) only if effects were large-scale.

3.4.1.7 Uncertainty and variability

We have concluded during the development of the risk assessment framework for aircraft overflights that: "It is evident from the exposure analysis component of the framework for military overflights that good, quantitative measures and models are available for estimating exposure of endpoint species to sound and other stressors" and that "The accuracy and precision of ecological risk assessments for aircraft overflights will probably not be very limited by the exposure analysis" (Efroymson and Suter 2001). In fact, the magnitude of the uncertainty associated with estimating noise contours may be as large as that associated with exposure-response thresholds. It is evident from the inconsistent outputs of MR_NMAP and NOISEMAP that noise contours and associated exposure estimates to mule deer are highly uncertain. The lack of consideration of topography, weather, and the flight and noise behavior of helicopters also leads to the conclusion that these results are uncertain.

Effects thresholds are estimated based on data that are not completely relevant to the Apache Longbow Hellfire missile test. That is, behavioral effects thresholds for sound are based on a variety of responses of a variety of ungulates to a variety of helicopter types in a variety of environments. This is a significant source of uncertainty.

The extrapolation of behavioral effects (or acoustic damage) to make predictions about population-level effects is highly uncertain, unless behavioral effects are not observed or predicted, in which case no population-level effect can occur.

3.5 RESEARCH GAPS

Several research and development topics related to aircraft overflights and desert mule deer would improve future risk assessments of testing programs at YPG and training and testing programs at other military installations. These recommended topics are based on the uncertainties identified within Chapter 3.

Clearly, some of the improvements in NOISEMAP and MR_NMAP that are expected in the near future are needed, such as the consideration of topography, weather, and the flight and noise behavior of helicopters. However, others (such as eliminating the altitude averaging algorithms of MR_NMAP and adding Lmax to NOISEMAP) are also recommended.

Research is needed to validate or verify results of MR_NMAP and NOISEMAP, particularly at locations below and near the flight tracks. A study using radio-collared deer equipped with acoustic monitors could serve this purpose, as well as providing information about movements of deer in the presence of aircraft overflights. For the Apache Longbow–Hellfire test, additional research on specific responses of desert mule deer to overflights of Apache Longbow would be recommended over the use of limited data on a variety of ungulates and a variety of helicopter models in a variety of environments.

More information is needed concerning the effects of aircraft overflights on vertebrate behavior and especially on direct measures of reproduction and abundance.

Research is needed concerning the relative sound frequencies that vertebrates other than humans hear. A-weighted decibels do not necessarily reflect ungulate or mule deer hearing. Similarly, thresholds for hearing damage could be investigated.

Mechanistic models that predict population-level effects from changes in home range, watering point locations, forage locations, timing and prevalence of migration, and timing of key reproductive activities would be useful. Such models could be demographic models or energetic models. These models would be particularly pertinent to the integration phase of the risk assessment (Chapter 6), in this case study as well as in applications of MERAF, generally.

4. RISK ASSESSMENT FOR HELLFIRE MISSILE FIRING

4.1 ACTIVITY-SPECIFIC PROBLEM FORMULATION

4.1.1 Potential Stressors and Modes of Action

Candidate stressors associated with missile firing are presented in Table 4.1. An activity-specific risk assessment framework is not available for this activity. All stressors that could be of significance in this assessment for YPG are

> A key stressor associated with missile detonations is sound.

included. Some will be determined to be insignificant (e.g., sound of missile launch) and not be carried through the entire process. Unexploded ordnance (UXO) is included in Table 4.1 for the sake of completeness but was deemed to be outside the scope of this demonstration assessment. UXO would probably be more appropriately addressed in a separate framework focusing on the unique aspects of that stressor. Also, UXO is not a significant problem for a testing activity of this size and frequency (i.e., tracking and recovery or destruction of individual warheads is feasible).

Table 4.1. Stressors and modes of action associated with missile firing

Stressor	Potential mode of action
sound	behavioral response of wildlife, auditory damage to wildlife, interference with foraging or predation, interference with mating
impact detonation	injury to wildlife and vegetation, modification of local hydrology
shrapnel	death or injury of wildlife and vegetation
fire	death or injury of vegetation and behavioral response of wildlife
chemical residue	contamination of soil, water, and food items; toxicity to wildlife and vegetation
unexploded ordnance	death or injury of wildlife and vegetation

4.1.2 Conceptual Model

The conceptual model for missile firing is depicted in Fig. 4.1. The model represents the combination of stressors associated with missile firing in the Apache Longbow–Hellfire missile test, without making an assessment of importance of each stressor. Stressors and their sources are evaluated for their importance in subsequent

> The conceptual model shows pathways between potential stressors (sound, disturbed soil) and potential effects.

sections. The result can range from excluding the stressor from consideration in the assessment, to qualitatively considering the stressor, to quantitatively assessing the risks due to the stressor. Stressors or portions of the activity that are not considered in the risk assessment are depicted in gray in Fig. 4.1.
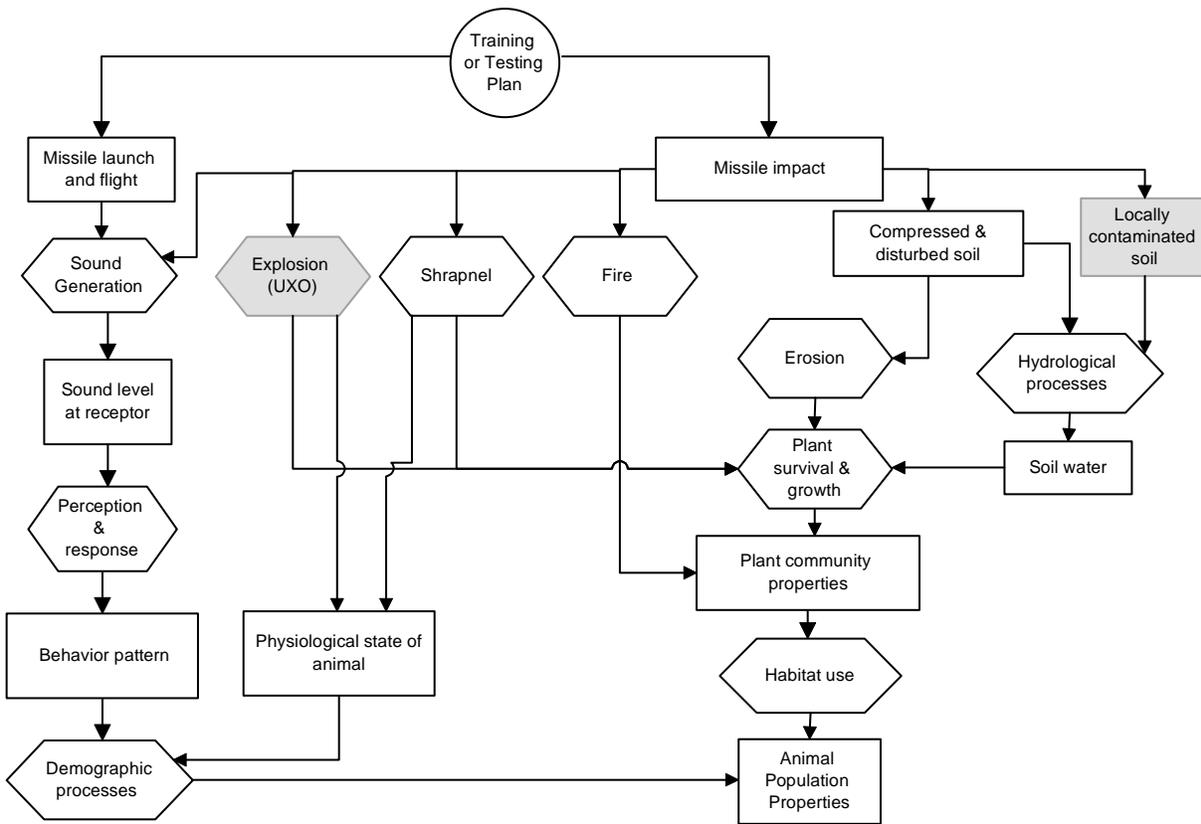
Fig. 4.1. Conceptual model for Hellfire missile firing component of Apache Longbow–Hellfire missile test at Yuma Proving Ground. Stressors and/or portions of the activity that were not considered in this assessment appear in gray.

4.1.3 Selection of Activity-specific Measures of Exposure

4.1.3.1 Intensity measures

Sound

The two principal measures of exposure to sound that provide a description of a Hellfire launch and detonation are the sound exposure level (SEL) and peak sound level (Lmax). The

> **The relevant sound metric is C-weighted SEL**

SEL takes into account both the maximum noise level of an event and its duration; all of the acoustic energy of an event is included. SEL is generally considered to be meaningful for evaluating responses to blast noise. Furthermore, decibels at various frequencies are adjusted (weighted) to represent the way the average human ear responds to various frequencies of sound. C-weighting is the human auditory weighting generally used for blast noise. It differs from A-weighting in that frequencies below 1,000 Hz are given more weight when C-weighting is used (Kryter 1985). C-weighting is used in this assessment because it is used to estimate exposure in the blast noise model BNOISE2 (Sect. 4.2.1.1). Human annoyance response is typically evaluated by means of a correlation relationship with long-term average sound level. This approach is not useful, however, for isolated noise events such as the present situation. The best available procedure is to use a single event noise measure for which some response information is available; CSEL satisfies that criterion.

Hellfire missiles do not generate a sonic boom during launch and flight of the missile. Therefore, sound intensity measures peculiar to that type of sound are not required or considered in this assessment.

Distance

The distance from an explosion to an animal is an exposure metric in some exposure-response models for blast noise. Distance is an indicator of average expected sound exposure, but actual levels can vary significantly from the mean under various meteorological conditions.

> Distance from missile detonation to receptor is a metric that represents average expected exposure to sound.

4.1.3.2 Temporal measures

Temporal aspects of exposure include duration, frequency of occurrence, and timing. Duration is accounted for by the SEL metric. None of the available exposure-response models use frequency of detonation (e.g., number of blast events per day or week) as a temporal measure of exposure, but frequency could be qualitatively used to estimate the likelihood of habituation of wildlife to missile firing. The timing of Hellfire testing is important as it relates to reproductive behavior and home range locations.

4.1.3.3 Spatial measures

Spatial measures of exposure include the spatial extent of the flight path; the spatial extent of craters made by missiles that miss their targets; the spatial extent of the debris field (i.e., shrapnel) or burn area; the habitats, home ranges, forage and water locations of mule deer; and the area where mule deer potentially receive substantial exposure to blast noise or shrapnel. Many of these exposure factors are described in Chapter 2.

4.1.4 Selection of Measures of Effects

Measures of effects are identified in the problem formulation. With knowledge of these measures, the assessor can determine the types of data that may be obtained or generated and the models that must be generated in order to perform the analysis of effects. The measures of effects may be obtained from field studies, from the laboratory, or from observations at the specific site of concern.

> Human behavioral responses and hearing damage as functions of CSEL are the best available measures for estimating effects on mule deer.

The primary measures of effects for missiles include the sound exposure level (CSEL) at which a response is expected (effects thresholds) and the distance from the detonation at which a response is observed. Both of these metrics relate to hearing damage and behavioral effects on ungulates or an acceptable surrogate. Human behavioral responses and hearing damage as functions of CSELs are the best available measures for estimating effects on mule deer.

4.2 CHARACTERIZATION OF EXPOSURE

4.2.1 Mule Deer

4.2.1.1 Sound contours calculated using BNOISE2

Sound levels experienced by mule deer were not measured as a part of this study. Therefore, sound levels on the ground were estimated using BNOISE2, an Army-developed software program which calculates and displays blast noise exposure contours resulting from specified operations involving large guns and explosive charges.

> The Army program BNOISE2 is used to estimate sound exposures to mule deer.

Program structure

BNOISE2 is a new version of a computerized tool that replaces the BNOISE computer program, which has been a primary model for blast noise assessment for over twenty years. BNOISE2 offers improved propagation algorithms, updated weapons source models, and an improved user interface. The software runs under the Microsoft Windows operating systems and includes consideration of type of weapon and ammunition, number and time of rounds fired, range attributes, weather, and assessment procedures and metrics. It also accounts for spectrum and directivity of both muzzle blast (or launch) and projectile sonic boom, which facilitates accurate calculation of propagation and frequency weighting. Source model parameter values are based on empirical data. The propagation algorithms are based on sophisticated calculations and experimental data. Available metrics include C-weighted sound exposure level (CSEL), peak level, and day-night noise level (DNL). Recent improvements account for the effects of land-water boundaries and terrain.

BNOISE2 features a point-and-click graphic user interface, pull-down menus, and on-line help. Information regarding the types of weapon and ammunition, the locations at which the firing takes place, the number of shots during daytime and nighttime, etc., is entered into an activity table. Required information regarding the guns and ammunition (source models) and ranges is stored in databases and chosen via pick lists. A library of database records, including weapons, metrics and frequency weighting schemes, is included with the program.

The propagation algorithm is used to calculate sound levels at each node of a user-defined geographical grid. The resulting array of noise level values is converted to contours and prepared for display by software known as NMPlot, developed by the U.S. Air Force. This software enables display of noise contours, has a zoom control for viewing various levels of detail, and can print map overlays. Results can be exported to a GIS.

BNOISE2 is currently in beta test by selected users, in particular the Environmental Noise Program of the U.S. Army Center for Health Promotion and Preventative Medicine (USACHPPM), which will be the primary DoD user and the transfer agent (http://chppm-www.apgea.army.mil/enp/enp.htm).

Implementation for Apache-Hellfire test at YPG

A single attack simulation was run in BNOISE2 for the following reasons: 1) the principal noise from firing a Hellfire missile is the explosion of the warhead at the target (i.e., launch noise is so insignificant that it is not included in the program), thus differences in launch points for the five test firings evaluated here would not affect the exposure estimates for mule deer; 2) definitive information on impact locations was not available; and 3) multiple explosions did not occur simultaneously, thus eliminating the need to model overlapping contour levels. Therefore, all targets were assumed to be at or near Pinkrock IP, and results of the single attack simulation were used for each individual test firing.

All noise level distances are measured from the Pinkrock impact point. The noise level contours for the Hellfire missile are expressed in terms of CSEL (C-weighted Sound Exposure Level). Contours were plotted for the effects thresholds and selected intermediate exposure levels (Sect. 4.3.1.2). Contours were exported as shapefiles to ArcView. The noise contour output map, draped on a Landsat 7 image, is presented as Fig. 4.2.

The sound level at a given location, for a given noise source, is highly dependent on sound propagation conditions, which are in turn strongly influenced by meteorological conditions such as wind and temperature variation in the atmosphere. The BNOISE2 default sound propagation conditions were used for the Hellfire simulation at YPG. The default conditions are represented by statistical distributions of possible conditions. Sound propagation accounts for the substantial variations shown in the table of noise level statistical expectations at a given distance (Table 4.2). Topographic features may also influence the received sound level at a given location. Although BNOISE2 is capable of accounting for topography, this data layer was not incorporated into the Hellfire simulations for various logistical reasons. This lack of topographic specificity was determined to be acceptable because of the location of the test between mountain ranges (rather than on a mountain) and because a major purpose of this assessment is the demonstration of the MERAF framework rather than assessment of actual risks.

Thus, over a wide range of sound propagation conditions that might be expected to occur, a mean CSEL of 91 dB is predicted to occur at a distance of about 2.4 kilometers from the explosion, with a standard deviation of about 8 dB. A mean CSEL of 116 dB (140 dB peak) is predicted to occur at a distance of about 350 meters from the detonation.

Table 4.2. Hellfire warhead blast noise level statistics at 2432 meters distance, based on variability in weather conditions[1]

Exposure Level, CSEL (dB)	Peak Level, PK (dB)	Percent Exceeding Sound Level	
116	141	0.13	($\mu + 3\sigma$)
109	134	2.28	($\mu + 2\sigma$)
100	125	15.87	($\mu + 1\sigma$)
91	115	50.00	($\mu + 0\sigma$)
82	106	84.13	($\mu - 1\sigma$)
76	100	97.72	($\mu - 2\sigma$)

[1] Statistics generated from BNOISE2 simulation of a Hellfire detonation under average weather conditions. Predicted variations in blast noise at 2432 meters is represented by the estimated percentage of blasts that would exceed various exposure levels. This variation is primarily due to assumed variations in weather conditions.

Model uncertainty

BNOISE2 is the best acoustic model currently available for predicting sound levels associated with weapons firing and detonation. However, these are complicated processes to simulate, and substantial uncertainties remain. Current efforts are focused on improving the prediction sensitivity to changes in weapon size, vegetation, weather, and terrain (http://owww.cecer.army.mil/facts/sheets/LL10.html).
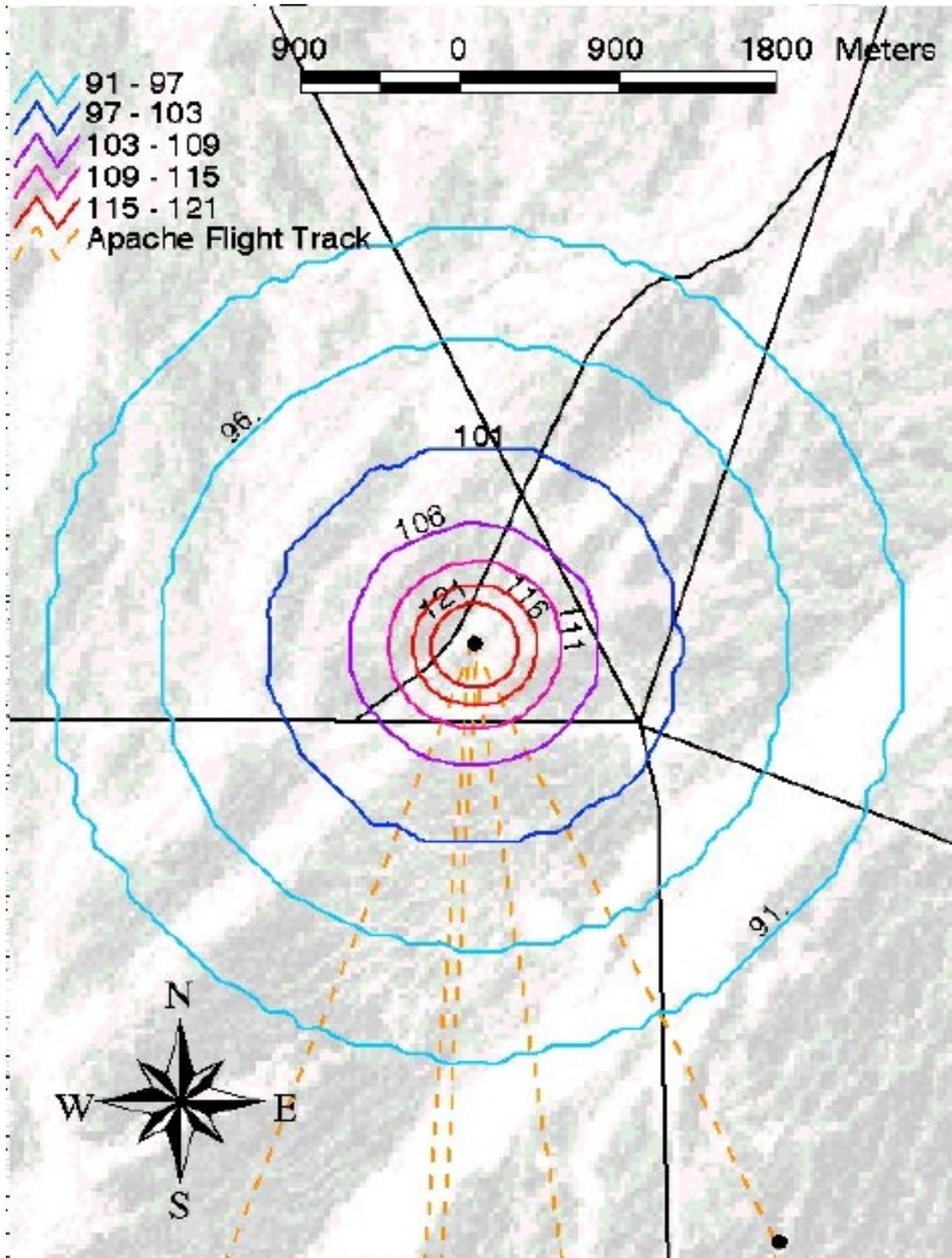
Fig. 4.2. C-weighted decibel sound contours in Sound Exposure Level (SEL) metric, produced using BNOISE2 software, draped over Landsat 7 image of study site. The impact location is assumed to be located at Pinkrock , the northernmost point of the Apache flight track. The Apache flight track is equivalent to the Hellfire trajectory. Contour levels are for a single explosion of a Hellfire warhead.

4.2.1.2 Sound exposure based on distance

As with the exposure assessment for the Apache Longbow (Sect. 3.2.2), the distance from a sound source (e.g., an aircraft or a Hellfire detonation) to an animal is an alternative exposure metric. Unlike exposures to aircraft, sight of the Hellfire missile by the animal is, for purposes of this demonstration of MERAF, assumed not to affect the distance at which a response is elicited. This assumption is based on the small size and the high velocity (i.e., short duration of visibility) of the missile. Therefore, distance from the blast is assumed to be primarily a measure of sound exposure.

> For the distance exposure metric, the distance from Pinkrock IP serves to characterize exposure. The calculation of distances to all deer is not possible.

The activity description, specifically the location of the detonation, assumed to be at Pinkrock IP, serves as the exposure assessment for the distance-response relationship. Locations of individual deer are not known, so is not possible to calculate the distance to each animal. Affected areas are calculated in the Risk Characterization (Sect. 4.4) using effects thresholds presented in Sect. 4.3.1.3. Distances associated with effects are described in Sect. 4.3.1.3.

4.2.1.3 Other blast-related stressors

A radius for the shrapnel impact zone around the Hellfire impact point was not available for this assessment. In an more comprehensive assessment, site- and weapon-specific information could be used to generate a reasonable exposure estimate. For example, one could measure the density of shrapnel per unit area with distance from the point of detonation. This could be done under standardized conditions or after each detonation at the specific site to be evaluated.

> The area of the shrapnel impact zone and concentrations of residual chemicals in soil are not available. These are likely to be negligible stressors.

Environmental concentrations of residual chemicals were not available for this assessment. In a more comprehensive assessment, this information could be obtained through site sampling, fate and transport modeling of known residues of Hellfire missiles, or a combination of the two.

4.2.1.4 Population issues

When extrapolating from exposures for individuals to exposures for the population, the temporal scale of the test must be considered. The exposure estimates above are for a single Hellfire detonation, but the August 2000 test consisted of five Hellfire detonations at roughly the same impact point over eight days. A highly conservative approach to estimating the fraction of the local population that was exposed (at a specified threshold level) over the duration of the test period would be to assume that no individual mule deer is exposed to more than one detonation (i.e., sampling without replacement). The total number of deer exposed would be estimated as the number of deer exposed per detonation times the number of detonations. For example, if five deer were within the zone of disturbance per hellfire detonation, then a total of 25 different individuals would have been exposed to blast noise exceeding the threshold of disturbance after five blasts. If the hypothetical population consisted of 100 deer, then 25% of the population would have been exposed under this assumption. At the other end of the spectrum is the

> The same mule deer are assumed to be exposed to sound from each explosion.

assumption that the same individual deer are exposed to all five detonations. In the example above, only five of the 100 deer in the hypothetical population (i.e., 5 %) would have been exposed.

If it were available, information on the movement of individual deer over a comparable time frame could be used to estimate how many different deer might enter the various zones of exposure over the duration of the test period. There would still be considerable uncertainty in this approach, because the Apache-Hellfire tests might disrupt this normal pattern of movement.

It is assumed in this assessment that the same individual deer are exposed to all five detonations. This is considered acceptable for several reasons: (1) data are not available to justify any particular approach; (2) this is a demonstration rather than a comprehensive assessment of blast impacts; and a simplified approach is easier to follow; (3) experience suggests that this approach is likely to be a closer approximation of reality than the sampling without replacement approach described above, especially considering the relatively short duration of the test period (five blasts in eight days).

4.2.2 Vegetation in washes

The characterization of exposure of vegetation in washes to Hellfire missiles is conceptually analogous to the assessment of exposure to tracked vehicles (Chapter 5). That is, stress on vegetation in washes could occur either by direct or indirect exposure to Hellfire missile detonations. While the exact mechanisms are different, the assessment methods are quite similar. Given that, a detailed discussion of the possible assessment methods is presented in Chapter 5 and only briefly discussed here.

4.2.2.1 Direct exposure

Direct exposures of wash vegetation to Hellfire missiles would include: (1) misses that detonate in the wash and obliterate vegetation in the impact crater, (2) shrapnel from hits and misses that damage vegetation in the immediate

> No direct exposures of wash vegetation to Hellfire missiles occurred.

area of the impact, (3) fires ignited by hits or misses that damage vegetation near the impact area, and (4) contaminants from shrapnel. It is assumed that direct exposures did not occur during the Hellfire test in question because the target was never missed. In addition, the vehicular targets were located on the MTI Road or at the Pinkrock IP and not in washes. Furthermore, evidence suggests that the targets (tanks) avoid traveling through washes at YPG (Sect. 5.2.1.1).

4.2.2.2 Indirect exposure

Indirect exposure to Hellfire missiles would consist of changes in hydrology due to misses up-gradient of the wash area. Craters in the desert pavement have the same effect as tank tracks (i.e., ponding of water and potentially increased permeability) and exposure could be

> Indirect exposure to wash vegetation via hydrological change is negligible because the Hellfires did not miss their targets.

modeled in the same manner if the spatial resolution of the model were adequate for small craters (Sect. 5.2). However, all Hellfire missiles hit their targets in the August 2000 test, eliminating the need to characterize indirect exposures to wash vegetation. It is worth noting that a miss has occurred in previous tests. The likelihood of misses might be expected to increase during training missions, because of the increased number of sorties and because trainees may be less familiar with particular weapons and aircraft than military personnel who regularly test them. On the other hand, developmental weapons may have a higher rate of failure than weapons in general use.

4.3 CHARACTERIZATION OF EFFECTS

Exposure-response relationships are models of the induction of effects by exposure to particular stressors that are associated with an activity. The level of expected effect increases with increasing exposure to the stressor. Typically, there is a threshold exposure level below which no consequential effects occur, an increasing level of effects with increasing exposure, and a level at which the maximum effects occur. The characterization of effects is usually not site-specific; most relationships are derived for a general case. The estimate of effects due to specific exposures at a particular site (i.e., estimate of risk) is provided in the Risk Characterization section (Sect. 4.4).

4.3.1 Mule Deer

4.3.1.1 Assessment endpoint property

The selected assessment endpoint property is the abundance or production of desert mule deer (Sect. 2.5.2). As with the effects assessment for the Apache Longbow, one would need to extrapolate qualitatively from behavioral effects in individuals to population-level effects (Sect. 3.3.1.1). However, not even behavioral effects of blast noise are known for ungulates, thus requiring further extrapolation from less related species (i.e., humans) for which qualitative and vague "disturbance" effects information is available.

4.3.1.2 Sound level effects thresholds

To assess noise impact for any species, one must first have dose-response information. This requirement is problematical, because the response to noise varies from species to species for a given type of noise, and also with type of noise for a given species. The most studied species in this regard is human beings. The human response criteria (ANSI 1996) for large arms, small arms, and aircraft noise are all different. No data are available for response of mule deer or other ungulates to low frequency blast noise. Therefore, we extrapolated from human response data to illustrate how more exact and relevant information would be used.

> Approximate disturbance and hearing damage thresholds for humans, 91 dB and 116 dB, CSEL, are assumed to apply to mule deer for the purpose of this study. Disturbance is assumed to be equivalent to behavioral effects.

Blast noise exposure is expressed in terms of CSEL (C-weighted Sound Exposure Level). Human response is usually judged in terms of annoyance or likelihood of complaints. It is the experience of one of the authors[5] that, for large explosions such as missile warheads, humans would almost never complain if the CSEL is lower than about 91 dB (about 115 dB peak sound level). Complaints from a very small percentage of humans become somewhat likely[6] if the CSEL exceeds about 106 dB (about 130 dB peak sound level). A very conservative threshold for hearing damage to humans is a 140 dB peak sound level (Mil. Std. 1474D, Department of Defense Design Criteria Standard: Noise Limits, 12 Feb 1997), which is equivalent to a CSEL of about 116 dB. No data are available for judging whether this threshold is valid for other mammals such as mule deer.

Based on this information, we selected the exposure levels of 91 and 116 dB CSEL, which correspond to estimated thresholds for disturbance and hearing damage, respectively. It is assumed in

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[5] Larry Pater of the U.S. Army Corps of Engineers Construction Engineering Research Laboratory has approximately twenty years of experience in acoustics engineering and bioacoustics and provided these data.

[6] No reliable statistical data are available.

this assessment that disturbance is equivalent to behavioral impacts. As noted previously, there are no quantitative data to support these thresholds for ungulates, nor indeed are there rigorous data for humans. However, experience suggests that these criteria are in fact extremely conservative for humans, though data would be required to better define the actual degree of conservatism.

4.3.1.3 Distance effects thresholds

Distance thresholds are an alternative exposure-response model for effects of blast noise. Two types of potentially useful distance thresholds can be estimated: 1) the greatest distance from the blast at which the selected response is observed, which is conceptually analogous to the Lowest Observed Adverse Effects Level (LOAEL) for chemical effects assessment; and 2) the shortest distance from the blast at which the selected response is not observed, which is conceptually analogous to the No Observed Adverse Effects Level (NOAEL) for chemical effects assessment.

Only one relevant study reporting distance thresholds was found (Andersen et al. 1996). It consisted of a comparison of general types of military disturbances for their ability to elicit short-term behavioral and physiological responses in moose (*Alces alces*). Cannonfire was the only disturbance tested for which blast noise would be the stressor. Unfortunately, moose did not respond to the blast noise, so that the only distance threshold reported for cannonfire was a minimum distance from the blast at which no response was observed (i.e., the NOAEL) of 400 m. Assuming the exposure area can be defined by a symmetrical circle with a radius of 400 m, the zone of disturbance would consist of 0.50 km^2. The usefulness of this threshold is uncertain, because the characteristics of the cannon (e.g., type, size, or munitions used) and the blast noise (e.g., direction of muzzle relative to receptor location or CSEL at a nominal distance, such as 1 meter) were not provided. Thus, it is unclear how blast noise from a Hellfire missile would compare to that of the cannonfire in the study.

It is interesting to note that Andersen et al. (1996) also evaluated the responses of moose to helicopters on six different occasions. They observed a maximum distance at which moose would flush from cover (i.e., a LOAEL) of 50 m and a minimum distance of approach of the helicopter at which no response was observed (i.e., the NOAEL) of 400 m. That is, the "NOAEL" distance for cannonfire was the same as for the helicopter and both were an order of magnitude greater than the "LOAEL" distance for the helicopter.

4.3.1.4 Other blast-related stressors

Blast noise is not the only potential stressor for mule deer. Shrapnel and, possibly, fire could also injure mule deer in the immediate area of the impact point or affect their behavior in the vicinity of the impact point. The obvious measure of these effects is the number of injured deer. This could be estimated based on a distance

> Effects of shrapnel could be determined through quick surveys. Toxicological data are available for some constituents of Hellfire warheads.

or area within which injury is expected or by observation. For example, one could use the radius for an impact zone within which injury to mule deer is more likely than not (i.e., probable). This might be based on the average size of a mule deer and the distance from the detonation at which the density of shrapnel (i.e., shrapnel per unit area) suggests that an organism that size has a 20% likelihood of being hit by shrapnel. It must be emphasized that there are no data to support this approach in this assessment. In an actual assessment, site- and weapon-specific information could be used to generate this type of estimate.

A survey of the impact area for mule deer could be performed during and after the tests to determine whether or not mule deer were injured by shrapnel from the tests. Such effects were not

reported for the August 2000 Hellfire tests at YPG, but an extensive search for injured animals was not performed.

Contamination of the environment with residual chemicals could also be evaluated in a comprehensive assessment, provided that toxicological data are available for most or all of known constituents of Hellfire warheads. This information could come from lab and field studies of individual chemicals or relevant combinations of chemicals.

4.3.1.5 Necessary extrapolations

As in the Apache Longbow helicopter assessment, a major extrapolation (and major source of uncertainty) is the extrapolation from behavior of individuals to population-level effects (Sect 3.3.1.2). The mechanisms by which these extrapolations can occur for blast noise are essentially the same as for the Apache Longbow, which are depicted in Fig. 3.6. Those mechanisms are not reiterated here, given that the thresholds for blast noise are intended only for demonstrating the general risk assessment process.

4.3.1.6 Factors that modify magnitude of effects

Habituation

Animals have in general been found to be much more tolerant of stimuli after they have learned by experience that a stimulus poses no threat to them. This is analogous to the habituation to low-altitude overflights that occurs for ungulates and other animals (Sect. 3.3.1.5).

Many mammals habituate to blast noise, and therefore mule deer are expected to habituate during the test.

As with the Apache Longbow, mule deer at Yuma Proving Ground might habituate to the Hellfire blast noise during the three-week test period. Also, other weapons firing programs from aircraft platforms are ongoing in the general area. The first day of the test probably determines if deer are going to move sufficient distances to change their home ranges.

Other factors

Other modifying factors noted for low-altitude overflights (Sect 3.3.1.5) might also be relevant for exposure to blast noise. Potential modifying factors include the activity that the animals are engaged in at the time (e.g., walking or resting), the time of year (e.g., calving season), and the type of vegetation cover that is available. Unfortunately, no data were found relating these potential modifying factors to mule deer responses to blast noise.

4.3.1.7 Biological survey

An ideal study of desert mule deer that would support this risk assessment or a larger scale assessment for a training program would be conducted with Hellfire missiles and free-ranging desert mule deer. Such a study would examine behavioral effects on all age and sex classes, especially during reproductively sensitive times, and more direct measures of reproduction (e.g., fawning success).

4.3.2 Vegetation in Washes

The characterization of effects on vegetation in washes from Hellfire missiles is similar to the assessment of effects from tracked vehicles (Chapter 5). Effects on vegetation could be classified as physical damage or hydrologic stress responses. A detailed discussion of the possible effects is presented

in Chapter 5 and only briefly discussed here, given the similarity of the effects and the fact that neither physical damage nor hydrologic stress from missile firing occurred during the August 2000 Hellfire tests.

4.3.2.1 Physical damage

Physical damages are the effects associated with direct exposure to Hellfire missiles (Sect 4.2.2). Physical damage to wash vegetation could include complete obliteration at the point of impact (i.e., inside the crater if a Hellfire missed the target), minor to severe damage in the immediate area of the impact point due to shrapnel, and fire damage in the vicinity of the impact point. Potential measures of these effects include the amount of vegetation killed (e.g., number of plants, fraction of standing crop, etc.) and the time required for recovery (e.g., re-vegetation with similar or other species). The presence or quality of relevant effects data was not investigated, because direct exposures to wash vegetation did not occur in the August 2000 Hellfire tests at YPG.

4.3.2.2 Hydrologic stress

Hydrologic stress is the effect associated with indirect exposure to Hellfire missiles (Sect 4.2.2). Hydrologic stress to wash vegetation results from changes in hydrology (e.g., surface runoff) due to Hellfire misses up-gradient of the wash area. The effects of these changes in hydrology are expected to be the same as those

> If missiles had missed their targets, risks from impact craters could be treated in a hydrological analysis analogous to that in Chapter 5.

due to tank tracks (see Chapter 5.3), when normalized for the magnitude of exposure (e.g., total area and geographic location of disturbed soils). Potentially relevant effects data were not investigated herein, given that all Hellfire missiles hit their targets in the August 2000 test, eliminating the need to characterize indirect exposures and effects for wash vegetation.

4.3.2.3 Surveys of vegetation

If missiles missed targets, it would be ideal to survey vegetation before and after Hellfire tests to provide additional evidence regarding effects on vegetation biomass and diversity. However, it could be many years before changes in the highly drought tolerant

> Surveys of vegetation are a useful line of evidence for a risk assessment, but they may be limited by natural variability.

plant communities in desert washes could be detected (see Sect. 5.3.1.3). A quantitative vegetation survey was not conducted as part of this study. It is worth noting that authors present following the August 2000 Apache-Hellfire test did not observe any evidence of fire damage to plants alongside roads where the target vehicles drove. Fire damage, unlike effects of altered hydrology, would be evident immediately.

4.4 RISK CHARACTERIZATION

4.4.1 Mule Deer

4.4.1.1 Expected behavioral impacts, based on CSELs

The selected threshold for disturbance is 91 dB CSEL. It is conservatively assumed in this assessment that disturbance is equivalent to behavioral impacts, although it is acknowledged that human annoyance is also factored into this threshold. The area within which Hellfire detonations are expected to produce sound levels

Based on the crude effects assumptions, approximately 10 deer would be expected to exhibit behavioral effects from the Hellfire component of the test.

greater than or equal to that threshold was estimated with BNOISE2 at 18.1 km^2. This area is approximated by a circle with a radius of 2.4 km centered at the Pinkrock Impact Point. For purposes of methods demonstration, mule deer within this zone of disturbance are assumed to be subject to behavioral impacts. Mule deer densities for the approximately 126 km^2 YPG Apache-Hellfire test area have been estimated at 0.56 deer per km^2, for an estimated local population of 70 mule deer. Based on these estimates, 10 deer (i.e., $18.1 \times 0.56 = 10.1$ deer) would be expected to exhibit a behavioral response (disturbance) per Hellfire test detonation. That would constitute 14.3 % of the local population. As stated in Sect. 4.2.1.4, these are assumed to be the same deer during every detonation.

4.4.1.2 Expected behavioral impacts, based on distance

The only relevant distance threshold for blast noise is the minimum distance at which moose did not respond to cannonfire, 400 m (Andersen et al. 1996). This distance is conceptually analogous to the NOAEL for chemical effects assessment. The area within which Hellfire detonations are expected to meet

Based on a NOAEL for cannonfire and moose, no deer would be expected to exhibit behavioral effects from the Hellfire component of the test.

or exceed that threshold was estimated at 0.50 km^2. This area is approximated by a circle with a radius of 400 m centered at the Pinkrock Impact Point. Mule deer within this zone of disturbance may be conservatively assumed to exhibit a behavioral response. Based on the estimated mule deer densities for the YPG Apache-Hellfire test area, no single deer (i.e., $0.5 \times 0.56 = 0.28$ deer; 0.4 % of the local population) would be expected to exhibit a behavioral response per Hellfire test detonation.

This estimate is likely to be conservative because it assumes that adverse effects occur just inside that 400-m radius (e.g., at a LOAEL of about 399 m). An approach for estimating chemical LOAELs when only NOAELs are available is to apply a NOAEL:LOAEL conversion factor to the NOAEL. Dividing the distance NOAEL by 10, which is a commonly used safety factor[7], yields an estimated maximum distance of 40 m from the stressor at which moose would be expected to flush. That is approximately the distance at which the combined sight and sound of helicopters caused moose to flush (Anderson et al. 1996). That distance would correspond to an area of 5000 m^2 (0.005 km^2) and to far less than one (0.003) of the estimated 70 mule deer comprising the local population. Even using a more conservative conversion factor of three corresponds to less than one (0.008) mule deer (i.e., a maximum distance of 133 m yields an area of 14,000 m^2). However, density estimates would vary with sources of water, minerals, and food.

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[7] Safety factors and conversion factors are typically agreed to by regulatory agencies and other risk managers. Thus, the specific conversion factor of 10 is chosen for illustration only.

4.4.1.3 Expected hearing damage, based on CSEL

The selected threshold for hearing damage, based on human data, is 116 dB CSEL. The area within which Hellfire detonations are expected to produce sound levels greater than or equal to that threshold was estimated with BNOISE2 at 0.385 km^2. This area is approximated by a circle with a radius of 350 m centered at the Pinkrock Impact Point. Mule deer within this zone of injury are assumed to experience temporary or permanent hearing loss. Based on the estimated mule deer densities for the approximately 126 km^2 YPG Apache-Hellfire test area, no single deer (i.e., 0.385 x 0.56 = 0.22 deer; 0.3 % of the local population) would be expected to be injured per Hellfire test detonation.

> Based on a threshold for humans, no hearing damage to mule deer is expected from the Hellfire component of the test.

4.4.1.4 Other blast-related stressors

Shrapnel and, possibly, fire could also injure mule deer in the immediate area of the impact point or affect their behavior in the vicinity of the impact point. There is no evidence that such effects actually occurred during the August 2000 tests. If exposure-response data relating the distance from the impact point at which shrapnel would be expected (with a specified probability) to injure an animal (with a specified level of severity) were available, then the risk estimation methods used above for blast noise could be used here also. That is, one could estimate the number of deer expected to be in the zone of physical injury and relate that to the number of deer in the local population. However, (1) it is highly unlikely that mule deer would stay in the immediate vicinity of moving tank targets, and (2) the zone of shrapnel and fire disturbance would not be likely to encompass even one deer, given the density of 0.56 deer/km^2 (1 deer per 1.8 km^2).

> Shrapnel, fire, and chemical contamination are expected to have negligible effects on mule deer, though specific exposure data were not available.

Risks from environmental concentrations of residual chemicals were not evaluated due to a lack of relevant exposure and effects data for this assessment. In an actual assessment, such risk could be estimated using standard techniques for exposure to chemicals. In any case, the zone of contamination would be expected to be negligible, compared to the zone of potentially effective sound.

4.4.1.5 Population issues

The primary issue in estimating effects on the local mule deer population from Hellfire testing is the need to extrapolate from hearing damage and disruption of behavior of individuals to population-level effects (e.g., reproduction). As in the Apache Longbow helicopter assessment (Sect. 3.4.1.4), there are currently no known data that would allow an assessor to perform those extrapolations quantitatively. Indeed, there aren't even reliable data for blast noise effects on individual mule deer. Given that a principal purpose of this assessment is to demonstrate the general MERAF process, and given that few response data are available for the missile firing activity, it is assumed herein that the hypothetical effects on individuals constitute a highly conservative estimate of impacts on the population. That is, if the percentage of behavioral effects in the mule deer population do not exceed the acceptable level of effect for the assessment endpoint (e.g., 20% decrement in abundance or reproduction), then we could be confident that population-level effects also would not exceed the acceptable level of effect.

4.4.1.6 Weight of evidence

As stated in Sect. 3.4.1.6, the following criteria may be used to weigh evidence: (1) data relevance (is the estimated effect a direct estimate of the assessment endpoint); (2) credibility of exposure-response relationship; (3) relevance of temporal scope of effect; (4) relevance of spatial scope of effect; (5) quality of exposure and effects data; (6) quantity of observations, especially related to variance and biases in sampling; and (7) relevance to a requirement to integrate risks from multiple activities (Suter et al. 2000, Suter et al. 2001). Although the exposure and effects levels used in this assessment are not based on reliable, quantitative data for mule deer (i.e.,are hypothetical), they are considered herein using the weight of evidence process for demonstration purposes (Table 4.3).

> The weight of evidence indicates that fewer than 20% of the deer would be expected to experience behavioral effects from the Hellfire detonation and the deer population is unlikely to exhibit changes in abundance or reproduction.

Behavioral effects

The weight of evidence suggests that the Hellfire component of the Apache Longbow test program would not elicit a behavioral response from a substantial portion ($\leq$ 20%) of the local population and would, therefore, not substantially affect abundance or reproduction of the local mule deer population. The risk estimate derived using the BNOISE2-predicted zone of disturbance indicated that 10 deer would be expected to exhibit a behavioral response per Hellfire test detonation. However, the risk estimate derived using the minimum distance at which moose flush in response to cannonfire indicated that fewer than one deer would be expected to exhibit a behavioral response per Hellfire test detonation (which is also equivalent to fewer than one deer per the Hellfire component of the Apache-Hellfire test program). Neither line of evidence is clearly superior to the other.

The exposure estimates produced by BNOISE2 are better than those reported in the study of moose responses to military disturbances (Anderson et al. 1996). BNOISE2 is a fairly sophisticated sound propagation model that accounts for the relevant characteristics of the missile and environmental variables (climate, topography) and its results are given in a highly relevant metric (i.e., CSEL). In contrast, none of the characteristics of the cannonfire were reported by Anderson et al. (1996), which precludes relating exposure to that cannonfire to exposures to Hellfire missile detonations.

The effects data, on the other hand, are somewhat better for the cannonfire tests than for the BNOISE2 simulations. The CSEL threshold for disturbance is based on the authors' experience that humans almost never complain about large explosions if the CSEL is below 91 dB. Although experience suggests that these criteria are very conservative for humans, there are no quantitative data to support these or any other behavioral, hearing, or reproductive thresholds for ungulates. In contrast, the distance threshold for disturbance is based on tests of blast noise with an ungulate, the moose (*A. Alsec*). The measured responses, flushing from cover and increased heart rate, are good measures of effects and relate well to those used for mule deer. This measure of effects is also conservative, given that it is based on the lack of an effect at the specified distance.

The weight of evidence suggests that the Hellfire component of the Apache Longbow test program does not disturb a substantial fraction of the local population and would, therefore, not substantially affect abundance or reproduction of the local mule deer population. Both the sound level- and distance-based risk estimates indicate that, at most, only a small fraction of the local population would be affected. The risk estimate derived using the BNOISE2-predicted zone of disturbance indicated that 14 percent of the local population would be expected to exhibit a behavioral response per Hellfire test detonation. The assumption that the same individual deer are exposed in each of the five test firings may underestimate the fraction of the population that is disturbed at least once during the entire test period. However, animals exposed multiple times to a blast are likely to become habituated and not to

Table 4.3. Summary of the risk characterization[1] for the desert mule deer population exposed to Hellfire missiles in the 126-km study area in Cibola Range, Yuma Proving Ground

Evidence	Behavioral Effect Result[2]	Population-level Effect[2] Result	Explanation
CSEL/ ungulate behavior relationship	–	–	The risk estimate derived using the BNOISE2-predicted zone of disturbance indicated that 10 deer in the 126 km^2 area would be expected to exhibit a behavioral response per Hellfire test detonation. That corresponds to 14 percent of the local population.
Distance/ ungulate behavior relationship	–	–	The distance-based risk estimate indicated that zero deer in the 126 km^2 area would be expected to exhibit a behavioral response to a Hellfire test detonation. Thus, population-level effects are not expected, based on this line of evidence.
CSEL / hearing damage relationship	–	–	The risk estimate derived using the BNOISE2-predicted zone of injury indicated that zero deer in the 126 km^2 area would be expected to exhibit a behavioral response per Hellfire test detonation. Thus, population-level effects also are not expected, based on this evidence.
Weight of evidence	–	–	The weight of evidence suggests that the Hellfire component of the Apache Longbow test program would not elicit a behavioral response from a substantial portion ($\geq 20\%$) of the local population and would, therefore, not substantially affect abundance or reproduction of the local mule deer population.
	–	–	The weight of evidence also suggests that the Hellfire component of the Apache Longbow test program does not cause hearing damage to a substantial portion ($\geq 20\%$) of the local population local population and would, therefore, not substantially affect abundance or reproduction of the local mule deer population.

[1] The authors have low confidence in the risk characterization for the Hellfire missile activity because of the paucity of relevant effects data.

[2] An effect is presumed to be negative if fewer than 20% of the mule deer are affected.

[3] Level of confidence in population-level effect would be low even if a large-scale behavioral effect was predicted.

exhibit the disturbance response. Because the distance-based assessment did not indicate a risk for individuals, it follows that there would not be a risk to the population.

Hearing damage

The weight of evidence suggests that the Hellfire component of the Apache Longbow test program does not cause hearing damage to either individuals or the local population and would, therefore, not substantially affect abundance or reproduction of the local mule deer population. Only one line of evidence, the sound level-based risk estimate, was available. That hypothetical estimate indicated

that not even one deer would be exposed to potentially damaging sound levels. Regarding the effects level, the CSEL threshold for injury is based on a very conservative threshold for hearing damage for humans, although no data are available for judging whether this threshold is valid for mule deer.

4.4.1.7 Uncertainty and variability

Sources of uncertainty and variability that are likely to affect this assessment have been discussed throughout the preceding sections. Major issues with respect to the Hellfire component of the Apache Longbow test are listed below:

The principal source of uncertainty is the lack of ungulate response data related to blast noise.

• No quantitative exposure-response data for blast noise and ungulates are available. The CSELs used herein are for "disturbance" and acoustic thresholds of humans, and the exposure characteristics for the cannonfire tested with moose were not specified.
• No quantitative data relating behavioral responses of individuals to population-level effects (i.e., abundance and reproduction) are available.
• Terrain was not included in the BNOISE2 simulations, though the capability is available.
• The extent of validation of the BNOISE2 model is unknown.
• Exposure and/or effects data are not available for other Hellfire-related stressors (i.e., shrapnel and fire) and ungulates.

4.4.2 Vegetation in Washes

4.4.2.1 Expected physical damage

The available evidence suggests that vegetation in washes was probably not substantially damaged by Hellfire missiles, shrapnel, or fire during the August 2000 tests. This is based on three primary observations: (1)

Vegetation in washes was not damaged by shrapnel or fire from the Hellfire detonations.

the targets did not travel in or near desert washes, (2) the missiles did not miss the targets during this test period, and (3) evidence of fire damage to plants alongside roads where the target vehicles drove was not observed following this test period. The primary uncertainty in this conclusion is the absence of quantitative pre- and post-test vegetation surveys for this or previous test periods.

4.4.2.2 Expected hydrologic stresses

The available evidence suggests that vegetation in washes were not substantially stressed via hydrologic changes created by the August 2000 tests. This conclusion is based on the observation that none of the Hellfire missiles missed their targets. That is, the desert pavement

Hydrologic change does not occur (or result in risk) because of the lack of Hellfires missing their targets.

was not exposed such that the local hydrology would be expected to change. Without exposure, there can be no risk.

It is worth noting that a miss was reported for a previous Hellfire test and that training activities would have a greater chance for misses because of the likely increase in the number of launches and lesser experience level of trainees. Therefore, this component of the assessment could be important for

future applications of the MERAF framework. Characterization of such risks could be performed using the tools and techniques described in Sects. 5.3 and 5.4.

4.5 RESEARCH GAPS

Additional data and methods that are needed to improve the assessment of risks from missile testing and training flow from the uncertainties identified throughout chapter 4. The primary data gap for missile tests is the lack of quantitative exposure-response data for blast noise and common ecological receptors. Efforts to fill this gap should focus on receptors that are likely to be sensitive and exposed at missile testing and training facilities (e.g., mule deer, antelope, and other ungulates). Potentially useful studies could include tests with individual animals where exposure (e.g., CSEL at receptor and distance from blast), effects (e.g., distance flushed and heart rate), and habituation could be measured under controlled conditions (e.g., fixed test charges) or field tests with representative munitions (e.g., Hellfire missiles) and free ranging animals.

Research is needed concerning the relative sound frequencies that vertebrates other than humans hear. C-weighted decibels do not necessarily reflect ungulate or mule deer hearing. Similarly, thresholds for hearing damage could be investigated.

Another major source of uncertainty is the lack of quantitative data relating behavioral responses of individuals to population-level effects (i.e., abundance and reproduction). Studies relating measurable responses for individuals (e.g., distance flushed, number of times flushed, and degree of habituation) to relevant measures of population-level effects (e.g., calving success or population abundance) would be the most useful from a risk assessment perspective.

For Hellfire missiles, exposure and effects data could be helpful for common ecological receptors and stressors other than sound (e.g., shrapnel and fire). These data might include the density of shrapnel per unit area with distance from the point of detonation, the likelihood and spatial extent of fires, and the severity of injury caused by shrapnel and fire. The research would be more pertinent to larger scale testing or training programs than small tests, because tests at a small scale could not cause adverse effects to a population. In addition, for a retrospective risk assessment, it would be possible to survey the area for impacts on plants and vertebrates. However, the shrapnel model described above could be useful for prospective assessments.

5. RISK ASSESSMENT FOR TRACKED VEHICLE MOVEMENT

5.1 ACTIVITY-SPECIFIC PROBLEM FORMULATION

5.1.1 Stressors and Modes of Action

Stressors and modes of action associated with movement of the target vehicles in the Apache Longbow–Hellfire missile test are listed in Table 5.1. The stressor that is emphasized in this activity-specific risk assessment is the disturbance of desert pavement, which causes altered hydrology, a secondary stressor.

Desert pavement disturbance is a primary stressor and altered hydrology is a secondary stressor associated with off-road, tracked vehicle movement.

Vibration is not included as a potential stressor, because the consequences of vibration are unknown.

Table 5.1. Stressors and modes of action associated with off-road[a] tracked vehicle movement

Stressor	Potential mode of action
sound of vehicle	behavioral response of wildlife, auditory damage to wildlife, interference with foraging or predation, interference with mating
sound level at a particular frequency	interference with signaling among wildlife[b]
physical tank	crushing of vegetation or wildlife; disturbance of soil, leading to changes in vegetation biomass
fuel leak	toxicity to vegetation or wildlife
dust	interference with plant evapotranspiration, respiratory effect in wildlife
disturbance of desert pavement	altered hydrology, leading to reduced vegetation biomass, and/or reduced herbivorous population

[a]On-road vehicle movement would be expected to result in all of these stressors except for the disturbance of desert pavement.

[b]No evidence for this effect, and not expected to be observed among mule deer.

5.1.2 Conceptual Model

The conceptual model for vehicle movement is depicted in Fig. 5.1. The model represents the combination of stressors associated with vehicle movement in the Apache Longbow–Hellfire missile test, without making an assessment of importance of each stressor. At

The conceptual model shows pathways between potential stressors (disturbed soil, sound generation, etc.) and potential effects).

YPG the stressor pathway of most importance relates to the effects of vehicle movement on soils, which affects hydrology, which can affect plant properties and habitat, and ultimately affect animal populations (Sect. 5.3). Fuel leakage, crushing, and sound generation are deemed to be of lesser importance for this test, and are discussed only briefly in the following sections. For the assessment of this test program, there is no pathway for development of roads in wash areas, because vehicle movement in washes is avoided. However, this pathway is indicated in the model (dashed lines in figure), because this possibility may need to be considered in other risk assessments of vehicle movement.

Fig. 5.1. Conceptual model for vehicle movement in Apache Longbow–Hellfire test at Yuma Proving Ground. Dotted line indicates that road development is not part of the Apache-Hellfire test program, but that risks from the development of roads or trails can be integrated with those of vehicle movement.

5.1.3 Selection of Activity-specific Measures of Exposure

5.1.3.1 Intensity measures

Type of tank

      The type of tracked vehicle is an indicator of its weight, track width, and how much the desert pavement may be disturbed by one pass. As a practical matter, however, the level of disturbance cannot be quantitatively linked to the type of tank.

> Intensity measures (weight of tank, number of tanks, sound of tanks) are not used, except to the extent that they are spatial measures as well (track width).

Number of tanks

      The number of tracked vehicles is also an indicator of ground disturbance. However, the exact locations where single versus multiple tanks traveled is not known. Disturbance of desert pavement by multiple tanks relates more to spatial measures of exposure (Sect. 5.1.3.3) than intensity measures.

Sound

Tank movement is not generally expected to be louder than helicopter overflights. Therefore the sound is negligible most of the time. However, if these vehicles perform stationary pivot turns, the sound and vibration can be very loud. Measurements or models to estimate this noise are not available.

5.1.3.2 Temporal measures

Temporal aspects of exposure include duration, frequency, and timing. The duration and frequency of tank movements can be an important consideration relative to noise effects; however, the duration of tank movements for this test is quite short, and the frequency is low (8 events). As is the case with overflights, the timing of tank noise can be important to wildlife, particularly as it relates to reproductive behaviors and home range locations.

Regarding tank effects on hydrology that could impact wash plant communities, repeated use of already disturbed pavement could exacerbate compaction and ponding of water, but repeated use of disturbed pavement is likely to result in small, incremental hydrological changes, relative to effects from disturbance of more pristine pavement.

An additional temporal measure of exposure is the duration of the disturbance, prior to recovery. Tank track disturbance zones may last for hundreds of years, and thus this temporal measure of exposure is not measurable.

5.1.3.3 Spatial measures

Tank track area

The extent of disturbance of soil from tracked vehicles and the associated hydrological change are highly dependent on the extent to which tanks drive off-road or on-road.

Tank track area is the most important measure of exposure for the vehicle component of the Apache-Hellfire test.

The off-road tank tread area is a measure of desert pavement disturbance, which is a measure of hydrological change, which is a measure of changes in wash vegetation. The greater the spatial area of disturbance, the less water potentially moving to desert washes and the greater the potential impact to wash vegetation. Spatially-explicit disturbances are considered, for example, in the ATTACC, model which measures training load in terms of maneuver impact miles (MIM) (USAEC 1999). "One MIM has the equivalent impact on soil erosion as an M1A2 tank driving one mile in an Armor battalion (BN) [field training exercise]" (USAEC 1999).

On-road tank tread area would be expected to have some minimal impacts (compaction of soil or erosion), but not the disturbance of desert pavement, which is the focus of this chapter.

5.1.4 Selection of Measures of Effects

The primary measures of the effects of tracked vehicle movement relate to the effect of soil disturbance on hydrology, and the effect of changes in hydrology on wash plant communities. The primary metrics are estimates of water loss

Measures of effects on the wash community (and potentially mule deer) include the volume of water passing over a land area.

from disturbance in particular soil types, and the modeled overall loss of water to the wash vegetation community. Water loss could effect plant biomass or community properties in desert washes (the selected assessment endpoint). Direct measurements of wash plant communities were not conducted as part of this assessment. Few data are available that document the direct effect of pavement disturbance

on hydrology and wash plant communities in this area. Supporting lines of evidence from other studies in the area and observational information were used as inputs to simulations.

5.2 CHARACTERIZATION OF EXPOSURE

5.2.1 Vegetation in Washes

5.2.1.1 Options for exposure analysis

Direct exposure

      The exposure assessment could focus on direct exposure of desert wash vegetation to crushing, erosion or dust from tanks traveling in washes. For example, models are available, such as the Army Training and Testing Carrying

Several options are available for the characterization of exposure.

Capacity (ATTACC) model, that could be used to estimate vegetation changes as a consequence of factors like erosion from tank movements. However, at YPG it is assumed that the tanks do not travel through washes, based on the description of the program by Yuma Proving Ground staff.

Contingent exposures

      The exposure assessment could focus on the connection between tank disturbance of desert pavement and changes in hydrology associated with that disturbance, which lead potentially to effects on vegetation in desert washes. Although the generic MERAF (Suter et al. 2001) suggests that intermediate exposures may be quantified in a section following the initial characterization of exposure, we do not organize this assessment in that manner, because altered hydrology is not an endpoint for this demonstration of MERAF. In fact, the primary approach to exposure assessment for the vehicle movement activity is the estimation of changes in hydrological exposures that are associated with areas of tracked vehicle disturbance.

      It should be noted that desert pavement is a unique surface found predominantly in the Sonoran Desert region in and near Yuma Proving Ground. Soil disturbance by tanks in most U.S. locations would be expected to cause soil compaction, lowering the permeability to water and increasing runoff (Ayers 1994, Prose 1985). However, as stated in Chapter 2, disturbance of desert pavement at Yuma Proving Ground is assumed to result in retention of water in the resulting ruts or depressions, which would decrease runoff to the washes (Ayres Associates 1996; McDonald 1999; Glass 2000; V. Morrill, YPG, personal communication, August 1, 2000).

Mechanistic exposure model

      The exposure assessment could use a mechanistic exposure model to predict changes in the plant communities from disturbances that affect hydrology. EDYS (Ecological Dynamics Simulation Modeling) is one ecosystem model that has been used in a wide range of applications, including ecological risk assessment on Army lands (Childress et al. 1999). EDYS includes climate, soils, plant, animal, hydrological, spatial, landscape, and management modules, and has an extensive list of hydrologic and vegetation input variables. EDYS was not used for this assessment because of the need for significant reparameterization of the existing model to address YPG's unique soil/pavement, water, and plant community conditions, and the general paucity of available local data to quantify many of the model's data requirements. For example, very little site-specific, species information from vehicle-disturbed and undisturbed habitats at YPG was available to characterize over 40 plant parameters included in EDYS. A mechanistic model such as EDYS, or a site-specific version thereof, would still be

a viable option at for risk assessment of tracked vehicle and other soil disturbances at YPG with further data and model interpretation and development.

5.2.1.2 Direct exposure to tank track disturbance

It was conceivable that tank track area could directly be related to the response of an ecological endpoint entity. However, because of a lack of a direct exposure-response relationship, in this assessment, the tank track area simply served as an input to the hydrological analysis described in Sect. 5.2.1.3.

> Pre-existing tank track areas were estimated from a DOQQ aerial photo. Test-associated disturbances were estimated from field observations.

Tank track areas may be estimated from a Digital Ortho Quarter Quad (DOQQ) photo of the study area (Fig. 5.2). For this assessment, the disturbed areas on the DOQQ (from July 1998) served as preexisting disturbances, and areas of disturbances that were assumed to be associated with the Apache Longbow–Hellfire missile test were estimated based on observations by coauthor W. H. Rose (Appendix D) and the assumption that most turnaround areas are approximately equivalent in size. The resolution of disturbance was adjusted to 30-by-30-m spatial cells (i.e., each whole cell was assumed to be disturbed or not) because this was the resolution of the digital elevation model. As stated in Sect. 2.2.2.3, one tank which travels off-road during the test travels on a preexisting path, and the tank turnarounds were created in borrow pits used for road development. However, for the purpose of this assessment, we assume that the off-road path and select turnarounds not apparently present in the 1998 DOQQ were created for this test, and therefore the hydrological impacts of these areas were estimated (Sect. 5.2.1.3). The disturbance areas estimated from Rose probably represent a conservative (i.e., high) estimate of impacts associated with this test, because other tests may have been performed in the area in the last two years.

In future risk assessments, an assessor could use a time series of DOQQs to attribute tank tracks to particular tests, with knowledge of which tests or training programs utilized the site during which period.

5.2.1.3 Indirect exposure to tank track disturbance via a change in hydrology

Hydrological change is a stressor that may result from the stressor of tank disturbance of desert pavement. Because hydrology is not an assessment endpoint entity (hydrology is not of ecological value in and of itself), the relationship between this "secondary stressor" and the "primary stressor" of soil disturbance is described in the Characterization of Exposure

> The hydrologic analysis tool in ArcInfo was used to assess the amount of runoff from disturbed and undisturbed soils and water loss in washes associated with disturbance.

section, as discussed above. Mechanistic models exist that can estimate soil-water balance in desert ecosystems (e.g., Simultaneous Heat and Water Model, McDonald et al. 1996), but few models consider the movement of water overland from one land area to another. Ayres Associates (1996), in modeling hydrology in Yuma Wash, used HEC-1, a computer program developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center (USACOE 1990), and a modified version of The Hydrologic Model (HYMO) computer program developed by the USDA Agricultural Research Service.

In this assessment of risks from vehicle movement associated with the YPG Apache Longbow–Hellfire testing, the hydrologic analysis tool within ESRI ArcInfo was used to provide a spatially explicit assessment of the amount of runoff and water loss in disturbed and undisturbed soils in the study area. In particular, the "flow accumulation" feature of the geographic information system (GIS) was utilized. This analysis made use of the digital elevation model (Sect. 2.3.3) and estimates of runoff

Fig. 5.2. Digital ortho quarter quad photo showing tank disturbance along MTI Road and neighboring roads. Dark areas represent desert pavement, lighter areas represent desert washes (with some vegetation observable as spots), and white areas represent surface disturbances, including roads.

from four soil complexes, under both disturbed and undisturbed conditions. The results of the analysis were maps of water loss in and around the test area. The rain event and runoff assumptions are presented first, followed by a description of the hydrologic analysis.

Rain event assumption

To provide estimates of differences in runoff associated with undisturbed and disturbed soil at the study site, this analysis focused on a simulated rainfall event of sufficient intensity and duration to provide runoff to the wash: 1inch of rain over a 1 hour duration, over the entire McAllister and Indian Wash watersheds. Rainfall events of exceptionally high intensity (10 to 100-year return periods) were not considered in this analysis because events of such rarity would not be relevant to plant wash communities in the short-term. Based on rainfall distribution calculations used by Ayres Associates (1996) for Yuma Wash, and using rainfall data from Hershfield (1961), a 1-inch rain over a 1-hour duration occurring over a watershed over a few square miles would be expected to occur at YPG every 3-5 years. This appears to be a time frame that has ecological relevance for riparian wash plants.

The rain event assumption is a 1-inch rain over a 1-hour duration.

Runoff and infiltration

The amount of runoff that reaches the desert wash is dependent on rainfall characteristics (e.g., duration, intensity, timing), soil characteristics (e.g., permeability, type of stone cover), vegetation characteristics [e.g., extent and type of vegetation can affect evapotranspiration (evaporation and transpiration)], and geomorphological characteristics (e.g., slope, erosion). In the desert of YPG, runoff rarely extends very far due to low rainfall, high evaporation, and infiltration of flow in the wide alluvial channels. This phenomenon is known as transmission loss. Low intensity rains in the winter months provide important inputs to desert washes by direct precipitation, but are unlikely to be sufficient to generate runoff that would provide significant quantities of water to the washes. High intensity, short-duration storms, occurring relatively infrequently in late summer over a multi-year cycle, appear to be critical events for runoff-related recharge of the wash water budget.

As stated above, the hydrologic analysis tool within ESRI ArcInfo was used to provide a spatially explicit assessment of the amount of runoff and water loss in disturbed and undisturbed soils in the study area. Because of the proximity of Yuma Wash to the study area and the similarities in soil types and rainfall, many of the same assumptions and input variables used in the hydrologic modeling of Yuma Wash (Ayres Associates 1996) were used for this hydrologic assessment. Using the infiltration rates (in/hr) of land treatment types presented by Ayres Associates (1996) and adjusting for the different percentages of soil families within each soil complex, infiltration rates were generated for each of the four soil complexes found at the study site (Table 5.2). The infiltration rates used here are also consistent with rates measured for YPG pavement by Glass (2000) (0.9 in/hr) and Musick (1975) (0.39 in/hr). Glass (2000) used for modeling purposes an infiltration rate for pavement of 0.4 in/hr, which is very close to the value of 0.5 in/hr that was utilized in this assessment (Table 5.2)[8].

Infiltration rates are provided for four soil complexes.

The delineation of soil complexes was based on soil surveys and mapping by Cochran (1991). Soil complexes in the study area are shown in Fig. 2.1. Transmission loss was not considered in this analysis. Ayres Associates (1996) found that total transmission loss for all modeled storms at the Yuma Wash outflow ranged between 0.5 and 1.2% of the total runoff, and remained low even if the infiltration

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[8]The Glass (2000) study was obtained after the hydrologic analysis was complete; thus her parameters represent an independent confirmation of the infiltration rates assumed in this risk assessment.

rates were increased significantly. However, it is important to note that transmission loss could be significant for localized, low-intensity storms.

Assuming a one-inch storm event for a one-hour duration, and assuming that water lost to the soil corresponds to the infiltration rates in Table 5.2 (evapotranspiration processes are not considered in this short-duration storm event), all remaining water is treated as runoff in this hydrologic analysis. This assumption would appear to be reasonable, based on the high percentage of precipitation in the first few minutes of the thunderstorm.

Essentially, the hydrologic analysis tool within ESRI ArcInfo requires weighting factors to distinguish between soil complexes that act as sieves and those that act as parking lots. Thus, two types of proportions are estimated for each 30-by-30 m cell in the digital elevation model (DEM): (1) proportion of water that runs off of each cell that it lands on directly during precipitation and (2) proportion of water flow that runs off of each cell that it passes by (Table 5.3). Runoff from cells is potentially available as moisture for the desert wash vegetation. It is assumed for this analysis that infiltration losses first reduce the water directly deposited to the cell (Phase I), and any remaining infiltration capacity of the soil reduces the runoff passing over the cell from adjacent areas (Phase II).

Both the proportion of water that runs off each cell during precipitation and the proportion of water that runs off each cell as it passes by are estimated for four soil complexes under undisturbed and disturbed conditions.

Table 5.2. Infiltration rate in soil complexes in study area at Cibola Range

Soil complex	Infiltration (in/hr)[a]	Soil and geological characteristics[b]
Riverbend family--Carrizo family	3.0	wash: relatively high permeability, low runoff
Cristobal family--Gunsight family	0.5	pavement: slow permeability, moderate runoff
Gunsight family--Chuckwalla family	0.9	sloping ridge: minor pavement, moderate-to-rapid runoff
Lithic and Typic Torriorthents	0.1	mountainous: low permeability, rapid runoff

[a] Note that the use of an "initial abstraction" term would result in less runoff.
[b] Based on soil survey descriptions by Cochran (1991).

The proportion of runoff on disturbed land was estimated by considering the likely impact of vehicle disturbance relative to the runoff proportions calculated for the undisturbed state. Considerations included the characteristics of the soils below the surface horizons, direct observations of the type of tracked vehicle disturbance, and recent investigations of runoff processes on disturbed soils at YPG (Ayres Associates 1996; McDonald 1999; Glass 2000; V. Morrill, YPG, personal communication, August 1, 2000). Tracked vehicle traffic at most desert military base locations would lead to compaction of soil and increased runoff (Ayers 1994, Prose 1985). Tank tracks have been shown to compact soil at YPG as well, but runoff processes at YPG may be very different from those at other installations. Glass (2000) reported an average infiltration rate of 0.5 in/hr for various tank track surfaces at a site in the Kofa Range of YPG, indicating some soil compaction and lower infiltration than other surfaces. Glass (2000) measured average infiltration rates of 3.1 in/hr in stream bed, 2.5 in/hr in creosote mounds, 0.9 in/hr in pavement, and 0.7 in/hr in jeep tracks. Measuring infiltration rates in desert pavements can be very difficult, so there is high degree of uncertainty associated with these values (Glass 2000 and P. Haff,

Duke University, personal communication, June 12, 2000). Loosening of soil by certain kinds of vehicle disturbance, resulting in increased infiltration, is also a possibility at YPG (Glass 2000). Higher infiltration rates were observed in creosote mounds that break the pavement surface, and exploding ordnance produces a similar effect of exposing and loosening fines below pavement clasts.

Regardless of the extent of changes in soil infiltration from disturbance, tracked vehicles on desert pavement soils can create ruts and depressions, as well as berms alongside their tracks, that result in enhanced ponding and less runoff to downstream areas. In time, all trapped water found in depressions among desert pavements will evaporate or infiltrate. Such depressional areas can also create microhabitats for disturbance-adapted plants, resulting in additional water losses via plant retention and transpiration. (Generally transpiration loss is minimal in the upland areas because of the general absence of vegetation in pavements and mountainous slopes. It is assumed for this analysis that tracked vehicle disturbance in pavement soils results in ponded water that is unavailable to downstream areas.

Table 5.3. Proportions of water that run off of 30m by 30m land cells during precipitation and overland flow phases

Process	Soil complex	Undisturbed land	Disturbed land
Direct Precipitation (water directly deposited to cell)	Riverbend family--Carrizo family complex	0[a]	NA[b]
	Cristobal family--Gunsight family complex	0.5	0
	Gunsight family--Chuckwalla family complex	0.1	0.05
	Lithic and Typic Torriorthents	0.9	0.9
Downgradient flow (water passing over cell)	Riverbend family--Carrizo family complex	water entering cell minus 2 inches lost by infiltration	NA[b]
	Cristobal family--Gunsight family complex	1	0
	Gunsight family--Chuckwalla family complex	1	0.8
	Lithic and Typic Torriorthents	1	1

[a] 1 indicates that all water leaves cell and is potentially available to lower elevation cells; 0 indicates that no water leaves cell (it infiltrates, ponds, evaporates or is transpired)
[b] The value for disturbed soils in the wash community is not applicable for this test.

A more detailed explanation of the calculations and assumptions used to generate the runoff proportions in Table 5.3 is provided in the following discussion for each soil complex.

Riverbend family--Carrizo family complex (wash). This complex constitutes the soils of the desert wash. The wash has a relatively high infiltration rate (3 in/hr). Given the low slope and relative runoff potential, it can be assumed that rain hits the cell, infiltrates the soil, and is initially available for plant use or moves to the vadose zone. (Evaporative losses are not considered here, because they are likely to be negligible during a 1-hr storm event; such losses would increase with increasing storm duration.) For

the undisturbed wash, infiltration rates suggest that up to 3 inches of water can be retained in the cell (1 inch of precipitation that hits the ground directly and 2 inches of runoff). The excess is treated as runoff in this analysis.

If vehicle disturbance occurred in the wash (not applicable to this test), it would be unlikely to affect the amount of water in the wash from direct precipitation. However, disturbances to the washes may include road crossings that could affect runoff, acting much like depressional disturbances of pavement that prevent water movement downstream. The amount of water retained upstream of the road is dependent on the intensity of the storm and the extent of road disturbance. Most roads in the study area are not sufficiently elevated from the surrounding topography to be a major factor in affecting runoff.

Cristobal family--Gunsight family complex (pavement). The majority of this soil complex is desert pavement (60%), and low permeability soils. Precipitation water losses that correspond to the soil infiltration rates are incorporated in the Phase I estimate for the one-hr storm. One-half inch of the one-inch rain that hits the cell directly is assumed to infiltrate, and one half inch would go to runoff (passed on to the next cell). Runoff from upstream cells would be expected to pass through the undisturbed cell with little loss; all runoff water is passed through the cell in this analysis (runoff value of 1, Table 5.3).

Because the simulated storm is of modest intensity and the slope of the desert pavement is not very steep, it is assumed that disturbed, depressional areas capture and retain almost all of the direct precipitation, as well as all the runoff water from upgradient of the cell. As previously discussed, depressional areas in desert pavement can retain and pond water (exacerbating losses via evaporation and infiltration), and create microhabitats where disturbance-adapted plants can move in (resulting in water losses via plant retention and transpiration). Our assumption of total water loss represents the worst case scenario. Actual water losses due to disturbance are dependent on a variety of factors, including the storm intensity and duration and the extent of soil disturbance. The proportion of water that passes over a disturbed cell would be expected to be higher in a very high intensity event, or if the soil disturbance does not result in sufficient depressional areas to hold much water. The shape and type of disturbance, in addition to slope, may be major factors defining the amount of runoff water that passes through these areas. For example, if the disturbance is parallel to a steep slope, the disturbance may act to funnel and channel water; however, disturbed, steep areas are not definitive of the desert pavements in the study area.

Gunsight family--Chuckwalla family complex (sloping ground; some pavement). This complex is characterized by sloping ground with some pavement (24%). The soil is transitional between pavement areas and mountainous terrain. Since the complex is more permeable than the Cristobal complex because of lower percentage of pavement, much of the precipitation that hits the ground for this storm simulation infiltrates (value 0.1 in Phase I). However, runoff is moderate to rapid on the higher sloping ground, and with no additional capacity of the soil to hold water in this simulation, all runoff water from upstream cells is passed over cells of this complex (runoff value of 1 in Phase II, Table 5.3).

Disturbances along this sloping ground may trap and retain small quantities of water; therefore the cell values were slightly lowered in the disturbed scenario. The major disturbance issue for this soil type may be related to exacerbation of erosional processes.

Lithic and Typic Torriorthents (mountainous terrain). This terrain has a high percentage of bare rock on steep terrain. Very little infiltration of precipitation is assumed for this simulation (runoff value of 0.9, Table 5.3), and all runoff is passed over the cells of this complex (runoff value of 1).

Disturbance, if present, is unlikely to retain water on such steep rocky soils. Runoff from this soil type was not treated differently between undisturbed and disturbed conditions.

Implementation of the spatial hydrological model

The hydrologic analysis occurs on a cell-by-cell basis over the entire study area. First, the flow direction is calculated for each 30-by-30-m cell. This direction is the single cell of the eight neighbors into which most of the water flows. The analysis only considers the maximum or majority flow direction; consequently water flow paths are narrow lines in the simulations (Fig. 5.3), whereas actual flow would be expected to be more widely distributed across space, particularly on relatively flat ground. Then, a flow accumulation analysis is performed, in which the total number of uphill cells contributing water to this cell is tallied. The resulting volume is a crude measure of the total water available to each cell, assuming completely impervious terrain and no water losses (to infiltration, ponding, etc.).

> A flow accumulation analysis determines the number of 30-by-30-m uphill cells contributing water to a given cell, adjusted for runoff loss percentages.

The method for simulating the hydrological effects of desert pavement disturbances resulting from Apache-Hellfire testing uses a two-step subtraction process that makes use of soil type and infiltration to estimate runoff in disturbed and undisturbed soils. The two-step method in ESRI ArcInfo can best be understood from the perspective of a single map cell. Three hydrological areas are of importance for each cell: (1) the upslope contributing area, from which water flows into this cell; (2) the cell itself; and (3) the downslope area into which water flows from this cell.

For the flow accumulation step of the analysis, a runoff weighting grid was devised. This grid consists of numbers between 0 and 1 representing the proportion of incipient precipitation falling on this cell which was lost to infiltration (Table 5.3). A unique loss percentage was supplied for each of the four soil types, depending on whether the cell was disturbed or undisturbed. Runoff losses from upslope areas were accounted for in a second, separate subtraction step from the flow accumulation layer. As in the first decrement step, the second subtraction also takes into account the infiltration capacity of the respective soil type and whether the cell is disturbed by tracked vehicles.

Several vehicle disturbance scenarios were considered (Table 5.4 and Fig. 5.4). The hypothetical disturbances are discussed in more detail in Chapter 7, rather than in this chapter, which is intended to estimate risk from the test itself. In the hydrological analysis, it is assumed that all or none of a 30-by-30-m cell is disturbed (the resolution of the DEM). Thus, disturbances of a spatial scales smaller than the majority of a 30-by-30 m cell ($about 450 m^2) are not considered.

After estimating runoff corrected by infiltration losses within every cell, disturbance difference layers were calculated by spatially subtracting runoff estimates of one scenario from another. The resulting runoff difference layers provide a map of the reduction in runoff due to the differences in disturbance between the two compared scenarios; the spatial subtractions were all ordered so that water flows associated with the more extensive disturbances are subtracted from those in the less-disturbed scenarios. The grids which result were converted to vector stream lines using the STREAMLINE command, and were portrayed graphically as streams with increasing width as estimated surface runoff is reduced. (Again, because the GIS analysis considers only the direction of maximum flow, hydrologic flow out of a single cell always takes the form of a single-cell-wide stream path.)

Results of hydrological analysis

Runoff volumes estimated for disturbance associated with the test itself were compared with existing disturbances from tracked vehicle movement on MTI road. The greatest absolute reductions in runoff occurred in cells below junctures of pairs of affected wash tributaries downstream from the spatial locations of the tracked vehicle disturbances (Fig. 5.5, magnified view in Fig. 5.6). This is largely because decrements to runoff are additive along the downstream flow path. Similar results were obtained when disturbances associated with the Apache-Hellfire test were added to prexisting disturbances, and compared to the hypothetically undisturbed conditions in the test area; that is, the greatest reductions in water volumes were within cells farthest downstream of the test disturbance area.
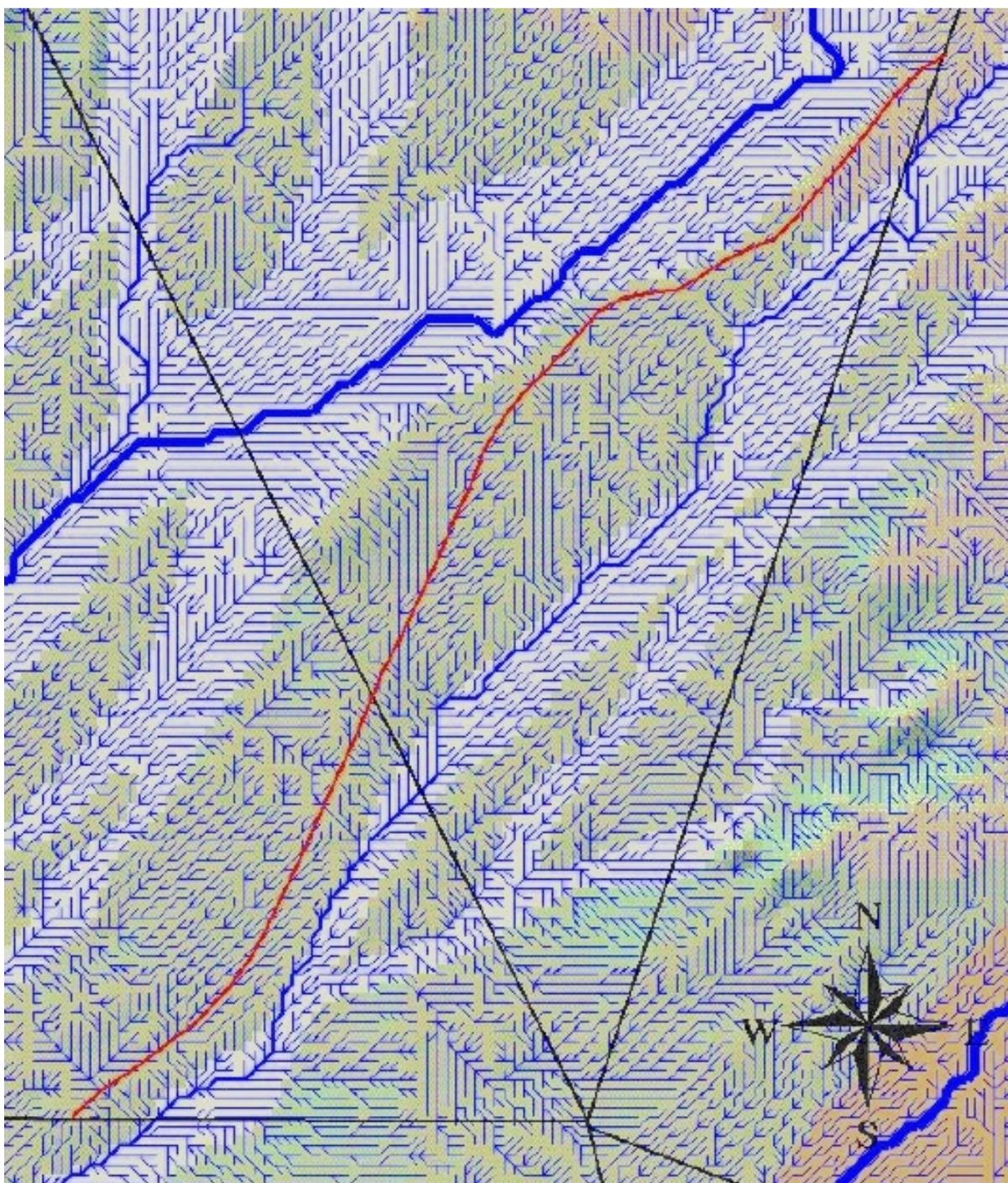
Fig. 5.3. A zoomed-in example of flow direction lines for the hydrologic analysis conducted within the Apache Longbow–Hellfire test area.
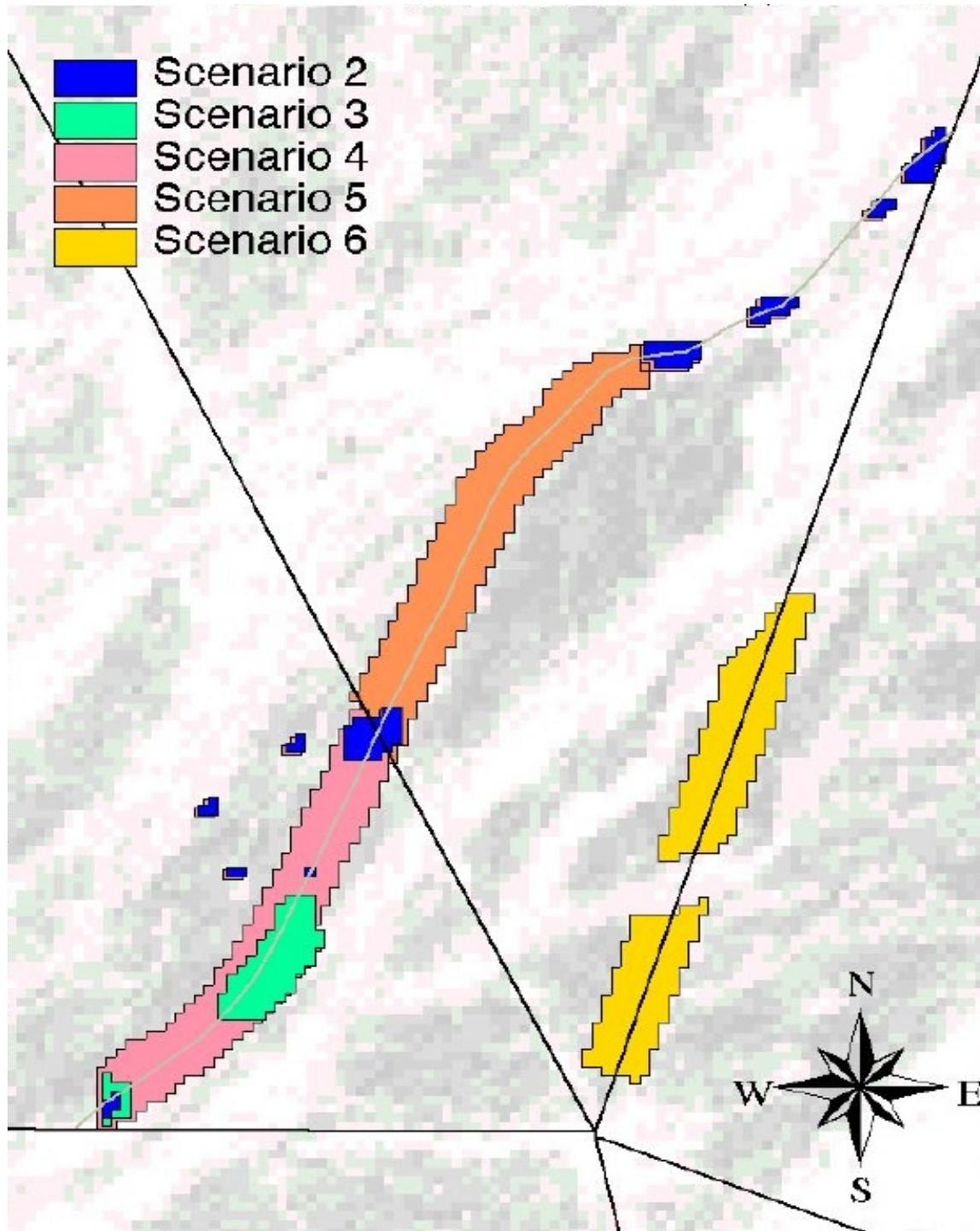
Fig. 5.4. Vehicle disturbance areas for which hydrological change was considered. Scenario 1, 2 and 3 are discussed in this chapter. Scenarios 4-6 are discussed in Chapter 7. Scenario 1 represents no disturbance to the test area. Scenario 2 represents existing disturbance from tests on and around MTI Road. Scenario 3 represents a conservative estimate of disturbance from the Apache Longbow–Hellfire test, plus existing disturbance (only the test-associated disturbance is depicted in green here, but Scenario 3 also includes Scenario 2, in blue).

Fig. 5.5. Water loss due to tracked vehicle disturbance associated with the Apache Longbow–Hellfire test combined with preexisting disturbance (Scenario 3), compared to preexisting disturbance (Scenario 2). The legend signifies the number of cells upgradient of a given cell (adjusted for permeability of cells) from which water no longer flows to the depicted cell; i.e., thickness of the stream line represents magnitude of reduction in water volume. Although difficult to see on this figure due to the small amount of disturbance associated with the test, there is an incrementally greater reduction of water volume below each juncture of a pair of affected wash tributaries.

81
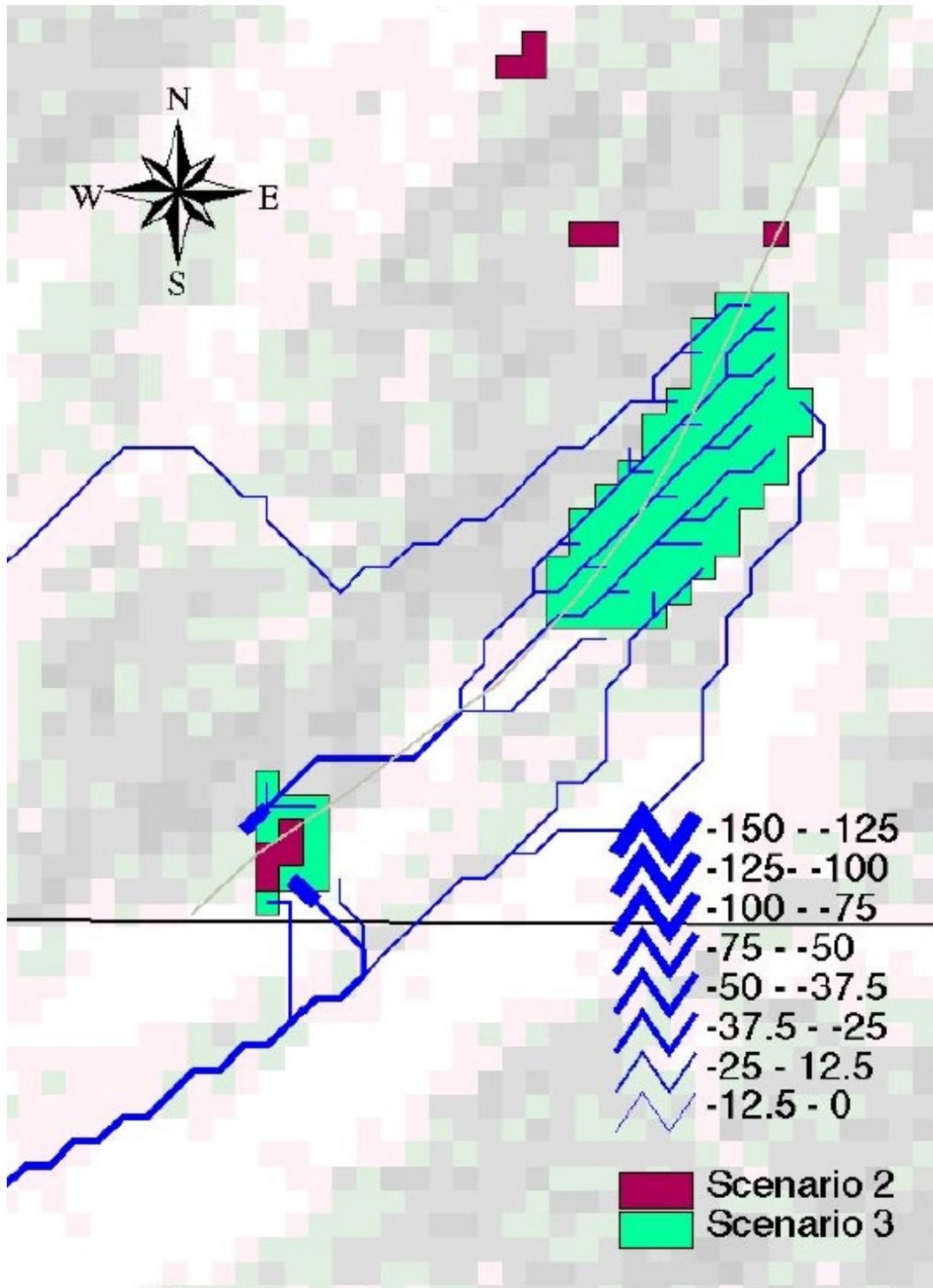
Fig. 5.6. Magnified view of Fig. 5.5. Water loss due to tracked vehicle disturbance associated with the Apache Longbow–Hellfire test combined with preexisting disturbance (Scenario 3), compared to preexisting disturbance (Scenario 2). The legend signifies the number of cells upgradient of a given cell (adjusted for permeability of cells) from which water no longer flows to the depicted cell; i.e., thickness of the stream line represents magnitude of reduction in water volume. Although difficult to see on this figure due to the small amount of disturbance associated with the test, there is an incrementally greater reduction of water volume below each juncture of a pair of affected wash tributaries.

Table 5.4. Vehicle disturbance scenarios for hydrological analysis

Scenario	Justification or Reference
(1) no disturbance	conditions prior to establishment of test area
(2) existing disturbance from tests on MTI Road	disturbance conditions evident from July 1998 DOQQ image
(3) conservative estimate of disturbance from Apache Longbow–Hellfire test, plus existing disturbance	field observations by Winifred Rose of CERL, August 15, 2000, Appendix D
(4) hypothetical estimate of disturbance if a 900-1000-m length of MTI Road, between West Target and Red Hill Roads were disturbed	Aviation and Airdrop Systems has authorization from the Environment Office to disturb land up to 100 m on either side of the center line of the roads (V. Morrill, YPG, pers. comm., August 14, 2000); thus this level of disturbance could occur.
(5) hypothetical estimate of disturbance if a 900-1000-m length of MTI Road, between Red Hill and East Target Roads were disturbed	Aviation and Airdrop Systems has authorization from the Environment Office to disturb land up to 100 m on either side of the center line of the roads (V. Morrill, YPG, pers. comm., August 14, 2000); thus this level of disturbance could occur.
(6) hypothetical estimate of disturbance if a 900-1000-m length of East Target Road, above West Target Road, were disturbed	Aviation and Airdrop Systems has authorization from the Environment Office to disturb land up to 100 m on either side of the center line of the roads (V. Morrill, YPG, pers. comm., August 14, 2000); thus this level of disturbance could occur.

Potentially more important to herbaceous vegetation than the absolute reduction in runoff, however, is the proportional reduction, i.e., the percentage of reduction of inflowing water compared to the total water originally available to plants located in the cell. The proportional water loss associated with the Apache Longbow–Hellfire test scenario, compared to a no-disturbance scenario is depicted in Fig. 5.7, and with a magnified view in Fig. 5.8. The proportion of water loss associated with the test scenario, compared to the pre-test disturbance estimated from the DOQQ is depicted in Fig. 5.9, and with a magnified view in Fig. 5.10. The maps of percent loss of water show that the greatest proportional impact occurs in areas physically close to the testing disturbances (Fig. 5.8, Fig. 5.10). The proportional water loss is increasingly ameliorated at downslope locations by the contribution of runoff water from additional upslope areas.

Model and parameter uncertainty

A great deal of uncertainty is associated with any hydrologic analysis in desert environments, and clearly this assessment uses many input variables and assumptions that need further empirical study. For example, the initial premise is that a 1 inch/hr rainfall every 3-5 years is of adequate intensity to be an important event; however, given the "normally" highly variable and multi-year cycle of rainfall at YPG, the exact level of rainfall that is most important for recharging the wash water budget is unclear. Accurately determining infiltration rates of various soil types is also difficult with typically-used field methodologies (P. Haff, Duke University, personal communication, June 12, 2001). More direct measurement of evaporation, transpiration, infiltration, and transmission losses over time, after rainfall of various levels of intensity, is needed to adequately assess hydrology at YPG. The significance of soil
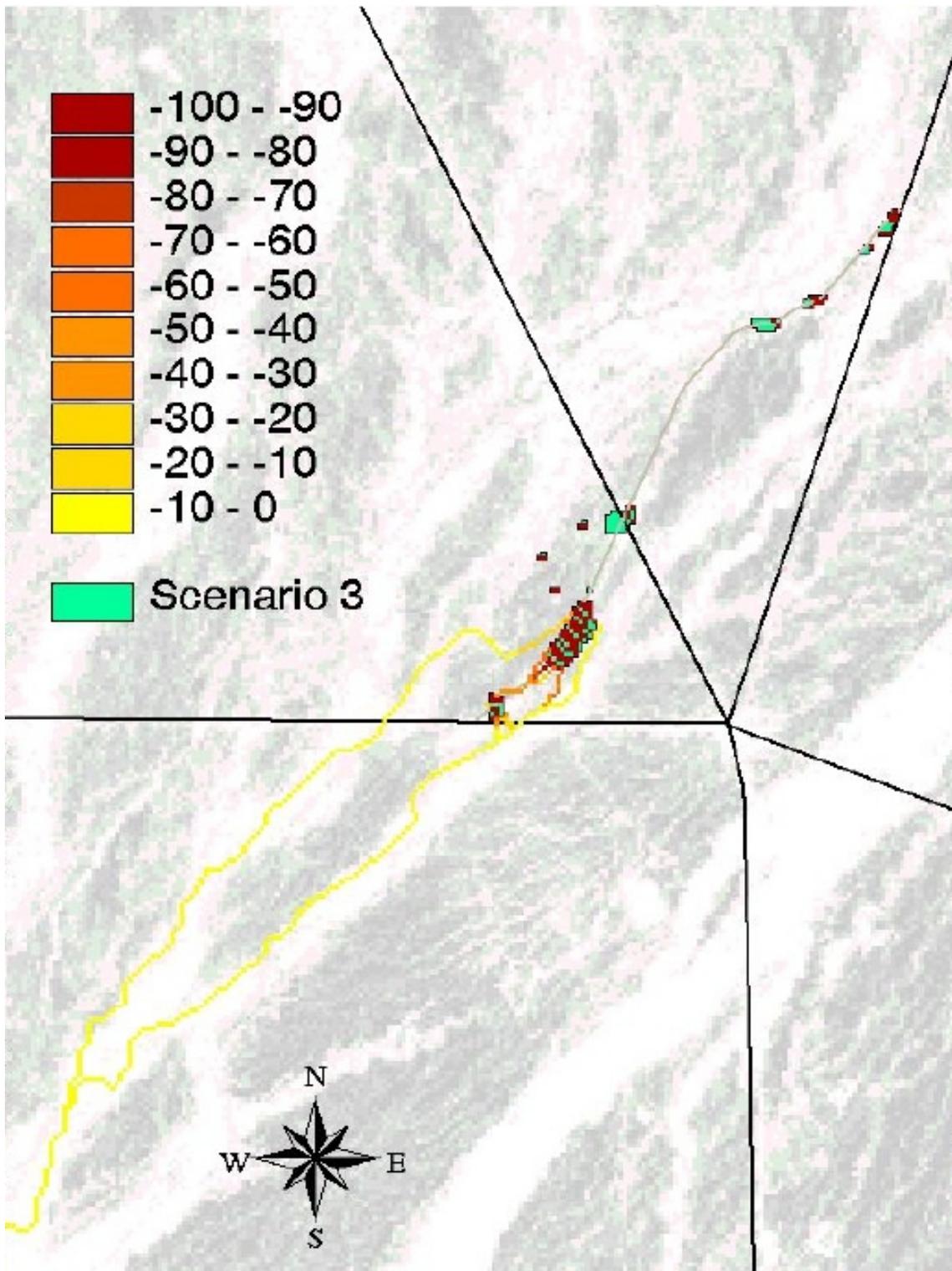
Fig. 5.7. Percent water decrement associated with approximate vehicle disturbance areas from the Apache Longbow–Hellfire test and pretest disturbance areas (Scenario 3), compared to a no-disturbance scenario (Scenario 1). The results are overlain on a Landsat 7 image, and desert wash areas appear in white.
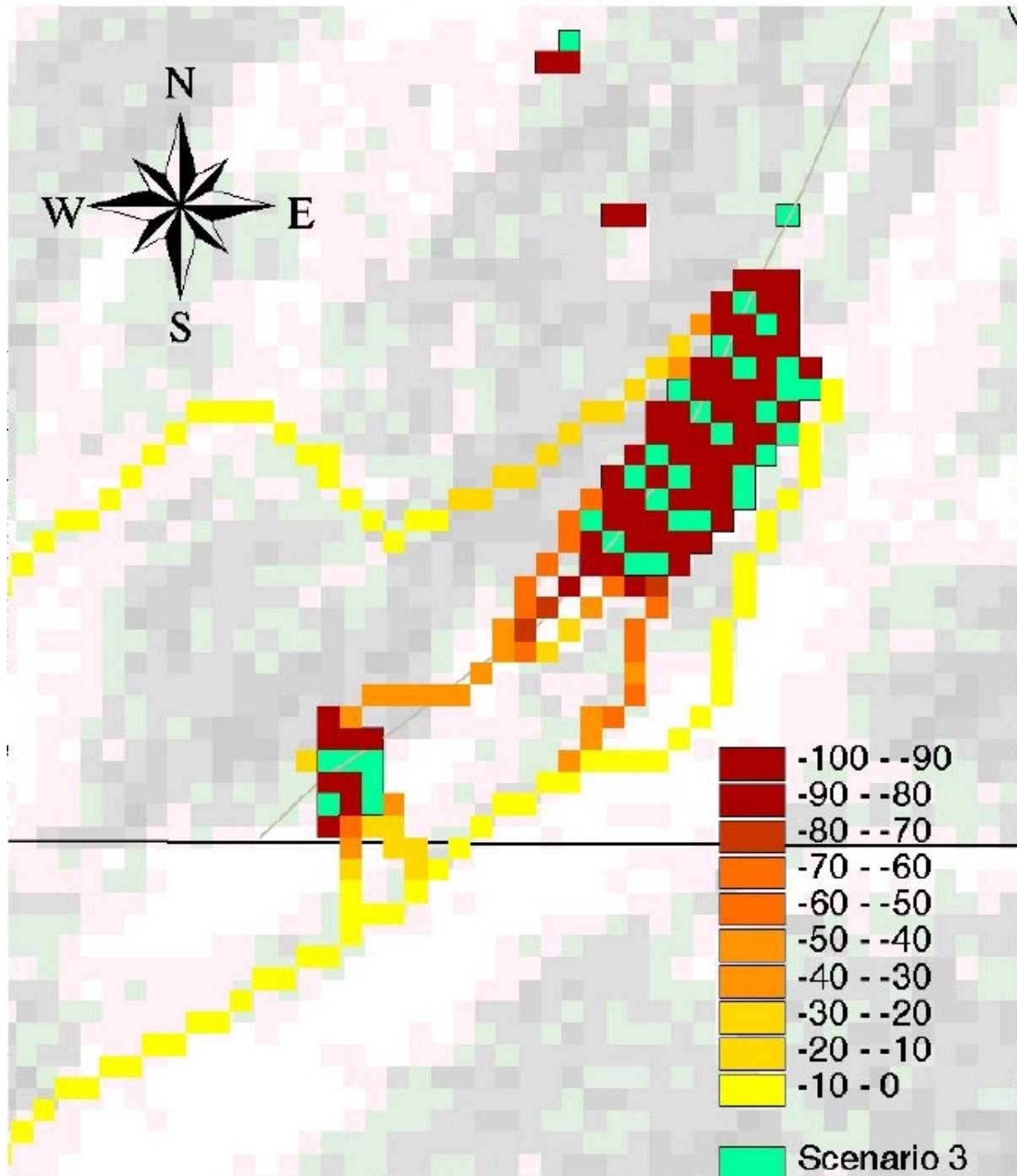
Fig. 5.8. Magnified view of Fig. 5.7. Percent water decrement associated with approximate vehicle disturbance areas from the Apache Longbow–Hellfire test and pretest disturbance areas (Scenario 3), compared to a no-disturbance scenario (Scenario 1). The results are overlain on a Landsat 7 image, and desert wash areas appear in white.
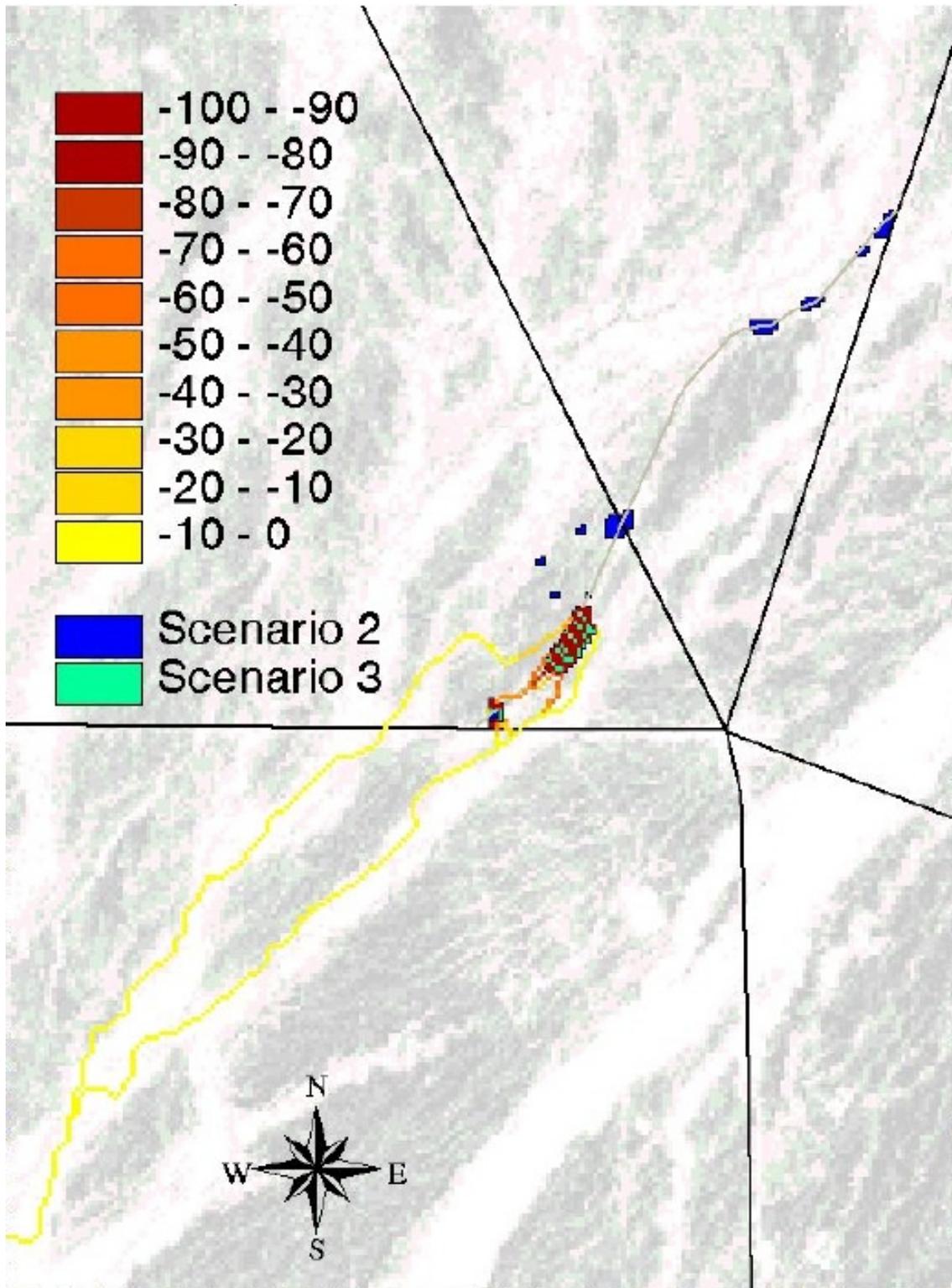
Fig. 5.9. Percent water decrement associated with approximate vehicle disturbance areas from the Apache Longbow–Hellfire test plus preexisting disturbance areas (Scenario 3), compared to the pre-test disturbance scenario (Scenario 2). The results are overlain on a Landsat 7 image, and desert wash areas appear in white.
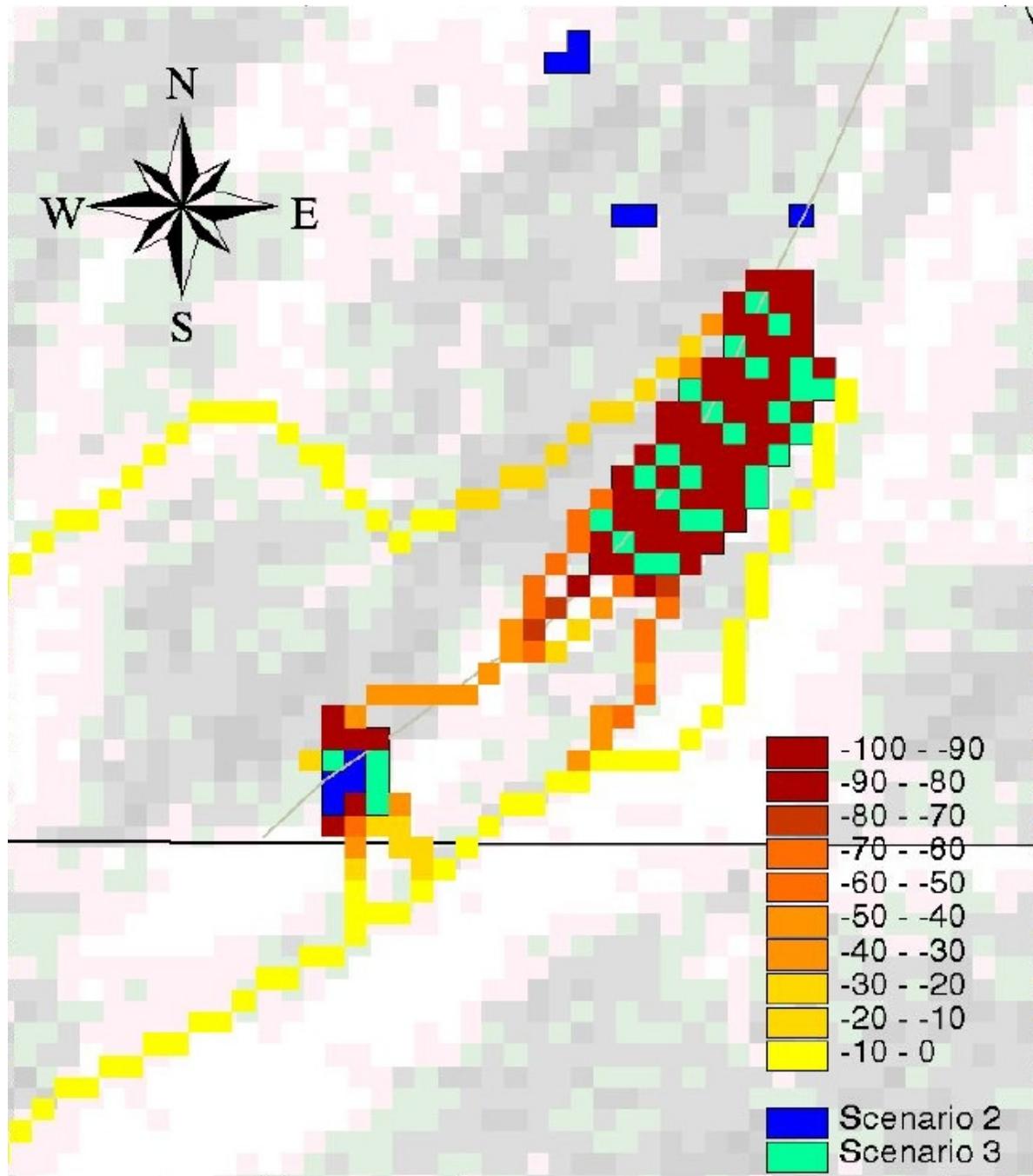
Fig. 5.10. Magnified view of Fig. 5.9. Percent water decrement associated with approximate vehicle disturbance areas from the Apache Longbow–Hellfire test plus preexisting disturbance areas (Scenario 3), compared to the pre-test disturbance scenario (Scenario 2). The results are overlain on a Landsat 7 image, and desert wash areas appear in white.

disturbances such as tracked vehicle disturbance on these processes, particularly for runoff processes at YPG, is not well understood. Subsurface processes, such as lateral movement of water through the vadose zone, are also not considered in this analysis. Lastly, direct measurement of the relationship between water loss and plant effects is needed (see Sect. 5.3).

Input values were chosen using the best available information, and the rationale for the assumptions used is presented throughout Sect. 5.2. The hydrologic model more accurately presents relative differences than it does absolute volumes of water.

5.2.1.4 Maneuver impact miles and erosion status

Exposure to erosion from tracked vehicles is ignored as part of this assessment, as loss of water to the washes, not too much water, is assumed to the primary action affecting wash plant species. However, if erosion were estimated using the ATTACC model, maneuver impact miles (MIMs) would be measures of exposure. In addition, ATTACC would require the vehicle type (to determine the vehicle severity factor and the vehicle conversion factor,

> Exposure to erosion from tracked vehicles is ignored as part of this assessment, as loss of water to the washes, not too much water, is assumed to the primary action affecting wash plant species. However, if erosion were a significant stressor, the ATTACC model could be used to determine exposure.

which adjusts for the width of the impact area, compared to the width impacted by an M1A2 tank), vehicle count, and vehicle miles per day off of improved roads (to determine the vehicle off-road factor) as inputs. An event severity factor adjusts for the relative impact of the event compared to an Armor Battalion field training exercise. The local condition factor adjusts for the susceptibility of land on a particular day, due to soil moisture, temperature, etc. (Dry soil is assumed to indicate low vehicle impact, which may be true for erosion of desert pavement, but not for overall impact at YPG.) Then MIMs are used to develop "Land Condition curves." The universal soil loss equation is used to estimate erosion (USAEC 1999).

If erosion of soil at YPG were of interest, one should note that Chris Cochran and Alan Anderson are conducting a vehicle-induced erosion modeling study (pers. comm., Valerie Morrill, YPG, Aug 2, 2001).

5.2.1.5 Exposure to dust

Exposure of wash vegetation to dust is likely to be negligible because of the distance of the test from washes.

> Exposure of wash vegetation to dust is negligible.

5.2.2 Mule Deer

Mule deer may be exposed directly or indirectly to stressors associated with vehicle movement. Direct stressors would include noise and dust. The major potential indirect stressor is the reduction in biomass of wash vegetation used for forage and cover.

5.2.2.1 Sound of tank

The sound of the tracked vehicles cannot be quantitatively determined. Neither a model nor field data is available. However, this sound

> Neither a model nor field data is available to estimate the noise from tracked vehicles. In turnarounds, tank noise could be significant.

could be locally significant, especially if tanks perform stationary pivot turns.

5.2.2.2 Exposure to dust

No models are available to characterize exposure of mule deer to dust that is associated with the Apache-Hellfire test. Any exposure would be expected to be highly localized and not to affect deer.

Exposure of mule deer to dust is unlikely.

5.2.2.3 Exposure to reduced vegetation biomass in wash

The potential for reduced vegetation biomass in the desert wash is treated in the Risk Characterization for the desert wash plant community, Sect. 5.4.1. With respect to mule deer, this risk characterization may be called an "intermediate risk characterization" (Suter et al. 2001, Suter 1999b). The analysis in 5.4.1 is especially pertinent to mule deer exposure, because the water volume-plant survival or growth relationship relies on data for ironwood, a primary forage species for mule deer.

The risk characterization for wash vegetation serves as part of the characterization of exposure for mule deer. Mule deer are not exposed to reduced vegetation biomass in the washes (Sect. 5.4.1).

Based on Sect. 5.4.1, no significant reduction in wash tree growth or survival occurs, as a result of the Apache-Hellfire test. More specifically, wash trees are not expected to be adversely affected in any 900 m^2 area in the affected watershed of McAllister Wash. Therefore, mule deer are not exposed to reduced vegetation biomass in the washes.

5.3 CHARACTERIZATION OF EFFECTS

5.3.1 Vegetation in Washes

Exposure-response relationships are models of the induction of effects by exposure to a particular stressor or set of stressors associated with an activity. That is, the level of expected effect increases with increasing exposure to the stressor. For many stressors and receptors there is a threshold exposure level below which no consequential effects occur, an increasing level of effects with increasing exposure, and a level at which the maximum effects occur (e.g., extinction or complete vegetation loss).

Direct measurement of vegetation in washes following the Apache-Hellfire test was not performed. However, interpretation of changes would be impeded by natural, temporal variability in wash vegetation.

Ideally, direct measurement of changes in vegetation as a consequence of tracked vehicle disturbance before and after the Apache Longbow–Hellfire missile test would be conducted as a line of evidence in the effects (and risk) characterization. However, the natural variability in vegetation variables that is associated with drought and other environmental influences can be difficult to capture with field plots. For example, in a 72-yr study Goldman and Turner (1986) observed that changes in blue palo verde cover over time fluctuated too much for trends to be discerned in 100-m^2 plots. Given the high drought tolerance of wash vegetation, it may be many years before changes in plant communities can be detected. A vegetation survey was not conducted as part of this study.

The characterization of effects for the assessment of tracked vehicle movement on wash vegetation relies on information derived from other studies. YPG-specific studies were found to be the most useful in characterizing effects. Estimates of response thresholds, in this case the volume of water needed for growth and survival of wash tree species, were generated using these study results. As these thresholds that relate hydrological exposure to plant survival are combined with the results of the hydrologic analysis (i.e., amount of water volume lost due to vehicle disturbance, Sect. 5.2), a specific estimate of risk can be determined in the Risk Characterization section, Sect. 5.4.

5.3.1.1 Relationships between surface hydrology and vegetation in washes

The condition of desert wash vegetation is in large part dependent on the timing and duration of precipitation and associated runoff. Many herbaceous wash species lie dormant as seeds until adequate rain is available for germination and subsequent flowering, which may occur once every several years. Because of

The importance of various hydrological variables to vegetation is emphasized in several studies of YPG and other arid environments.

the capacity of seeds to remain viable over a decade or longer, the long-term effects of low moisture on herbaceous plant populations is extremely difficult to measure. The extent of moisture stress of woody shrub and tree species is also difficult to evaluate. Short-term impacts from drought may be measurable in individuals (e.g., loss of leaves, presence of standing snags, low growth), but may not indicate population-level impacts over the long-term. Interpretation of population level metrics is also complicated by the spatial variation of wash species. For example, locally significant desert wash tree species such as palo verde (*Parkinsonia spp.*), ironwood (*Olneya tesota*), catclaw acacia (*Acacia greggi*), and smoketree (*Psorothamnus spinosa*) are adapted to low moisture regimes, and populations may expand or contract with the changing channel and shifting of alluvial deposits typical of wash soil dynamics.

Schlesinger and Jones (1984) (as reported in Schlesinger et al. 1989) showed that diversion of overland flow from alluvial piedmonts resulted in lower shrub density and biomass compared to that in adjacent areas that received overland flow. At YPG, water available to wash tree species is dependent on adequate runoff from the adjacent desert pavements during storm events. Pavement disturbances that affect runoff to the washes have the potential to affect the quality and quantity of wash vegetation, thereby affecting wildlife that utilize this vegetation (Fig. 5.11).

McDonald (2000), in a SERDP-funded project, has been directly studying the relationship between surface and soil moisture and desert shrubs and trees at YPG. Spring and mid-summer predawn and midday water potentials achieved in palo verde and ironwood are much higher than would be expected, given the very low volumetric moisture content of the soils (<1m). McDonald suggests that these species have access to deep water supplies (2-6 m, vadose zone, not groundwater). His preliminary results indicate that infrequent, high energy storms may be necessary to create enough overland runoff to recharge deep soil depths in the wash. These deep water supplies may help sustain wash plant activity over prolonged dry periods (>1-3 years), where direct precipitation may be insufficient to recharge shallower surface layers.

Ayres Associates (1996) identified changes in hydrologic processes (particularly erosion from runoff) from historical military disturbances as a major factor affecting vegetation in Yuma Wash, although specific changes in vegetation metrics as a result of changes in water volumes were not quantified. As part of the Land Condition Trend Analysis (LCTA) program, the number of ironwood and palo verde were counted "upstream" and "downstream" of Pole Line Road in the Kofa range, and the number of plants were reduced downstream (4 compared to 20 upstream), presumably due to changes in hydrology due to the road crossing of the wash (Bern 1995). The number of dead plants was also twice as high on the downstream plot. Reductions in plant biomass below road crossings, where the road was

sufficiently elevated over the surrounding landscape, were also observed as part of MERAF team site visits.
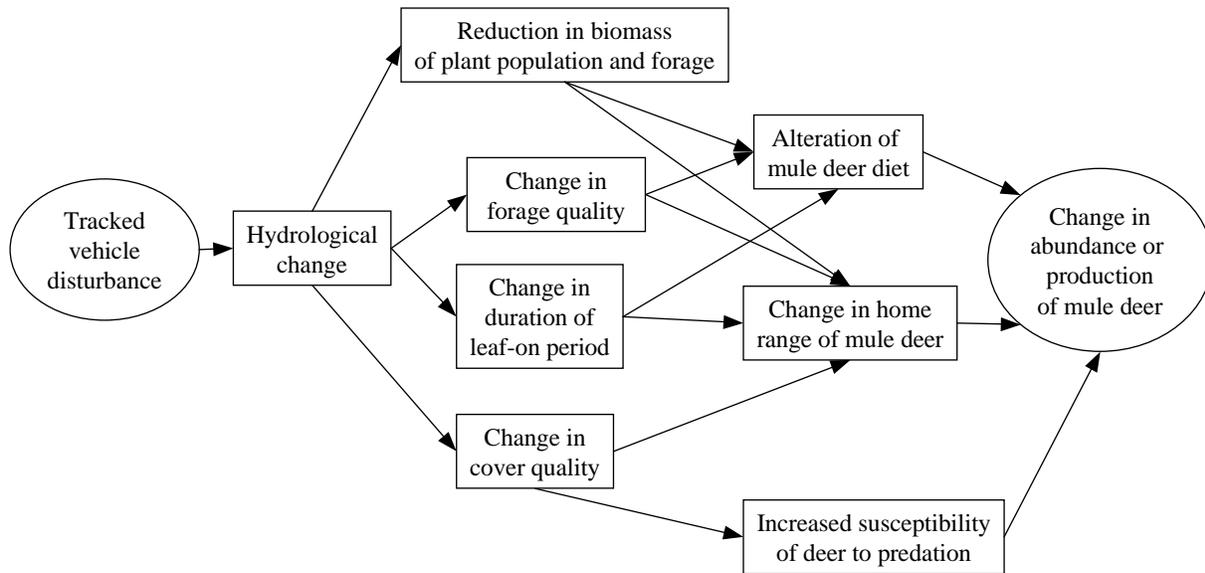
Fig. 5.11. Mechanisms by which tracked vehicle disturbance could effect hydrology, the quality and quantity of vegetation, and abundance or production of mule deer.

Glass (2000) investigated the relationship between disturbance in hydrology and channel vegetation in a very small, undisturbed watershed (0.2 km^2) in the Kofa region of YPG. Results show that for a 20% increase in infiltration depth (i.e., loss of runoff), representative of maneuver disturbances, the percentage of the total gully length no longer supporting wash trees increases between 6% and 18%. Although the vegetation measures conducted for the Glass (2000) study do not represent a detailed botanical assessment, the study nevertheless provides useful YPG-specific information for making a more quantitative link between water loss due to disturbance and changes in vegetation. The Glass (2000) study was used extensively to characterize effects on wash vegetation in the Apache-Hellfire test area and is discussed in greater detail in the following sections of the report.

5.3.1.2 Physiological water requirements of wash species

Data on the specific water requirements of tree and shrub species in the study area, in terms of volume of water, are not readily available in the literature. Clearly, wash shrub and tree species, by the nature of their presence in washes and absence in more upland areas, have higher water requirements than the more abundant species found at YPG [such as white bursage (*Ambrosia dumosa*) and creosote bush (*Larrea tridentata*)]. Using water potential from various literature sources as an index for how much water a plant requires, Glass (2000) ranked four desert plant species in the following order for water need (reported water potentials in parentheses): ironwood (-22 to -35 bars) > foothill paloverde (-36 bars) > brittlebush (-37 bars) > creosote (-40 to -60 bars). Glass

Data on water requirements of particular wash species are not available. Limited data on relative water requirements of species are available.

(2000) also measured vegetation frequencies of these species in two gullies within YPG, and these results correlate with the water potential data: creosote and brittlebush are the first to appear in the upper section of the gully, followed by paloverde, then ironwood.

5.3.1.3 Determination of water volume thresholds for wash trees

Empirical relationships can be developed to determine the watershed area or water volume requirements of desert wash species. A field study has been suggested by J. McAuliffe (Desert Botanical Garden, pers. comm. June 8, 2001). Ironwood trees tend to be 2-4 m tall at the tops of first order channels, and they become

> The thresholds for growth and survival of wash trees in a 30-m wide wash area are 1500 m^3 and 5900 m^3 of water during a significant storm event (1 in/hr).

increasingly large with increasing order of the wash. One could assume that they are growing to their maximum potential height and biomass in each wash. Then, one may perform an empirical study to determine the watershed area requirement for a tree of a specific biomass. The current study provides a more sophisticated approach to the watershed area determination, as watershed area is adjusted for runoff potential over different soil types. This type of approximate, empirical relationship may be extracted from a study of gullies in Glass (2000). Glass assumes that the position of the species in the gully is an indicator of water requirement; that is, plants with greater water need would require greater runoff contributing area, and would be located further downstream.

The relationship presented in the Glass (2000) study between contributing area runoff and vegetation observed in gullies in the Kofa Range of YPG was used to estimate the volume of water produced during a significant storm event that is needed for growth or survival of wash tree species. The Glass (2000) study area has some distinct similarities to the Apache-Hellfire test area, although clearly the Glass (2000) study is of much smaller scale and is on relatively narrow gullies, relative to the wide, braded channels of the wash test area. The Glass (2000) study area was dominated by pavement with little or no vegetation, dissected by gullies where plants with higher moisture requirements predominated. Gully infiltration rates were similarly high as those in McAllister Wash, and the surrounding pavement had low infiltration rates. Glass (2000) cites the similarity of the site on Kofa Range to many areas of YPG, and particularly mentions its relevance to an adjacent watershed where Pole Line Road crosses the wash, resulting in dead and dying ironwood trees downstream of the crossing.

Glass (2000) divided her study area into three subbasins, each with 2-6 individual gullies where the number of individuals of ironwood and palo verde species were recorded at select intervals over the entire length of each gully. Of importance in the analysis is the furthest upstream location in each gully of an individual plant of ironwood and palo verde. Assuming the first location of ironwood or paloverde in each basin represents the limit of the species' water requirements (further upstream, a tree would not have enough water to survive, further downstream it would), the associated water volume[9] running over and into the soil is the minimal volume required for the plant to survive. It is important to note that in the Glass (2000) analysis, many of the same assumptions were used as in the MERAF hydrologic analysis. The Glass (2000) simulations use a 0.03-m storm (1.2 in) for a 1 hour duration (a once every 5-yr event), and an infiltration rate of 0.01-m (0.4 in) for the surrounding pavement, to calculate discharge volumes at various points within each sub-basin.

Glass (2000) did not conduct a detailed botanical assessment, and further study is needed regarding vegetation water requirements (P. Haff, Duke University, personal communication, June 12, 2000). However, given the paucity of information available on the effects of water loss on wash plants, the vegetation results from Glass (2000) were deemed the best available for the basis of an exposure-

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[9] calculated as $(P - I = R) \times A = V$,
where P is precipitation, I is infiltration, A is contributing area, and V is discharge volume

response relationship for water volume and wash vegetation and for the demonstration of MERAF. Glass concludes that the volume of water needed in the simulated event for ironwood and palo verde survival ranges from 150 to 350 m³. The average value, often used in the analysis and discussion, is 250 m³. This is the survival effects threshold for an approximately 5-m-wide gully. A conversion factor of 6 was used to calculate a volume of water needed for survival of wash trees for each 30×30-m cell in the MERAF hydrologic model (1500 m³) because of the factor-of-6 greater width. (Differences in lengths of gullies and wash cells should not be significant determinants of runoff water volumes.)

Glass (2000) also measured the sizes of ironwood and palo verde trees, and classified them as small (< 2m), medium (2-4m), and large (5-7 m). A pattern was observed of small individuals near the top of the gully, and increased numbers and sizes of individuals with distance downstream. A growth effects threshold was estimated by determining the point where large trees were first observed, assuming that smaller individuals represent stressed (or water-challenged) individuals. Large ironwoods are important for wildlife cover, and large trees may be important for successful propagation of the ironwood species. Glass (2000) reported the first downstream location of large trees was approximately 100 to 300 m farther downstream than the first small tree in three representative gullies. 220 m was the assumed distance between first small and first large trees, as determined from graphs in Glass (2000).

Using slopes for the 3 gullies relating distance downstream (m) to discharge volume (m³), an average discharge volume of 987 m³ was needed for "growth" of wash trees. Using the 6X conversion factor as above, the volume of water that must be provided by a significant storm event for adequate "growth" of wash trees for each cell in the YPG MERAF hydrologic model is about 5900 m³.

It should not be assumed that the 1500 m³ volume of water associated with survival and the 5900 m³ volume of water associated with growth of wash trees are physiological water requirements. Far more water permeates the soil and runs overland than is needed for plant growth. The values are more representative of watershed areas, and the amount of water that permeates soil without evaporating or leaching appreciably (plant-available water) is assumed to approximate physiological water requirements. It is also important to note that the defined growth threshold is necessarily based on the location of the first large tree; some water limitation on growth of large trees could be expected at higher water volumes.

5.3.1.4 Timing of precipitation

The timing of precipitation is important to plant biomass in desert ecosystems. Factors include: rainfall during periods when high temperatures cause large losses via evapotranspiration, rainfall during periods when plants are in a state of high temperature dormancy, high intensity rainfall where runoff is considerable, and cool spring temperatures that decrease evapotranspiration, permitting more soil moisture to be utilized in transpiration. However, the timing of precipitation is not explicitly included in the exposure-response relationship derived for the YPG risk assessment (Sect. 5.3.1.3).

5.3.1.5 Relationship between dust and plant viability

As stated above, the exposure of wash plants to dust from the test is assumed to be negligible. No relevant exposure-response model is available.

5.3.2 Mule Deer

5.3.2.1 Potential relationship between biomass of wash vegetation and mule deer population

A relationship between wash vegetation and mule deer populations is not needed, because there is no significant exposure (Sect. 5.2.2.3). If the exposure were significant, a relationship between mule

deer reproduction, foraging and habitat could be developed through the use of a mechanistic model. This model could include the potential for reduction of forage (e.g., reduction in biomass or change in duration of leaf-on period), change in forage quality (Sect. 2.6.2.4), or change in cover quality, leading to an alteration of the deer diet (2.6.2.4), home range (2.6.2.2), and or likelihood of predation (Fig. 5.11). For example, Schmitz (1992) developed a foraging

> A mechanistic model relating changes in wash tree biomass to mule deer reproduction or abundance could be developed, but because of the lack of an exposure pathway in the Apache-Hellfire test, such a model is not needed.

model for white-tailed deer (*Odocoileus virginianus*) to predict the diet selection when deer face starvation risks during a reproductive period. A related field experiment suggested that deer select diets that balance reproduction with starvation risk in the presence of low forage availability, while in the absence of starvation risk, deer maximize their mean energy intake rates.

5.3.2.2 Sound level thresholds for behavioral effects

As stated above, the exposure of mule deer to tank noise cannot be quantified. Behavioral response thresholds for sound would be expected to be A-weighted decibels close to those that cause behavioral responses due to aircraft overflights (Sect. 3.3.1.3).

5.4 RISK CHARACTERIZATION

5.4.1 Wash Vegetation

The amount of water needed in the modeled storm event for survival and growth of key wash tree species is about 1500 m^3 and 5900 m^3 respectively, and these values represent the selected thresholds for assessment of vegetation effects. A depiction of areas of McAllister wash that would have adequate quantities of water to support the growth and survival of wash tree species, in the absence of any disturbance (Scenario 1), is depicted in Fig. 5.12. Note that in this undisturbed setting, the main wash channels have adequate water for growth and survival of wash trees, and areas of the washes where growth is affected are most pronounced in the upstream sections of the tributaries. The results of this simulation are consistent with field observations and the available literature describing the relationship between hydrology and wash tree populations (Section 5.3.1.1).

Only one line of evidence is available for the characterization of risks to wash vegetation, so no "weight of evidence" approach is used for this assessment.

5.4.1.1 Expected impact of test tank disturbance on survival and growth of wash trees

Based on the results of the MERAF hydrologic analysis, test tank disturbance of desert pavements is predicted to result in water losses to McAllister Wash and tributaries, with the greatest percentage of water loss in a respective cell occurring nearest the area of

> Tracked vehicle movement associated with the Apache-Hellfire test will not affect the survival or growth of desert wash trees.

disturbance (Fig. 5.9). The predicted amount of water in each cell as a result of tank disturbance, relative to the amount of water in each cell under pretest conditions, was compared to the selected thresholds for survival of wash trees of 1500 m^3 and growth of wash trees of about 5900 m^3.
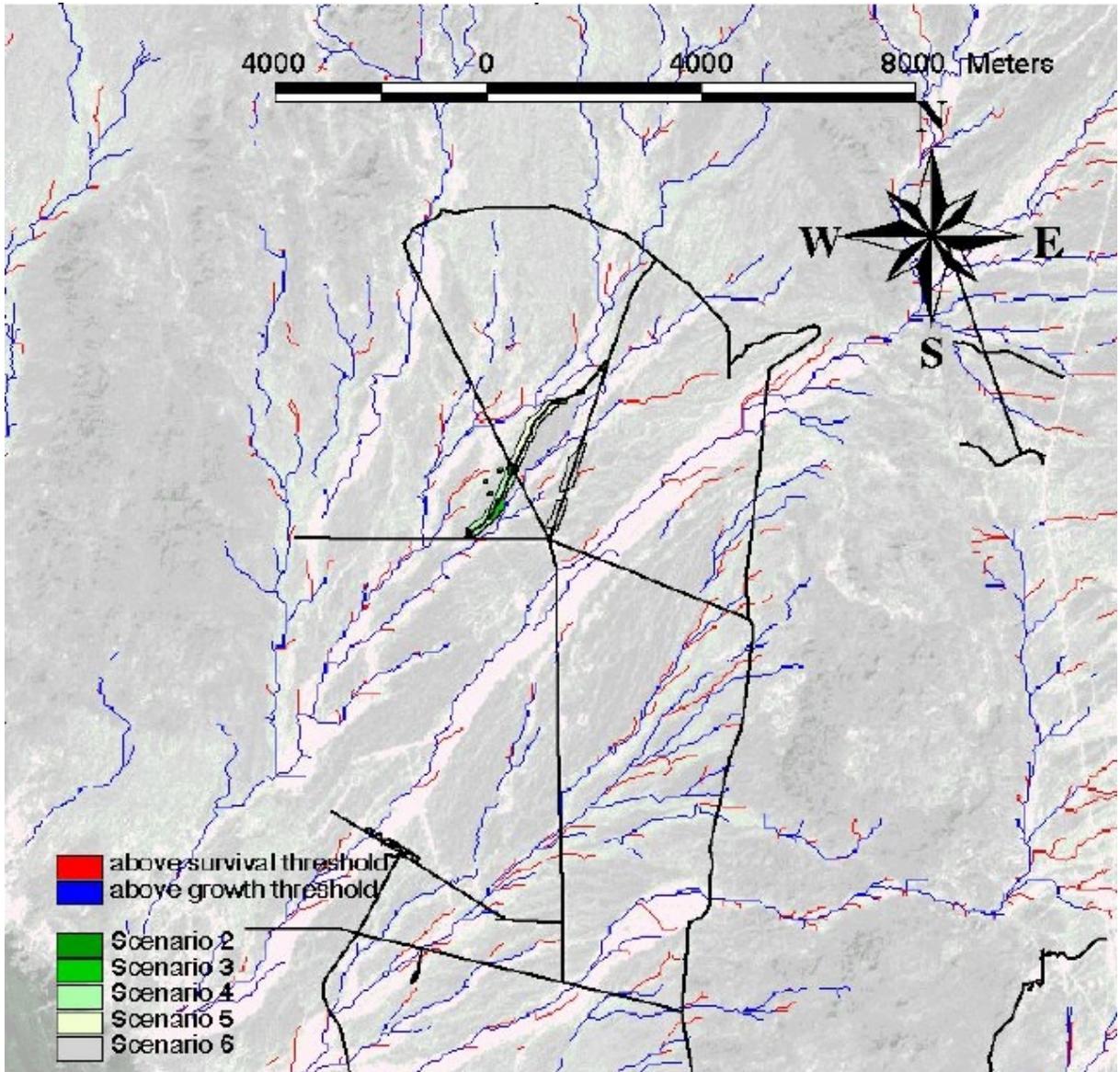
Fig. 5.12. Available water in the model was compared with a survival threshold (1500 m^3) and a growth threshold (5900 m^3) to produce this map showing areas predicted to have enough water for tree survival and growth. Since porous soils are found only in wash areas, this coverage was clipped to wash areas to increase the accuracy of the spatial prediction. The narrow lines are due to the assumption in the hydrologic analysis that flow direction always follows the single majority flow direction (this effect is exacerbated by flat ground). Washes appear as lighter areas in the Landsat 7 background image on these maps.

Based on the results of this comparison (water flow Scenario 3 minus Scenario 2, Table 5.4), test tank disturbance is not expected to result in enough water loss to the washes to affect the survival or growth of desert wash trees.

5.4.1.2 Impact of test tank disturbance and preexisting disturbance on survival and growth of wash trees

An assessment of potential effects to wash trees from test tank disturbances that includes preexisting disturbances was conducted. Test and preexisting disturbances (defined as disturbances evident in the 1998 DOQQ) were compared to the undisturbed condition (water flow in Scenario 3 minus Scenario 1, Table 5.4). The results of the hydrologic analysis indicated that areas in the wash would have less water from these disturbances then in the undisturbed scenario. However, when water volumes in each modeled 30×30 m cell were compared to the wash tree thresholds stated above, no additional areas in the Apache-Hellfire test scenario were defined as having wash trees that could not survive or grow, relative to the undisturbed state.

> Cumulative tracked vehicle movement and other desert pavement disturbance in the study area will not affect the survival or growth of desert wash trees.

5.4.1.3 Uncertainty and variability

Sources of uncertainty and variability that are likely to affect the risk characterization have been discussed throughout the preceding sections. See Section 5.2.1.3 for a discussion of parameter and model uncertainty. Key assumptions relate to quantities of water assumed in this assessment: the amount of precipitation, the amount of infiltration, etc. For example, one of the key initial premises is that a 1-inch storm event is important for wash vegetation, although the relationship between rare rain events and wash plant communities is extremely difficult to study and little empirical information is available. Actual water losses due to infiltration and vehicle disturbances on a large scale have not been conducted. The hydrologic model more accurately presents relative differences than it does absolute volumes of water.

The thresholds used here, however, seem to be a reasonable start, in that the threshold limits in the undisturbed scenario spatially represent what might be expected if vegetation was measured directly (see Fig. 5.12). Although there is some uncertainty in the empirical relationship developed from Glass (2000) to relate hydrology to wash tree survival and growth, the credibility of the relationship is bolstered by the fact that some inhibition of vegetation is predicted for larger scale disturbances than vehicle movement in the Apache Longbow–Hellfire test (Sect. 7.3.2).

The 30×30 m resolution of the digital elevation model limits the resolution of the results. Smaller-scale vehicle disturbances were not included as disturbed cells; thus very small-scale impacts on vegetation may have been missed.

More direct, quantitative assessments of plant responses to changes in hydrology are needed. If hydrologic-vegetation relationships can be more clearly defined in future studies, it would be straightforward to generate an estimation of area and distribution of tank tracks required to significantly lose a plant species in a wash. These thresholds might be analogous to the "training land carrying capacity thresholds" that are generated by the ATTACC model (USAEC 1999).

5.4.2 Mule Deer

5.4.2.1 Risk to mule deer population from tank tracks associated with the Apache-Hellfire test

There is no risk to the mule deer population from tank tracks associated with the Apache-Hellfire test. No exposure pathway exists, because no appreciable loss of wash vegetation biomass is predicted.

5.4.2.2 Impact of sound of tank on mule deer

The impact of tank noise on mule deer behavior is unknown. As in the aircraft overflight and missile firing activities, even if limited behavioral impacts were expected, it would be unlikely that population-level effects would occur.

5.4.2.3 Uncertainty and variability

As no rigorous assessment of the effects of vegetation loss was required, a detailed assessment of uncertainty in the estimate is not presented. However, uncertainties associated with the hydrological modeling are presented in Sect. 5.2.1.3.

5.5 RESEARCH GAPS

Several research gaps exist in the pathway from tracked vehicle disturbance to hydrological change to biomass of wash vegetation to production and abundance of mule deer. Empirical studies could be performed to relate particular types of disturbance (disturbance by X number of tanks of Y weight and Z track width on pavement or other soils; craters from missile firing, Chapter 4) to water infiltration, runoff and other changes in hydrology. Although the observations of Glass (2000) are relevant to this assessment at YPG, these results may not be as pertinent in other soils, and the cause-effect relationship between water and plant growth and survival should be validated. (Other environmental factors could vary along a wash trajectory.) The importance of particular intensities and durations of precipitation events on disturbance-impacted vegetation growth should be studied. Changes in hydrology, watershed areas, or tank track disturbance areas could be related to vegetation loss or inhibition through empirical studies in the desert washes of Yuma Proving Ground and elsewhere. For some arid installations these studies are just as important as the validation of ATTACC erosion estimates.

Validation of the ESRI ArcInfo hydrological analysis, in comparison to field data and/or results from site-specific hydrological models would be useful.

In addition, a study could be performed to relate hydrological change resulting from vehicle disturbance at installations of different topographies to the resolution of the digital elevation model that supports the analysis.

Mechanistic demographic or energy balance models should be developed for key vertebrate species that are prevalent at multiple installations. If such a model were available for mule deer or related species, it could have been utilized in this study if the Apache-Hellfire-test-related reduction in biomass of wash vegetation had been significant.

6. RISK CHARACTERIZATION–INTEGRATED ACTIVITIES IN APACHE-HELLFIRE TEST

The integration of risks that are associated with multiple activities can be carried out most efficiently if the assessment is performed in a step-wise fashion. Suter (1999a) provides a series of questions that should be asked to optimize the analysis (see below). In this demonstration, abundance and production of the desert mule deer is the integrating assessment endpoint entity. That is, effects on wash vegetation may only result from one activity (tracked vehicle movement); thus this endpoint entity is excluded from the risk integration[10].

> No integrated risk assessment for mule deer abundance and reproduction is needed, because risks are not associated with any of the three activities. However, relevant issues are discussed as a generic demonstration of the integration phase.

There is no need to conduct an integrated risk characterization for the Apache-Hellfire test, because risks to mule deer abundance and reproduction are inconsequential for all three activities, and the cumulative risks are not likely to be significant. However, we proceed to describe how the integrated risk characterization would be carried out if risks were significant because of the purpose of this risk assessment as a demonstration of MERAF. To determine whether or not an integrated risk characterization is needed at all, the following three questions should be asked[11].

6.1 GENERIC QUESTIONS FOR INTEGRATED RISK ASSESSMENTS

(1) **Are multiple agents effectively the same?** That is, do the multiple activities each involve vehicles or helicopters or some other common agent? If yes, then an integrated risk characterization is not needed.
- In the Apache Longbow–Hellfire missile test, the answer is no; multiple agents (tanks, helicopters, and missiles) are involved in the test.

(2) **Do the activities and/or their effects overlap in space and time?** The issue of spatial overlap concerns whether or not (a) activities are performed in the same or overlapping areas, (b) stressors generated directly or indirectly by an activity extend into areas where other activities occur, and (c) endpoint populations or communities interact in the activity areas. Temporal overlap occurs if (a) activities are performed at the same time or (b) activities are performed at different times, but the latter activities occur before recovery from the former has occurred. If spatial or temporal overlap of activities does not occur, then an integrated risk characterization is not needed, and the risks from the individual activities in their separate spatial areas and times may be presented.
- In the Apache Longbow–Hellfire missile test, the answer is yes; sound from overflights and missiles, as well as potential hydrological impacts from tracked vehicle disturbance occur in the same area.

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[10] Actually, wash vegetation is dependent on mule deer for survival to the extent that particular tree species require the passage of seeds through the guts of herbivores prior to germination. In addition, dung and urine inputs are important sources of nutrients for arid lands. These links between wash vegetation and mule deer are not considered here.

[11] It is assumed that the assessor has already asked if risks from any of the activities are significant. Obviously, no integration of insignificant risks is needed if the integration of these risks is unlikely to result in significant risks.

(3) **Are risks from all but one of the activities relatively inconsequential?**
•   In the Apache Longbow–Hellfire missile test, risks from all of the activities are inconsequential. If behavior of deer is considered, then the answer is unknown. Risks from the helicopter overflight and missile explosion have rather uncertain behavioral consequences. Based on NOISEMAP sound projections, the impacts of helicopter noise are inconsequential; however, that is not the case if MR_NMAP results are used. According to BNOISE2 and very uncertain effects models, the Hellfire firing is expected to result in behavioral impacts to several deer. The loss of desert wash vegetation biomass from the vehicle movement activity of the test is predicted to be so small as to be unmeasurable (i.e, smaller than about 450 m^2), which is very small compared to the density of mule deer. The integrated risk characterization could end here, because of the inconsequential risk from one activity and the uncertain risk from the other two. However, we continue the exercise because this risk assessment is a demonstration of MERAF.

If an integrated risk characterization is needed, based on the responses to the questions above, the following two questions are pertinent.

(1) **Are the effects additive?** If the answer is yes, the effects may simply be added.
•   The effects that have been quantified (to the extent possible) in Chapters 3, 4, and 5 are generally additive. That is, estimated behavioral responses of mule deer that are associated with aircraft overflights may be added to expected behavioral responses to missile detonation. However, the following caveats should be considered: (a) behavioral impacts of deer in overlapping areas should only be counted once unless there is evidence that deer exposed to overflights and missiles simultaneously respond more strongly than other deer and (b) behavioral impacts of different types may need to be disaggregated for the purpose of developing a mechanistic model that predicts reproductive effects, and different types of behavioral responses may be associated with overflights and missiles. (These effects are not always well-specified.)
•   Also, if decreased abundance, biomass or fecundity were associated with a loss of vegetation in washes, this decrease could not simply be added to the behavioral effects associated with the sounds of overflights and missile firing.

(2) **Can exposures be added and risks be recalculated?**
•   The sound associated with the Apache overflights and missile firing should not be added. This addition of continuous sound and blast noise (impulsive sound) ignores the frequency differences in the sounds that would need to be determined before a true noise addition could occur. Also, the addition of sound cannot occur within any of the sound contour programs used (NOISEMAP, MR NMAP, or B-NOISE), because they are unique to particular activities (overflights or missile launches). In general, response data for different types of sounds, including blast noise, small arms, and aircraft are different. Thus, with respect to other applications of MERAF, noise levels from different military activities should generally not be added.

6.2 MECHANISTIC MODEL

If effects and/or exposures are not simply additive, a mechanistic model is needed. A field study is recommended if the testing or training program has not yet occurred.

A mechanistic model would be advisable to integrate impacts of sound and hydrological change if both were significant. If risks were significant from the helicopter overflight, the Hellfire missile explosion, and vehicle movement, the mechanistic

A mechanistic model for mule deer populations could integrate effects of all activities and their component stressors.

99

model would have to be able to integrate the behavioral impacts of sound (changes in home range, changes in distance to water, changes in migration patterns), the mitigating influence of habituation to sound; changes in forage and cover availability and quality; and fragmentation of habitat due to vegetation changes or noise to produce an estimate of changes in reproduction and growth. The model could be a demographic model, or an energy budget model.

6.3 RESEARCH GAPS

Two research areas would aid in the integration of risks from different activities in testing or training programs that involve aircraft overflights, missile firing, and/or vehicle movement. First, as stated in Sect. 6.2, a mechanistic model would be useful for combining behavioral effects of sound from the overflight and missile-firing component activities and changes in abundance or reproduction resulting from wash vegetation losses from vehicle movement. Secondly, empirical relationships are needed for vertebrate responses to different types of sound (e.g., helicopter overflight and blast noise).

7. QUALITATIVE RISK CHARACTERIZATION–INTEGRATED TEST PROGRAMS AND ROAD DEVELOPMENT AT SITE

7.1 SCOPE

The demonstration of MERAF focuses on ecological risks from a single test–the Apache Longbow–Hellfire missile test described in previous chapters. This chapter considers potential additional risks that are not associated with the assessment goals. These include risks from (1) road development, (2) other test programs in the area, and (3) disturbance of desert pavement in larger areas and in locations other than the test area.

7.2 ROAD DEVELOPMENT

The test area of concern, including the MTI Road, was established in the early 1990s, in about 1993 (V. Morrill, YPG, personal communication, August 2000). The road development is not part of the Apache-Hellfire test program, but could be considered as a component of the cumulative impacts in the study area, or as part of the background topography controlling water distribution.

7.2.1 Road Dimensions

The lengths and widths of roads are measures of exposure and effects on vegetation communities that resided where the roads were developed. Blading of surface material can extend the footprints of roads, and the practice is evident in some locations adjacent to the MTI Road. The topography and elevation of the road relative to the surrounding landscape is a determinant of changes in water and nutrient transport.

7.2.2 Road Permeability

The permeability of unpaved roads such as the MTI Road is unknown. These roads would be expected to be more permeable than desert pavement, but less permeable than other soil types. In most ecosystems, the compaction of soil caused by road development would be assumed to decrease permeability. Road permeability is not factored into the hydrological analysis in Chapter 5 because roads were not constructed to support the Apache Longbow–Hellfire missile test alone, and thus, they would have appeared in both pre-test and post-test scenarios.

7.2.3 Water and Nutrient Distribution

Dams and road crossings of washes and drainage ways (particularly if roads are built up from the surrounding channel) can have effects similar to those of dams on free-flowing streams in retaining water upstream and preventing water from moving downstream. The effects of this hydrological alteration on vegetation are described below.

7.2.4 Vegetation Impacted by Road Crossings

As stated by Johnson et al. (1975), the most obvious effect on vegetation from road development is the elimination of plants in the pathway cleared for vehicles. Vehicle movement

Road development can result in two principal types of impacts on wash vegetation: (1) direct vegetation removal where roads cross washes and (2) reduction of biomass downgradient of roads.

across washes would be expected to eliminate limited plant biomass from the wash crossing area. However, road development may result in other impacts to remaining vegetation.

In an August 2000 site visit to Yuma Proving Ground, clearly visible differences in vegetation density and structure were observed at locations where the road was elevated above the floor of the wash that it crossed (e.g., the MTI Road). The magnitude of this difference would be expected to be reduced if a culvert was present, and it was observed to be negligible if the road elevation was below the floor of the wash.

These observations of the impacts of roads on hydrology are confirmed in other desert studies. Bolling and Walker (2000) found that road crossings constructed before the regulation of washes appeared to have deprived ironwood trees of surface water flows in washes and adjacent flood plains. At YPG in the early 1990s, ironwood trees appeared to be declining south of east-west roads in the Kofa Range. Therefore, LCTA plots were established upgradient and downgradient from Pole Line Road in Kofa Range, and these data showed a reduction of ironwood tree density downslope of Pole Line road in Kofa relative to upslope (Bern 1995). In addition, Glass (2000), and Valerie Morrill (pers. comm., Yuma Proving Ground, August 1, 2000) confirmed that vegetation biomass differences upstream and downstream of roads were sometimes observed at Yuma Proving Ground. Johnson et al. (1975) also observed differences in shrub biomass (factor of 6 difference), density, and richness on the upslope and downslope sides of unpaved roads crossing Mojave desert bajadas.

Differences in biomass of vegetation upslope and downslope of roads do not necessarily indicate a decrease in overall biomass. It is just as possible that biomass upslope of roads is increased, as that biomass downslope of roads is decreased. Additional studies are needed to define the effect of roads.

Species diversity was not different above and below Pole Line Road in Kofa Range (Bern 1995).

7.3 HYPOTHETICAL SOIL DISTURBANCES

As stated in Table 5.4, three hypothetical disturbance scenarios were considered in the hydrological analysis of vehicle disturbance along with the test and pre-test scenarios. These disturbances are depicted in Fig. 7.1. Essentially, disturbance scenarios 4, 5, and 6, described in Table 5.4, involved the disturbance of land on either side of the road to approximately 100 m and to a length of 900-1000 m for three road areas: (1) MTI Road, between West Target and Red Hill Roads; (2) MTI Road, between Red Hill and East Target Roads; and (3) East Target Road, above West Target Road.

> Three hypothetical scenarios of soil disturbance were considered, each of a 200 m wide by 900-1000 m long area.

7.3.1 Characterization of Exposure–Hydrological Change

Methods for the characterization of exposure (i.e., hydrological change associated with tank track disturbance) are described in Sect. 5.2.1.3.

Percent water decrements associated with the hypothetical disturbance scenarios are depicted in Figs. 7.2 (MTI Road, between West Target and Red Hill Roads), 7.3 (same as 7.2, magnified) 7.4 (MTI Road, between Red Hill and East Target Roads), 7.5 (same as 7.4, magnified), 7.6 (East Target Road, above West Target Road), and 7.7 (same as 7.6, magnified). Clearly, the hypothetically disturbed areas, which are larger than the test disturbance area depicted in Chapter 5, are associated with larger areas and quantities of water loss (compared to Fig. 5.4). In all of these scenarios, the water loss would be to plants growing in and near

> Hypothetical disturbances were associated with larger quantities of water loss than the vehicle disturbance associated with the Apache-Hellfire test.
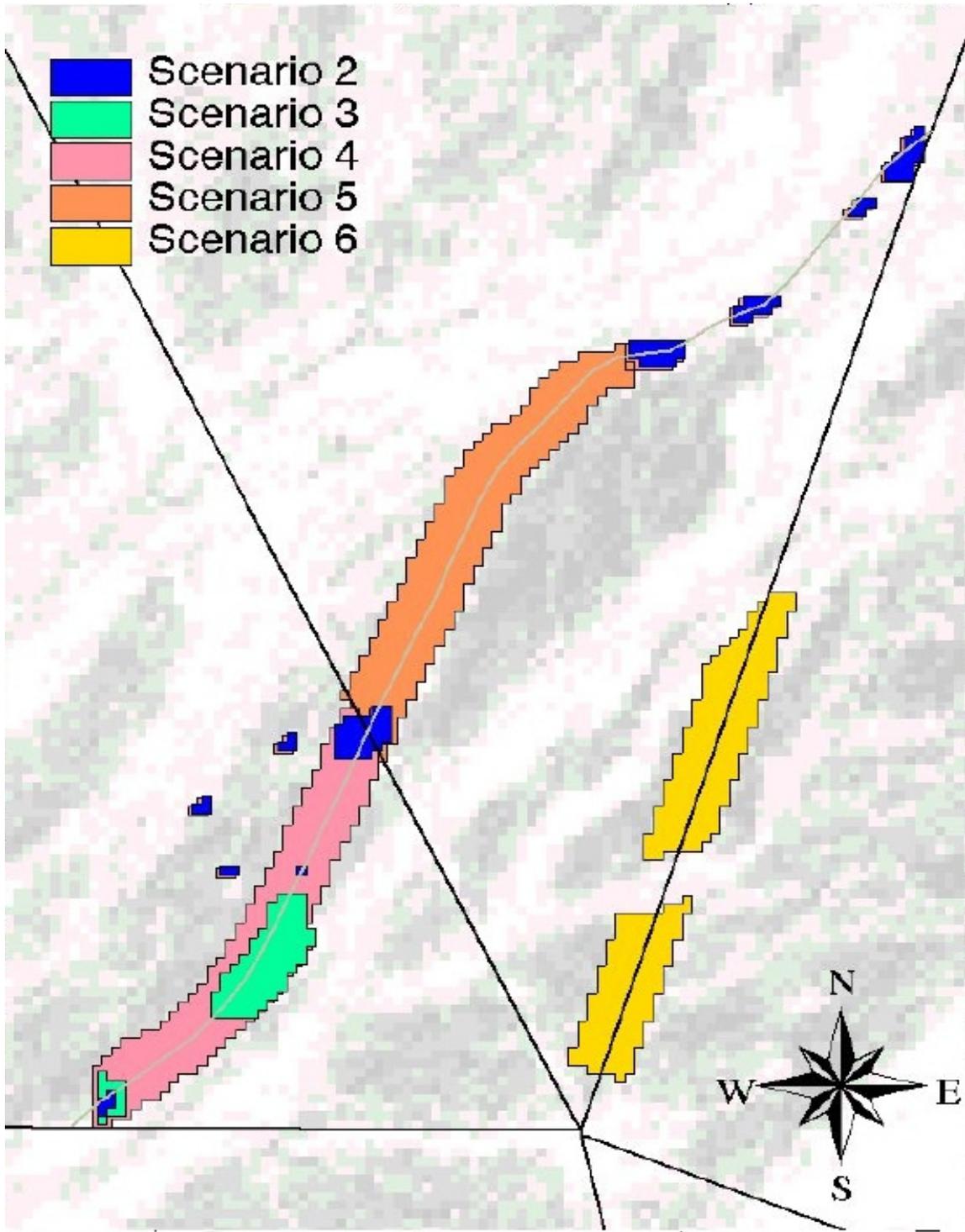
Fig. 7.1. Vehicle disturbance areas for which hydrological change was considered. Scenario 1, 2 and 3 are discussed in Chapter 5. Scenario 3 is the test scenario and includes scenario 2 (preexisting disturbance). Scenario 4 includes the test scenario plus disturbance of 100 m on either side of the lower MTI Road. Scenario 5 includes the test scenario plus disturbance of 100 m on either side of the upper MTI Road. Scenario 6 includes the test scenario plus disturbance of 100 m on either side of the East Target Road. The results are overlain on a Landsat 7 image, and desert wash areas appear in white.
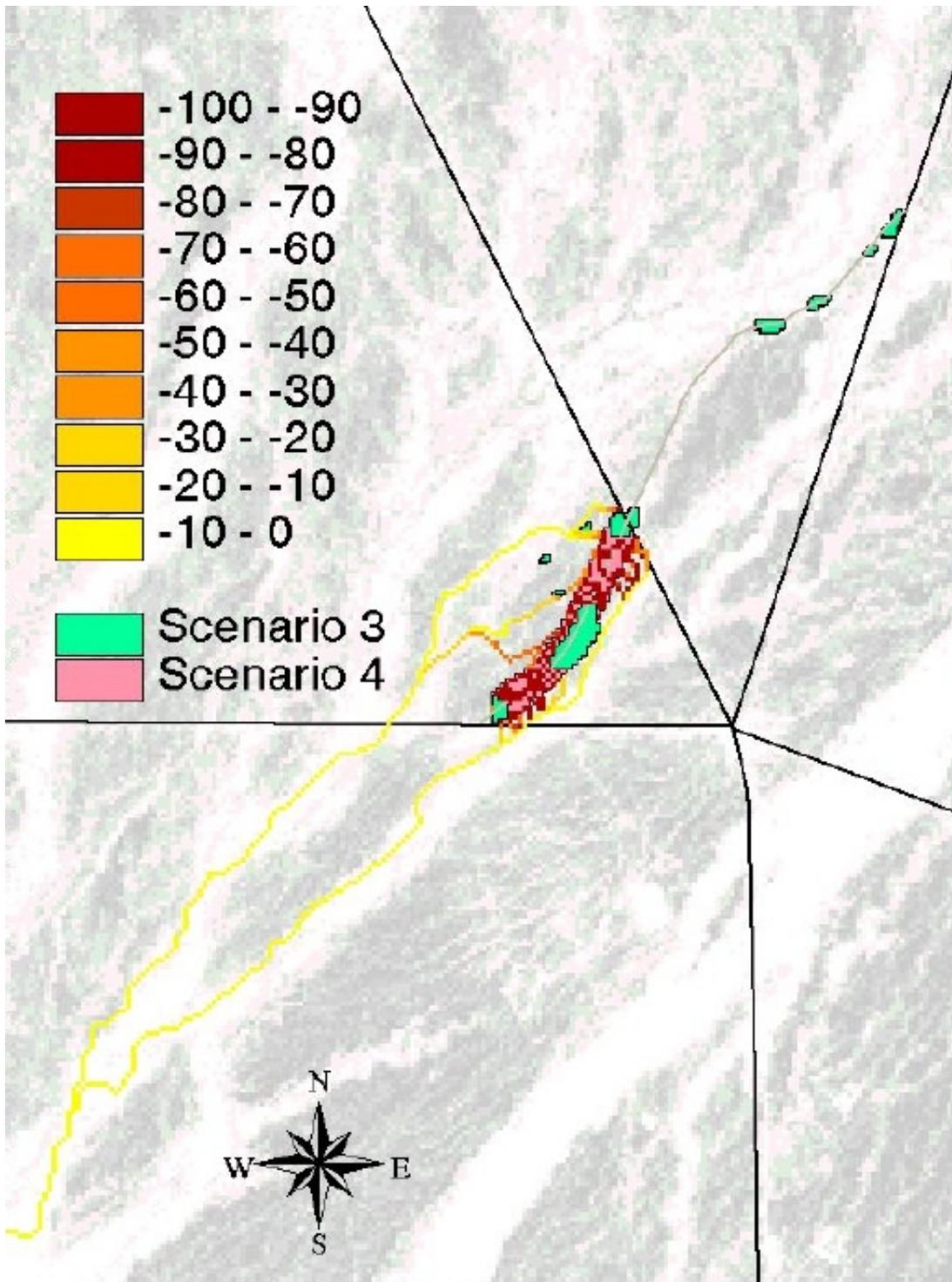
Fig. 7.2. Percent water decrement associated with a hypothetical disturbance of a 100-m area on either side of the lower MTI Road (south-west of Red Hill Road) for a distance of 900-1000 m, combined with the test scenario and preexisting disturbance (Scenario 4); compared to the approximate disturbance associated with the Apache Longbow–Hellfire missile test and preexisting disturbance (Scenario 3). The results are overlain on a Landsat 7 image, and desert wash areas appear in white.
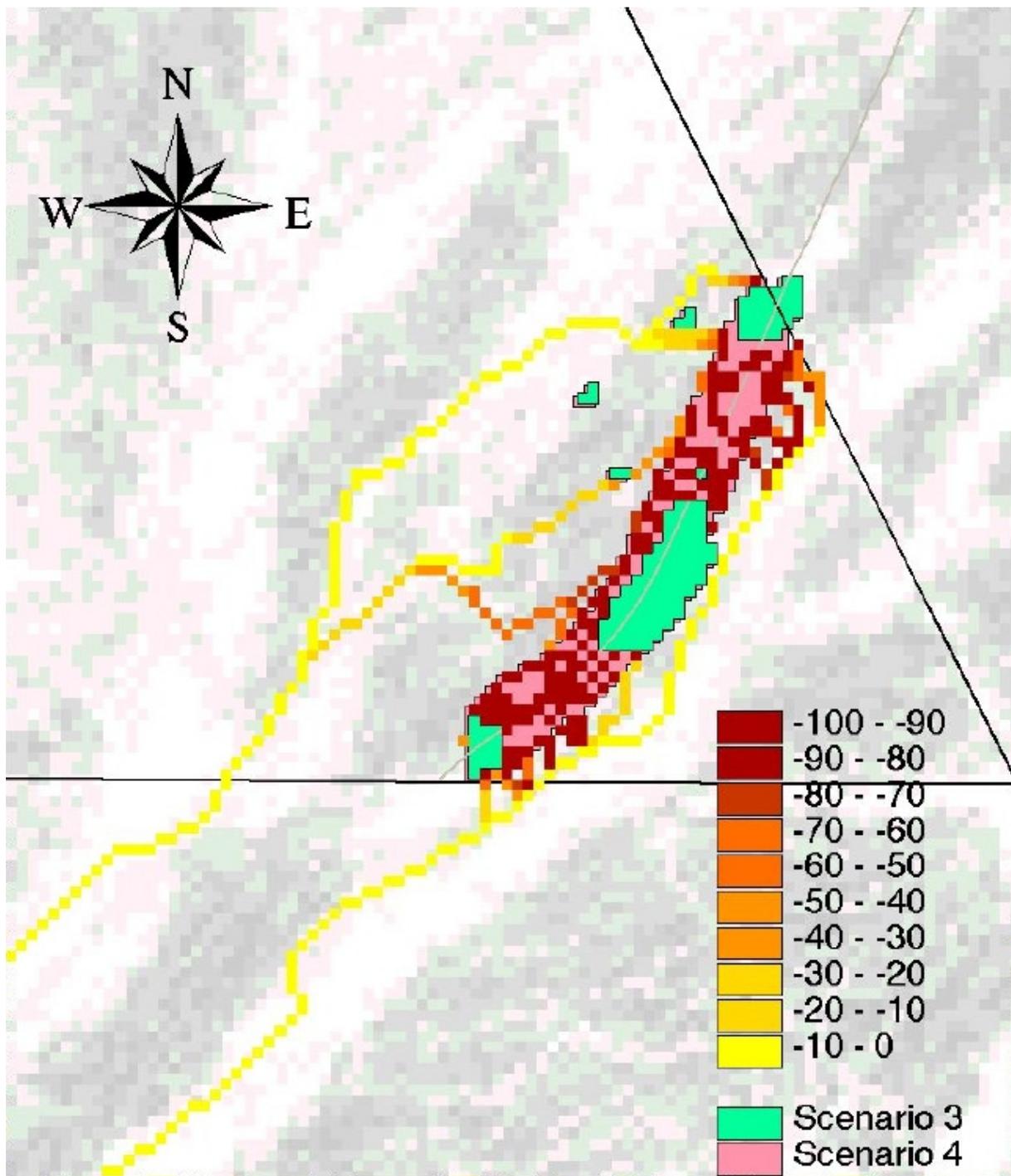
Fig. 7.3. Magnified view of Fig. 7.2. Percent water decrement associated with a hypothetical disturbance of a 100-m area on either side of the lower MTI Road (south-west of Red Hill Road) for a distance of 900-1000 m, combined with the test scenario and preexisting disturbance (Scenario 4); compared to the approximate disturbance associated with the Apache Longbow–Hellfire missile test and preexisting disturbance (Scenario 3). The results are overlain on a Landsat 7 image, and desert wash areas appear in white.

Fig. 7.4. Percent water decrement associated with a hypothetical disturbance of a 100-m area on either side of the upper MTI Road (north-east of Red Hill Road) for a distance of 900-1000 m, combined with the test scenario and preexisting disturbance (Scenario 5); compared to the approximate disturbance associated with the Apache Longbow–Hellfire missile test and preexisting disturbance (Scenario 3). Scenarios 2, 4 and 6 are not depicted. The results are overlain on a Landsat 7 image, and desert wash areas appear in white.
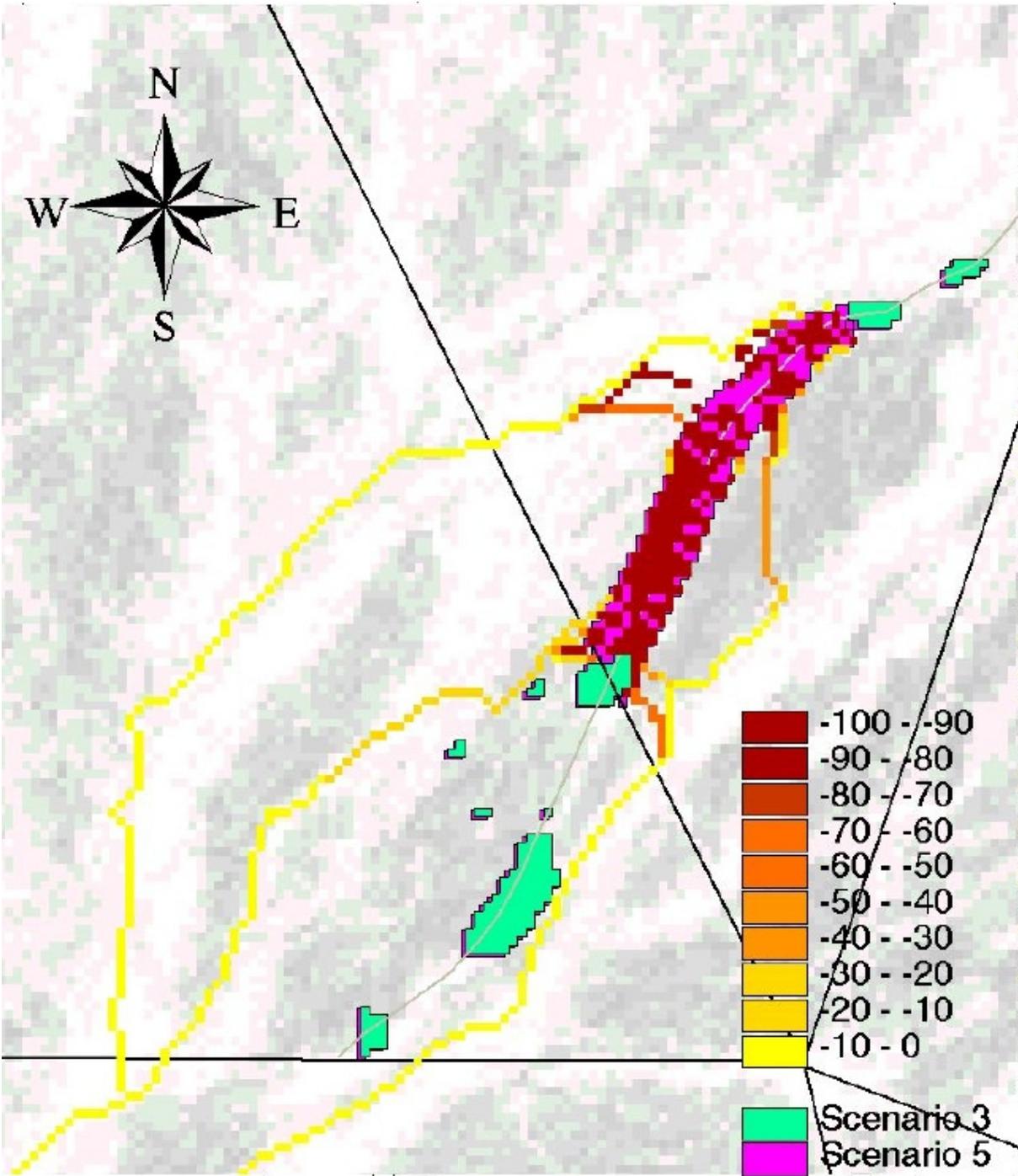
Fig. 7.5. Magnified view of Fig. 7.4. Percent water decrement associated with a hypothetical disturbance of a 100-m area on either side of the upper MTI Road (north-east of Red Hill Road) for a distance of 900-1000 m, combined with the test scenario and preexisting disturbance (Scenario 5); compared to the approximate disturbance associated with the Apache Longbow–Hellfire missile test and preexisting disturbance (Scenario 3). The results are overlain on a Landsat 7 image, and desert wash areas appear in white.

Fig. 7.6. Percent water decrement associated with a hypothetical disturbance of a 100-m area on either side of East Target Road for a distance of 900-1000 m, combined with the test scenario and preexisting disturbance (Scenario 6); compared to the approximate disturbance associated with the Apache Longbow–Hellfire missile test and preexisting disturbance (Scenario 3). The results are overlain on a Landsat 7 image, and desert wash areas appear in white.
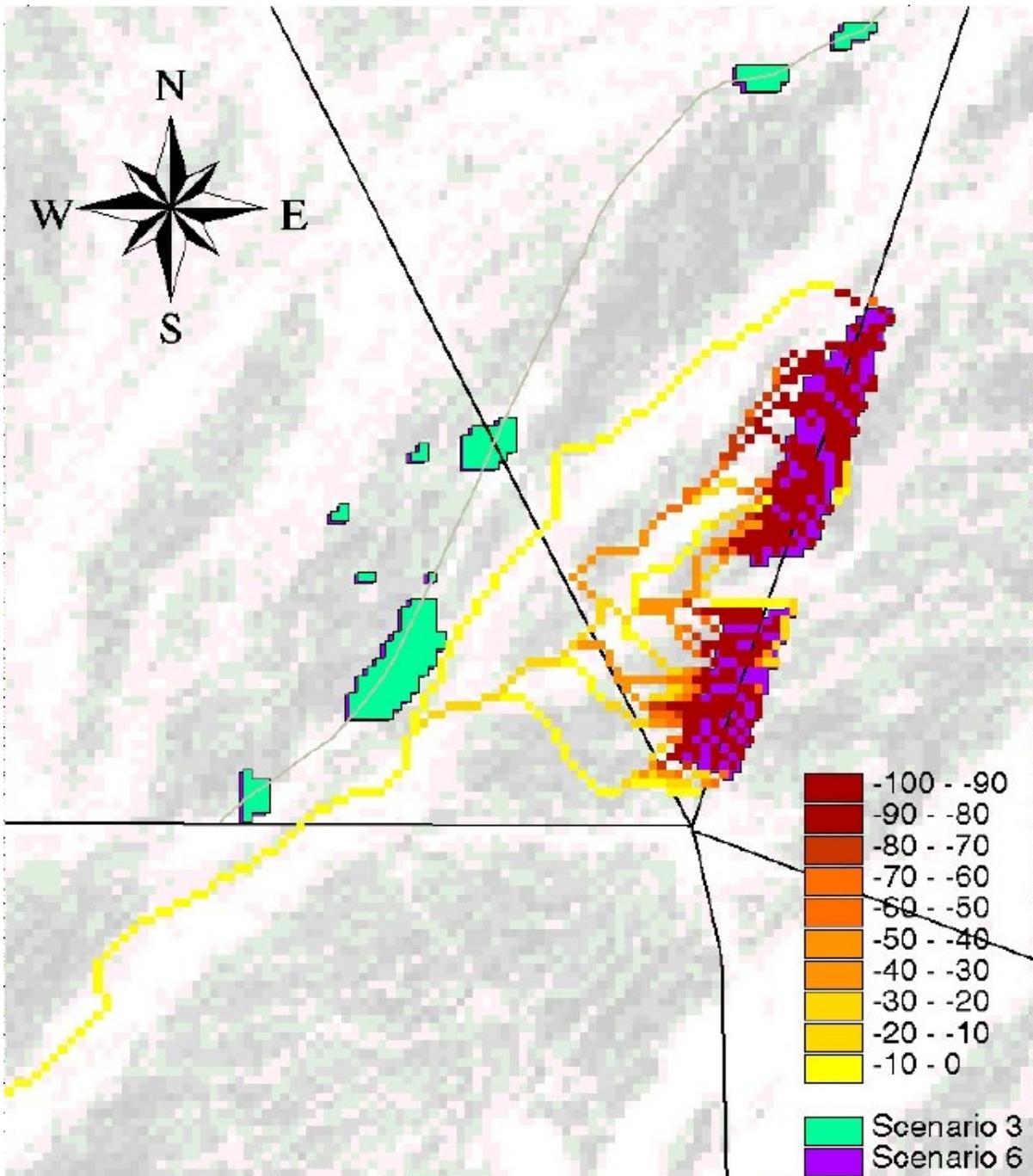
Fig. 7.7. Magnified view of Fig. 7.6. Percent water decrement associated with a hypothetical disturbance of a 100-m area on either side of East Target Road for a distance of 900-1000 m, combined with the test scenario and preexisting disturbance (Scenario 6); compared to the approximate disturbance associated with the Apache Longbow–Hellfire missile test and preexisting disturbance (Scenario 3). The results are overlain on a Landsat 7 image, and desert wash areas appear in white.

McAllister Wash. The transfer of a test activity to another watershed, such as Indian Wash, would be expected to result in comparable levels of water loss.

7.3.2 Characterization of Effects

The characterization of effects of hydrology is presented in Sect. 5.3, with the only valuable (if uncertain) exposure-response relationship for wash plants and hydrology in Sect. 5.3.1.3. Essentially, Glass (2000) provides data from which approximate water volume thresholds for wash trees can be calculated, with respect to a significant rain event. That is, for an ironwood or other wash tree in a 30-m-wide wash, the volumes of water that are required to pass over the soil are 1500 m^3 for survival and 5900 m^3 for growth.

> Water volume thresholds for wash trees in a 30-m-wide wash during a significant rain event are 5900 m^3 for growth to large size and 1500 m^3 for survival .

7.3.3 Risk Characterization

The risk characterization for the three hypothetical disturbance scenarios does not require a weight of evidence, as the only line of evidence is from Glass (2000) above. Areas of woody wash vegetation loss or growth decrement that would be associated with the hypothetical disturbance scenarios are depicted in Fig. 7.8 (MTI Road, between West Target and Red Hill Roads), Fig. 7.9 (MTI Road, between Red Hill and East Target Roads), and Fig. 7.10 (East Target Road, above West Target Road).

> The risk characterization for the three hypothetical disturbance scenarios indicates that wash tree growth and/or survival may be inhibited in areas of up to 1.35 and 0.54 ha, respectively.

The risks that are expected from the three scenarios are presented in Table 7.1.

Table 7.1. Risk characterization for three hypothetical disturbance areas

Location of disturbance	Area where wash trees cannot survive[1] (m^2)	Total area where wash trees have stunted growth[1] or cannot survive (m^2)
MTI Road, between West Target and Red Hill Roads	900	1800
MTI Road, between Red Hill and East Target Roads	5400	8100
East Target Road, above West Target Road	0	13500

[1]Compared to the test plus preexisting disturbance case.

Thus, the area of risk to vegetation in washes is predicted to be quite small, even in these scenarios that involve a relatively large disturbance area. In addition, risk to mule deer from loss of vegetation is predicted to be insignificant. Given that the density of deer is assumed to be 0.56 deer per km^2 (or one deer per 179000 m^2), even a loss of deer in proportion to the areal loss of vegetation will result in no deer lost.
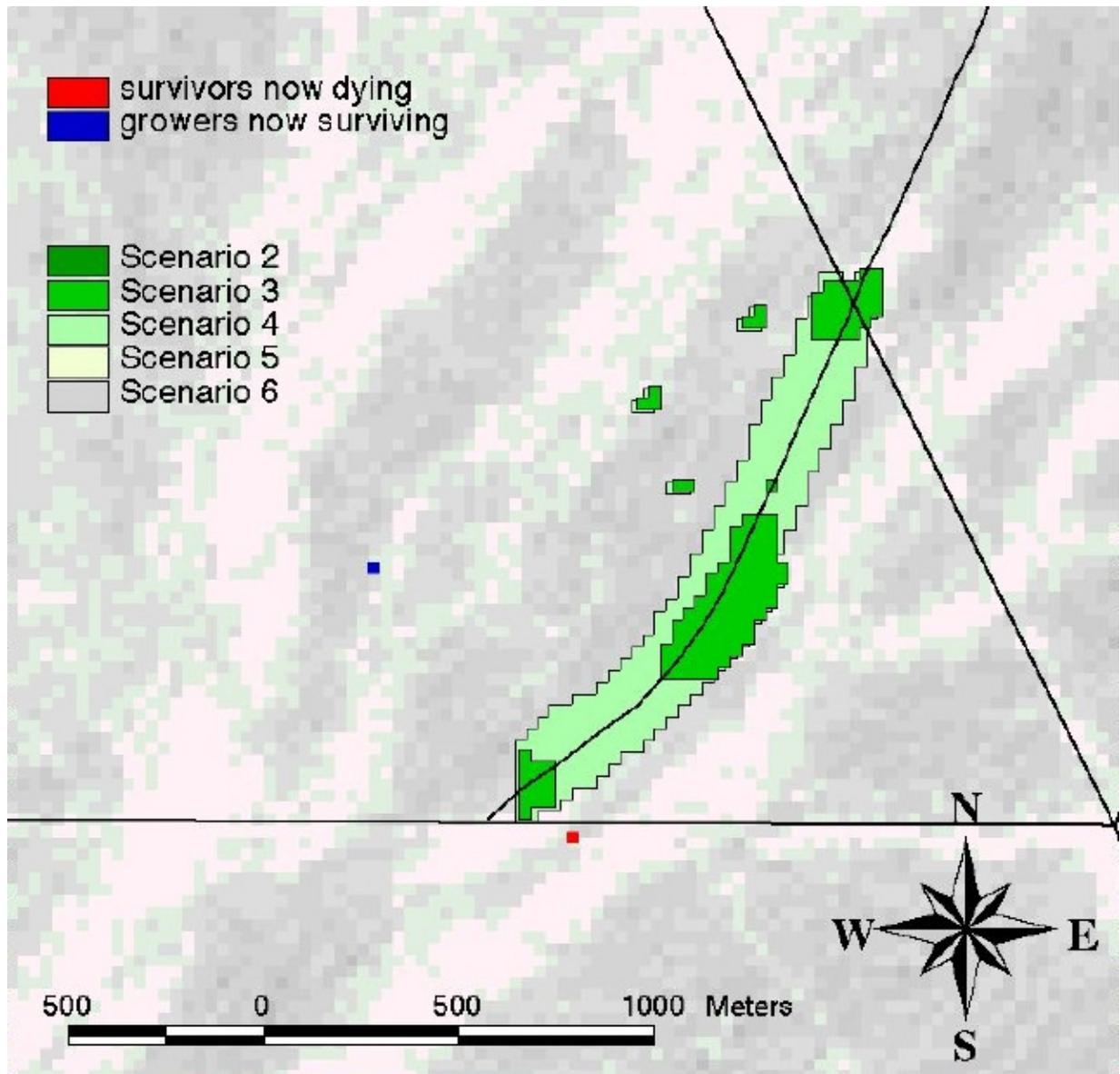
Fig. 7.8. Areas where wash trees are expected to be at risk from hypothetical disturbance of a 200m by 1000 m area along MTI Road, between West Target and Red Hill Roads, combined with test and preexisting disturbance (Scenario 4); compared to preexisting plus test disturbance (Scenario 3). Blue indicates 30 by 30 m land areas where trees are expected to receive water below the threshold for growth under the hypothetical scenario, compared to the test scenario. Red indicates land areas where trees are expected to receive water below the threshold for survival. Scenarios 5 and 6 are not depicted.
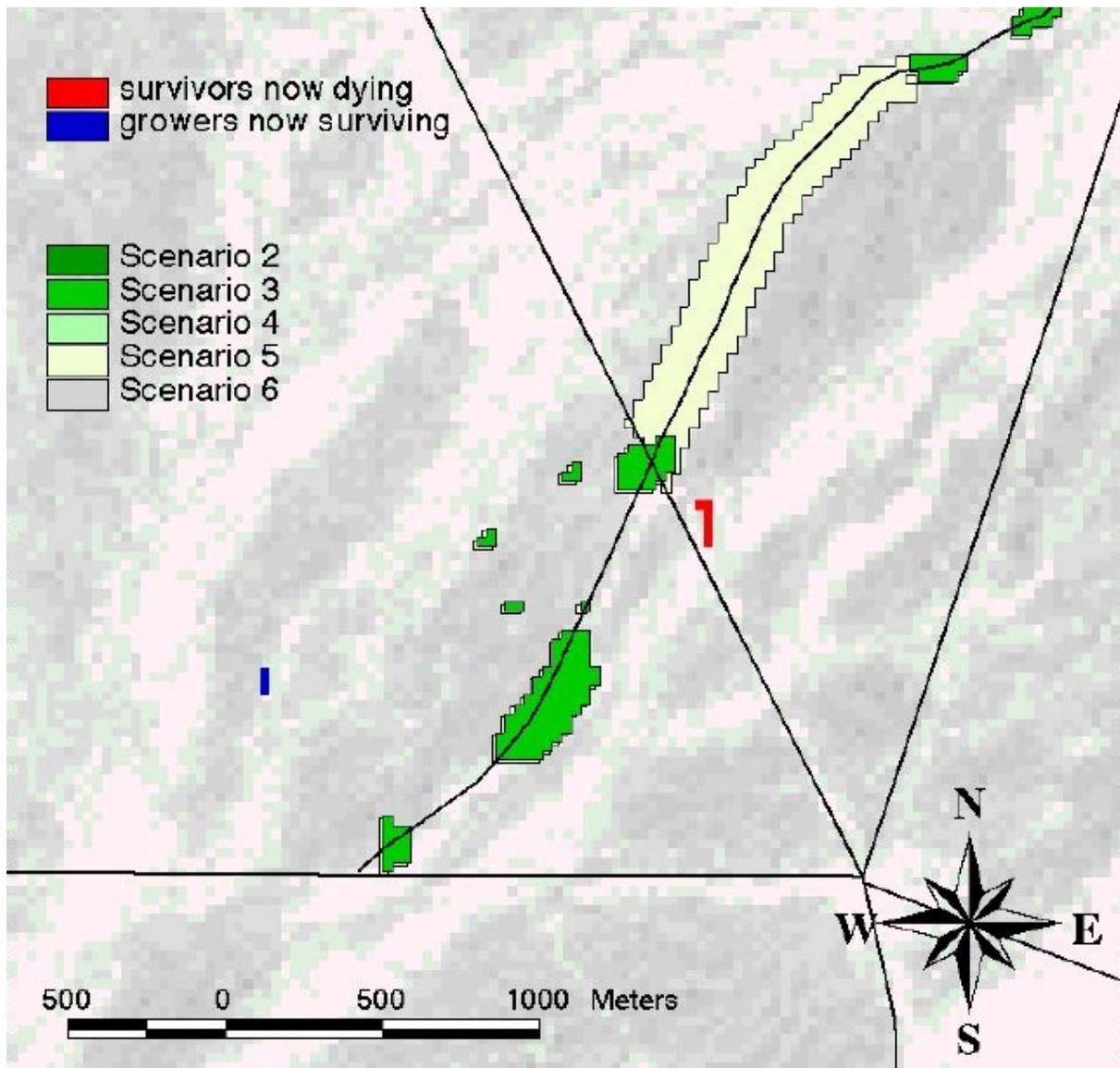
Fig. 7.9. Areas where wash trees are expected to be at risk from hypothetical disturbance of a 200m by 1000 m area along MTI Road, between Red Hill and East Target Roads, combined with test and preexisting disturbance (Scenario 5); compared to preexisting plus test disturbance (Scenario 3). Blue indicates 30 by 30 m land areas where trees are expected to receive water below the threshold for growth under the hypothetical scenario, compared to the test scenario. Red indicates land areas where trees are expected to receive water below the threshold for survival. Scenarios 4 and 6 are not depicted.

Fig. 7.10. Areas where wash trees are expected to be at risk from hypothetical disturbance of a 200m by 1000 m area along East Target Road, above West Target Road, combined with test and preexisting disturbance (Scenario 6); compared to preexisting plus test disturbance (Scenario 3). Blue indicates 30 by 30 m land areas where trees are expected to receive water below the threshold for growth under the hypothetical scenario, compared to the test scenario. Red indicates land areas where trees are expected to receive water below the threshold for survival. Scenarios 4 and 5 are not depicted.

7.4 ADDITIONAL PROGRAMS IN THE AREA

Additional test programs in the area are described in Sect. 2.2.3. Potential additional stressors include: helicopters, fixed-wing aircraft, explosive weapons, and tracked vehicles. Sound from multiple helicopters and fixed-wing aircraft may be added, but existing noise software considers only single training or test operations on MOAs or MTRs. Sound from tanks could also be added to sound from aircraft, but existing software does not apparently have this capability. Blast noise from explosive weapons should not be added to continuous sound from aircraft. Disturbances from tracked vehicle testing and rocket impact areas may be added to disturbances associated with the Apache Longbow–Hellfire missile test to estimate hydrological change. A risk assessor could use a time series of DOQQs to attribute tank tracks to particular tests, with knowledge of which tests or training programs utilized the site during which period. Risks associated with cumulative programs in middle Cibola Range would be expected to be greater than risks associated with the Apache Longbow–Hellfire missile test.

> Risks from stressors associated with additional test programs in the vicinity of the Apache-Hellfire test may be determined by adding similar types of exposures or similar types of effects.

Behavioral or reproductive effects on vertebrates from different stressors may be added through the integrated risk assessment methodology presented in Chapter 6. Similarly, effects on growth or survival of wash vegetation from different stressors may be added as described in this integrated risk assessment methodology.

Additionally, test programs in the area can affect risks to mule deer by increasing the probability of habituation, which actually lowers behavioral effects on mule deer and many other wildlife.

7.5 THRESHOLDS FOR ECOLOGICAL EFFECTS

An additional use of MERAF that is beyond the scope or this demonstration would be to establish thresholds for ecological effects that result from stressors associated with different test activities. Such thresholds could be used to "screen out" activities or particular stressors that are unlikely to cause significant risk. For example, noise contour model (evaluated or validated using field data) might be able to determine the maximum number of helicopters flying concurrently at a certain altitude in approximately the same location that would cause sound to cross some threshold at some location. If the boundary of a reproducing population of mule deer were known, one could determine the minimum area that helicopters would need to fly over to impact behavior (or physiology) in a population-relevant area. Similarly, one could assess how much disturbance of desert pavement would be required to significantly affect biomass or diversity of a predetermined area or fraction of desert wash vegetation. Moreover, one could assess the area and distribution of tank tracks required to significantly impact abundance of mule deer.

> Thresholds for ecological effects from various stressors may be developed to facilitate MERAF assessments. These could be used to screen out activities or stressors that are unlikely to cause significant risk.

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APPENDIX A

LCTA DATA

Appendix A. Vegetation observed in nine Land Condition - Trend Analysis (LCTA) plots in the vicinity of the Apache Longbow–Hellfire missile test area

Plot-ID[1]	Easting[2]	Northing[2]	Date	Genus	Species	Number of Observations
95	737851	3667244	5/23/91	Ambrosia	dumosa	6
95	737851	3667244	5/23/91	Encelia	farinosa	4
95	737851	3667244	5/23/91	Larrea	tridentata	13
95	737851	3667244	5/23/91	Opuntia	basilaris	1
95	737851	3667244	5/23/91	Parkinsonia	microphylla	1
95	737851	3667244	4/3/98	Ambrosia	dumosa	7
95	737851	3667244	4/3/98	Encelia	farinosa	7
95	737851	3667244	4/3/98	Larrea	tridentata	11
95	737851	3667244	4/3/98	Opuntia	basilaris	2
95	737851	3667244	4/3/98	Parkinsonia	microphylla	1
96	748737	3667659	5/10/91	Ambrosia	dumosa	1
96	748737	3667659	5/10/91	Larrea	tridentata	11
96	748737	3667659	4/9/98	Ambrosia	dumosa	1
96	748737	3667659	4/9/98	Encelia	farinosa	1
96	748737	3667659	4/9/98	Larrea	tridentata	10
98	747735	3666047	5/10/91	Larrea	tridentata	30
98	747735	3666047	5/10/91	Opuntia	echinocarpa	1
98	747735	3666047	5/10/91	Tiquilia	canescens	2
98	747735	3666047	4/9/98	Ambrosia	dumosa	1
98	747735	3666047	4/9/98	Larrea	tridentata	27
98	747735	3666047	4/9/98	Opuntia	echinocarpa	1
99	738557	3664830	5/23/91	Acacia	greggii	3
99	738557	3664830	5/23/91	Larrea	tridentata	4
99	738557	3664830	5/23/91	Lycium	andersonii	6
99	738557	3664830	5/23/91	Olneya	tesota	1
99	738557	3664830	5/23/91	Shrub		1
99	738557	3664830	5/23/91	Unknown	snag	1
99	738557	3664830	4/3/98	Ambrosia	ambrosioides	2
99	738557	3664830	4/3/98	Ambrosia	dumosa	1
99	738557	3664830	4/3/98	Argythamnia	lanceolata	22
99	738557	3664830	4/3/98	Argythamnia	species	3
99	738557	3664830	4/3/98	Encelia	farinosa	24
99	738557	3664830	4/3/98	Larrea	tridentata	2
99	738557	3664830	4/3/98	Lycium	andersonii	9
99	738557	3664830	4/3/98	Olneya	tesota	1
99	738557	3664830	4/3/98	Physalis	crassifolia	1
99	738557	3664830	4/3/98	Unknown	snag	2
101	745482	3665353	5/10/91	Ambrosia	dumosa	1
101	745482	3665353	5/10/91	Hymenoclea	salsola	2
101	745482	3665353	5/10/91	Larrea	tridentata	8
101	745482	3665353	5/10/91	Lycium	andersonii	3
101	745482	3665353	5/10/91	Olneya	tesota	3
101	745482	3665353	5/10/91	Parkinsonia	microphylla	1

101	745482	3665353	4/1/98	Ambrosia	dumosa	1
101	745482	3665353	4/1/98	Larrea	tridentata	8
101	745482	3665353	4/1/98	Lycium	andersonii	1
101	745482	3665353	4/1/98	Olneya	tesota	4
101	745482	3665353	4/1/98	Parkinsonia	microphylla	1
102	747247	3664599	5/28/91	Bebbia	juncea	14
102	747247	3664599	5/28/91	Encelia	farinosa	4
102	747247	3664599	5/28/91	Krameria	grayi	4
102	747247	3664599	5/28/91	Larrea	tridentata	27
102	747247	3664599	5/28/91	Olneya	tesota	2
102	747247	3664599	5/28/91	Opuntia	basilaris	2
102	747247	3664599	5/28/91	Opuntia	echinocarpa	1
102	747247	3664599	4/2/98	Argythamnia	lanceolata	3
102	747247	3664599	4/2/98	Bebbia	juncea	10
102	747247	3664599	4/2/98	Encelia	farinosa	7
102	747247	3664599	4/2/98	Justica	californica	1
102	747247	3664599	4/2/98	Krameria	grayi	4
102	747247	3664599	4/2/98	Larrea	tridentata	28
102	747247	3664599	4/2/98	Lycium	andersonii	2
102	747247	3664599	4/2/98	Olneya	tesota	2
102	747247	3664599	4/2/98	Opuntia	basilaris	2
102	747247	3664599	4/2/98	Unknown	snag	2
103	743969	3664485	5/23/91	Acacia	greggii	1
103	743969	3664485	5/23/91	Bebbia	juncea	2
103	743969	3664485	5/23/91	Hyptis	emoryi	1
103	743969	3664485	5/23/91	Lycium	andersonii	2
103	743969	3664485	5/23/91	Olneya	tesota	1
103	743969	3664485	5/23/91	Simmondsia	chinensis	1
103	743969	3664485	4/2/98	Acacia	greggii	1
103	743969	3664485	4/2/98	Hyptis	emoryi	1
103	743969	3664485	4/2/98	Lycium	andersonii	7
103	743969	3664485	4/2/98	Olneya	tesota	1
103	743969	3664485	4/2/98	Simmondsia	chinensis	1
108	737711	3656194	5/15/91	Larrea	tridentata	31
108	737711	3656194	5/15/91	Parkinsonia	microphylla	1
108	737711	3656194	4/2/98	Larrea	tridentata	25
108	737711	3656194	4/2/98	Parkinsonia	microphylla	1

[1]Plots 106 and 108 are located down-gradient of the study area on Indian Wash, and plots 96, 98, 101, and 103 are located on or near Indian Wash, close to the study area.

[2]The coordinates supplied for each plot in UTM Zone 11 meters show the location of the base of each transect.

APPENDIX B

INPUT FILE FOR MR_NMAP

SETUP PARAMETERS
0   5
643
2389707   11957064
2579308   12065582
95   32   30
65
LOCATION
032d55'00.0000"N   114d33'00.0000"W
033d12'00.0000"N   114d16'00.0000"W
0
TRACK SPECIFICATION
W46
4

NW	2438479	11995930	30380	30380	0	0	0	0
NW	2432839	12004312	30380	30380	0	0	0	0
NW	2434365	12025345	30380	30380	0	0	0	0
NW	2438479	11995930	30380	30380	0	0	0	0

TRACK SPECIFICATION
W49
4

NW	2438479	11995930	30380	30380	0	0	0	0
NW	2433755	12012239	30380	30380	0	0	0	0
NW	2434365	12025345	30380	30380	0	0	0	0
NW	2438479	11995930	30380	30380	0	0	0	0

TRACK SPECIFICATION
W50
4

NW	2438479	11995930	30380	30380	0	0	0	0
NW	2433144	12009036	30380	30380	0	0	0	0
NW	2434365	12025345	30380	30380	0	0	0	0
NW	2438479	11995930	30380	30380	0	0	0	0

TRACK SPECIFICATION
W51
4

NW	2438479	11995930	30380	30380	0	0	0	0
NW	2440156	12013610	30380	30380	0	0	0	0
NW	2434365	12025345	30380	30380	0	0	0	0
NW	2438479	11995930	30380	30380	0	0	0	0

TRACK SPECIFICATION
W52
4

NW	2438479	11995930	30380	30380	0	0	0	0
NW	2429942	12013151	30380	30380	0	0	0	0
NW	2434365	12025345	30380	30380	0	0	0	0
NW	2438479	11995930	30380	30380	0	0	0	0

MISSION
AH64-40
296   40   40
7

```
0       50      5
50      100     5
100     150     5
150     200     5
200     250     20
250     300     30
300     350     30
TRACK OPS
5
W46                     20
W49                     20
W50                     20
W51                     20
W52                     20
1
AH64-40  14.0    0       0
LMAX
ASCII GRID
TAPER 0
END
USER INFO
BLAH
YPG TEST
TEST
COORDINATES
W46
033:01:07N,114:23:45W
033:02:31N,114:24:48W
033:06:00N,114:24:25W
033:01:07N,114:23:45W
W49
033:01:07N,114:23:45W
033:03:50N,114:24:37W
033:06:00N,114:24:25W
033:01:07N,114:23:45W
W50
033:01:07N,114:23:45W
033:03:18N,114:24:43W
033:06:00N,114:24:25W
033:01:07N,114:23:45W
W51
033:01:07N,114:23:45W
033:04:02N,114:23:21W
033:06:00N,114:24:25W
033:01:07N,114:23:45W
W52
033:01:07N,114:23:45W
033:04:00N,114:25:21W
033:06:00N,114:24:25W
033:01:07N,114:23:45W
```

APPENDIX C

INPUT FILES FOR NOISEMAP

.run file
"N 33 -05-59   ","W 114-24-25   ","N 33 -1 -7   ","W 114-23-45   ","0","0","10","030"

.rac file
no data

.pow file
"TST2","KNOTS","0",8
"60","0","200","40","40"
"60","29560","350","40","40"
"77","29760","0","40","40"
"83","29761","0","40","40"
"60","29960","300","40","40"
"60","39816","300","40","40"
"60","39817","300","40","40"
"60","60962","200","40","40"
"TST3","KNOTS","0",8
"60","0","200","40","40"
"60","29560","350","40","40"
"77","29760","0","40","40"
"83","29761","0","40","40"
"60","29960","300","40","40"
"60","46824","300","40","40"
"60","46825","300","40","40"
"60","59936","200","40","40"
"TST4","KNOTS","0",8
"60","0","200","40","40"
"60","29560","350","40","40"
"77","29760","0","40","40"
"83","29761","0","40","40"
"60","29960","300","40","40"
"60","43889","300","40","40"
"60","43890","300","40","40"
"60","60299","200","40","40"
"TST5","KNOTS","0",8
"60","0","200","40","40"
"60","29560","350","40","40"
"77","29760","0","40","40"
"83","29761","0","40","40"
"60","29960","300","40","40"
"60","47501","300","40","40"
"60","47502","300","40","40"
"60","60616","200","40","40"
"TST6","KNOTS","0",8
"60","0","200","40","40"
"60","29560","350","40","40"
"77","29760","0","40","40"
"83","29761","0","40","40"
"60","29960","300","40","40"
"60","49062","300","40","40"

"60","49063","300","40","40"
"60","62031","200","40","40"

.pad file
no data

.id file
"/* BASEOPS OPERATIONS data file version 5.0 */"
"HARGROVE"
"hargrove"
"hargrove"
"hargrove"
"241-2748"

.flt file
"HEADER","W46","030","C",5,0
"29756","0"
"1","154"
"10061","0"
"1","38"
"21142","0"
"HEADER","W49","030","C",5,0
"29756","0"
"1","172"
"17069","0"
"1","19"
"13108","0"
"HEADER","W50","030","C",5,0
"29756","0"
"1","166"
"14133","0"
"1","26"
"16407","0"
"HEADER","W51","030","C",5,0
"29756","0"
"1","-167"
"17746","0"
"1","-31"
"13111","0"
"HEADER","W52","030","C",5,0
"29756","0"
"1","161"
"19306","0"
"1","48"
"12966","0"

.fac file
"HEADER","TST2","H","AH64",0,1
"W46","1","0","0"
"HEADER","TST3","H","AH64",0,10

"W49","1","0","0"
"HEADER","TST4","H","AH64",0,19
"W50","1","0","0"
"HEADER","TST5","H","AH64",0,28
"W51","1","0","0"
"HEADER","TST6","H","AH64",0,37
"W52","1","0","0"

<u>.air file</u>
"MCM version"
"YPG Hellfire test",1
"Yuma Proving Grounds"
"0","EAST","0","95","32",0
-114.4069444,33.0997222,.8377213

APPENDIX D

THRESHOLDS FOR EFFECTS OF OVERFLIGHTS ON UNGULATES

FROM EFROYMSON ET AL. (2000)

Aircraft thresholds for effects on ungulates.

Species	Stressor	LOAEL	NOAEL	Response	location	Reference
mountain goat (*Oreamnos americanus*)	Bell-212 twin engine and Bell-206B turbo helicopter	>1500 m horizontal distance		37% of flights caused at least moderate group reaction (movement of 10-100 m or alertness between 2 and 10 min, over 50% of animals)	Caw Ridge, Alberta	Côté 1996
desert mule deer (*Odocoileus hemionus crooki*)	Cessna 172, Cessna 182 or Maule (M-5-235C)		<50 m altitude	animals did not change habitat	Picacho Mountains, south-central Arizona	Krausman et al. 1986
mountain sheep (*Ovis canadensis*)	F-16 aircraft, 90% power setting		125 m above ground level, 85 to 110 dB	no altered behavior	Desert National Wildlife Refuge, Nevada	Krausman et al. 1998
mountain sheep (*Ovis canadensis*)	Cessna 172 or 182	> 100 m		23% of sheep moved up to 100 m and continued their pre-survey activities		Krausman and Hervert 1983
mountain sheep (*Ovis canadensis*)	helicopter surveys, sampling intensity 0.8 min/km^2 or 2.0 min/km^2	50-200 m		moved 2.5 times farther the day following survey than previous day; 35-52% of animals changed polygons (8-83 km2) following sampling, compared to 11% day before	San Bernardino County, California	Bleich et al. 1990
mountain sheep (*Ovis canadensis*)	Bell 206B-III turbine powered helicopter	100 m above ground level		about 33-47% more animals changed their use of vegetation types following overflights; about 20-45% more animals changed sampling blocks following overflights	San Bernardino County, California	Bleich et al. 1994
mountain sheep (*Ovis canadensis*)	Bell 206B-III turbine powered helicopter	100 m above ground level		female mountain sheep moved farther the day of the survey than other days in spring, summer, and fall, but not in winter	San Bernardino County, California	Bleich et al. 1994
desert bighorn sheep (*Ovis canadensis nelsoni*)	helicopters	250-450 m slant distance		reduction in foraging efficiency; effect may only exist in winter	Grand Canyon National Park	Stockwell et al. 1991

D-3

Species	Stressor	LOAEL	NOAEL	Response	location	Reference
pronghorn antelope	OH-58 helicopter	150 m slant distance, 46 m altitude, 77 dBA	120 m altitude, slant range 900 m (60 dBA)	running	Otero Mesa in southern New Mexico	Luz and Smith 1976
moose	fixed-wing aircraft	60 m altitude		"frightened"		EPA 1980
woodland caribou (*Rangifer tarandus caribou*)	F-4, F-5, F-16, F-18, Tornado fixed wing aircraft, 775-825 km/h	300 m altitude, 70 m horizontal distance		30% response (daily activity level or daily distance traveled)	Canadian Forces Base, Goose Bay	Harrington and Veitch 1991
woodland caribou (*Rangifer tarandus caribou*)	F-16 fixed-wing	25-60 m altitude		15-50% response (movement several meters after pass)	Canadian Forces Base, Goose Bay	Harrington and Veitch 1991
woodland caribou (*Rangifer tarandus caribou*)	Bell 206L helicopter	30 m altitude		movement of 100% of individuals away from helicopter's path, prior to passing	Canadian Forces Base, Goose Bay	Harrington and Veitch 1991
woodland caribou (*Rangifer tarandus caribou*)	A-star 300D helicopter	30-150 m altitude		movement away from helicopter path prior to passing	Canadian Forces Base, Goose Bay	Harrington and Veitch 1991
Peary caribou (*Rangifer tarandus pearyi*)	Bell 206B helicopter	301-400 m altitude		trotting or galloping by 29.3% of animals	Prince of Wales Island	Miller and Gunn 1979
barren-ground caribou (*Rangifer tarandus*)	jet turbine helicopters	150 m	about 300 m	10% to 25% of groups exhibited at least a mild escape response	northern Yukon and Alaska	Calef et al. 1976
barren-ground caribou (*Rangifer tarandus*)	fixed wing aircraft	150 m	about 300 m	65% to 75% of groups exhibited at least a mild escape response	northern Yukon and Alaska	Calef et al. 1976
caribou	helicopter	150-300 m		30000 animals "fled"		Jakimchuk et al. 1974
muskox	Bell 206B helicopter	301-400 m		32% trotting or galloping		Miller and Gunn 1979

Species	Stressor	LOAEL	NOAEL	Response	location	Reference
non-habituated horse	simulated F-4 aircraft noise	113.4 dB max, 112.2 SEL 4 exposures per day		all horses (pregnant mares) exhibited flight posture (highly elevated head, wide open eye lids, dilated nostrils, quick forward or sideways movement) and movement of horses was significantly higher in treatment group	barn	LeBlanc et al. 1991
habituated horse	simulated F-4 aircraft noise		113.4 dB max, 112.2 SEL 6 events per hour	no horses (pregnant mares) exhibited more than an alert or irritated posture; no horses had elevated cortisol levels	barn	LeBlanc et al. 1991
non-habituated horse	simulated F-4 aircraft noise	113.4 dB max, 112.2 SEL 4 exposures per day		38% of horses (pregnant mares) had mild heart rate increases sustained for 20 sec	barn	LeBlanc et al. 1991
non-habituated horse	simulated F-4 aircraft noise	113.4 dB max, 112.2 SEL 4 exposures per day		cortisol elevated in 3 of 8 tested mares	barn	LeBlanc et al. 1991
lamb	USA Standard Institute White Noise (USASI)	100 dB	75 dB	increase in heart rate of lamb not acclimated to sound		Aames 1978
lamb	USA Standard Institute White Noise (USASI)		100 dB	no increase in heart rate of lamb acclimated to sound		Aames 1978
sheep	USA Standard Institute (USASI) White Noise	75 dB, continuous for 14 days		lower dry matter intake (only 2% difference)	laboratory	Harbers et al. 1975

APPENDIX E

OBSERVATIONS OF DISTURBANCE ALONG MTI, WEST TARGET, AND RED HILL

ROADS

Field Observations from Moving Target Route for Apache Hellfire Program
Yuma Proving Ground, Cibola Range, 16 August 2000
Winifred Rose, USACERL

Field observations began at the crossroads in front of CM1, where West Target Road, Red Hill Road, East Target Road, CM1 Access Road, and Cheyenne Base Road all meet. This is located north of gridline 3664N, and just east of gridline 743E, on the Red Hill topo quad map. The tank targets for the Hellfire tests drive along West Target Road, MTI Road, and Red Hill Road. Val said she thinks this test area was established in the early 1990s, around 1992 or 1993. This should be kept in mind when evaluating possible cumulative effects of the trails and activities on the landscape.

Observations were made while driving along this route, stopping at each 0.1 mile and sometimes at 0.05 mile for visual observations of conditions easily visible from the vehicle. (I think the tanks drive the opposite direction than I did when making the observations. I drove along West Target Road, MTI Road, then Red Hill Road; whereas I think they told us they drive Red Hill first, to MTI, then West Target Road.).

In general, the upland land surface was covered with desert pavement or malapai (spelling?). This is formed by the removal of fine soil particles from the surface, by wind deflation, water erosion, and/or percolation below the surface of the soil. The remaining closely-packed gravel-, pebble-, and cobble-sized rocks on the surface become coated with a lacquer formed from manganese and iron oxides derived from the underlying soil, forming a hard, dark surface that absorbs and radiates a lot of heat from the sun. This surface is uncongenial to plant germination and growth except where it is disturbed, and probably sheds most of the rainfall down to the wash areas. The wash areas do not exhibit desert pavement surfaces.

Observations begin at 0.1 mile from CM1 crossroads. All distance measurements are relative to this point. Percent disturbance is based on visual estimates and should be considered only approximate.

West Target Road, heading west

0.1 mile

Both sides appear to have gravel added to the malapai surface, parallel to the road for approximately 12 feet on either side. 10-15% disturbance on both sides of road to a distance of approximately 100 ft.

0.2 mile

N of road, 90% disturbance out to dropoff into gully at approximately 200 ft. Disturbance pattern is fairly uniform. S of road 90-95% disturbance to appr. 100 ft from road. Areas of 100% disturbance are intermixed with patches of relatively undisturbed malapai. Targets are laid out in this area and have access trails that have apparently been graveled. Disturbance on both sides consists of traffic churning, bulldozing, and old borrow-strips. One borrow strip lies on the south side, about 120 ft long by 12 ft wide (may be able to use this as a reference point if it shows on the DOQ).

0.3 mile

N of road: 80% disturbance, churned by traffic, S side 10-15% disturbance on malapai surface. Small rill on S of road, flowing away at an angle; less malapai in rill.

0.4 mile

N side: 75% disturbance from traffic churning. Trench-shaped borrow pit ca. 350 feet from road with relatively large amount of vegetation, including 8 creosote bushes, 2 catclaw, grasses & forbs. No vegetation on surrounding malapai. S side: 50-60% disturbance.

0.5 mile

N side: 90+ % disturbance to ca 150 ft, then 20-30% farther out. S side: 45% disturbed. Rill leading away from road to wash running approx. parallel to road.   Much debris: small shrapnel probably from projectiles, bullet casings, pieces of targets, com-wire, bottles & other trash.

0.6 mile

Road enters sharp dip into wash. No malapai.   Roadbanks from road maintenance are relatively high but road surface itself is at or lower than bottom of wash. See little or no difference in vegetation density in wash above and below road, presumably because the low road surface does not act as a checkdam. Within wash see little deposition of soil except for road debris.   Much vegetation in wash, including palo verde, creosote bush, catclaw or ironwood, white bursage, grasses/forbs.   One piece of vehicle shrapnel (most likely from a tank—the metal is thick) ca 2.5 feet long by 8 inches wide on side of road.   Since there is no sign of impact in the soil where the shrapnel is lying, presumably this piece dropped off a vehicle rather than being the site where the tank was hit and damaged.

0.7 mile

Still within wash area; no malapai. One large channel crosses here.   Tire tracks in channels N & S of road.

Between 0.7-0.8 mile

Still within wash; road now on rising slope heading west.   Tire tracks along channel S of road.

0.8 mile

No malapai yet, still in wash area, where another channel crosses the road. Little disturbance; a few tire tracks visible toward the north.

0.85 mile

Malapai begins again.   This place was the 4th photo stop from 8/15/00, where we took a photo of what appears to be a hull-down or defilade tank position but may instead be another borrow-pit for road maintenance.   This depression is right next to the road and about the size of a tank.   Beginning to come out of wash area, but road surface is still level with water flow area.

0.9 mile

Near junction of West Target Road with MTI road. N side: 80% disturbance of malapai in inside corner (NE) of road junction, due to corner-cutting—extends about 30 feet from road.   Beyond that is relatively undisturbed malapai.   S side: 30% disturbed malapai.

0.95 mile

Junction of West Target Road and MTI Road. N side: 95% disturbed.   S side: 65% disturbed; small channel leads away from road.

MTI Road, heading north-east

1.0 mile

East of road: 98-100% disturbance to edge of rise at about 200 ft from road; many ruts.

West side: 95% disturbance to ca 300 ft; tracked vehicle signs off road.

1.1 miles

East side: tracked vehicle signs near road, including turns, plus a few wheeled vehicle tracks heading east across the malapai.   75-80% disturbance to ca 150 ft, little disturbancee after that.

1.2 miles

Broad, flat area surrounding road. East side: 20-30% disturbed. Clump of vegetation next to road, including catclaw, creosote bush. Signs of tank turning.   W side: 30-40% disturbance; tank turns.

1.3 miles

Bare area around road. E side: 100% disturbed; churning, possibly gravel added to surface.   W side: 100% disturbed; no malapai visible near road.

1.4 miles

East side: 90% disturbance, no malapai immediately apparent, to ca 400 ft from road. Target emplaced here.   W side: 85% disturbance out to ca 200 ft; some malapai, some vegetation.

1.5 miles

Appears that a tank or other vehicle recently burned on the road—road surface is blackened and there are signs of some POL (petroleum/oils/lubricants) spillage. E side: 50-60% disturbed to ca 500+ ft from road; W side—same.

1.6 miles

Bulldozer blading one blade wide on both sides of road.   Beyond that: E side 60% disturbed, W side 70% disturbed.

1.7 miles

E side: blading next to road, 20 % disturbed beyond that.   W side : 70% disturbed. Rills leading away from road.

1.8 miles

Circles left by (?) wheeled and tracked vehicles on both sides of road; blading on both sides next to road. E side: 30-40% disturbed.   W side: 40% disturbed.

1.9 miles

E side: 100% disturbance, including bulldozer blading and turns by tracked vehicles, to a distance of ca 250 ft.   This side forms the corner with Red Hill Road.   W side: 95% disturbance out to a rill about 150 ft from road.

Red Hill Road, heading south

1.95 miles from CM1-crossroads starting point

Turnoff from MTI road into Red Hill Road.

2.0 miles

Starting to head down into a small wash crossing the road. E side (upstream): 20% disturbance; creosote bush, catclaw, forbs & grasses. W side (downstream): 50% disturbance; ocotilla (the only one I noticed on this route), creosote, palo verde, forbs & grasses. No malapai in wash area. Disturbance is individual vehicle tracks—tracked and possibly wheeled.

2.1 miles

Dropping into wash area proper. Road surface is low, at level of wash; little or no apparent checkdam effect on vegetation up and downstream.   Seems undisturbed. No malapai.

2.15 miles

A few tracked vehicle lines on west side near road.   Don't see tracks in channel proper but see some in general wash area to west.

2.2 miles

Wide channel area. A few jeep or car tracks along channel to the west. Generally little disturbance. Just ahead the channel runs parallel to a low but steep ridge running approx. east to west. The road rises up over this ridge. This is probably the area where they told us the tanks were not visible to the helicopters from the south.

2.25 miles

Have reached top of small ridge that borders the foregoing channel; now on a flattish upland area. A dirt trail splits off from Red Hill Rd toward the south, along the ridge. West side of Red Hill Rd: 30% disturbance out to ca. 800 ft from road.   E side: 50% disturbance out to ca 200 ft.

2.3 miles

Rolling stretch of road. Rill crosses from east to west. E side: 10% disturbance; old borrow pit with vegetation, including creosote bush.   W side: 5% disturbance.

2.35 miles

Channel crossing here.   This is the same place as my photo stop #7, where we took a picture of the saltcedar growing in the channel just east of the road, as an example of an invasive species (I think this was the only example we noticed out there.) Channel profile is very "lumpy"—probably disturbed from road and perhaps channel repair operations.   Road surface rises ca 2 ½ to 3 ft above bed of wash. Greater density and size of vegetation upstream versus downstream is visually apparent, presumably caused by greater water availability when the road slows the water flow and allows it to percolate. Deposition of water-borne fine particles in channel upstream (east), presumably deposited when the water was slowed by the higher roadbed. Vegetation upstream (east) includes the saltcedar and catclaw.   Vegetation downstream (west) includes creosote bush, white bursage, also road debris.   Surface soils are finer upstream in comparison with coarser surface downstream.

2.4 miles

Mostly out of wash area here, but not much malapai yet except off to the west starting at about 70 ft from road. Mostly a dusty surface.   Dust apparent on vegetation out to about 15 ft from road; does not seem especially dusty beyond that. West of road: 25% disturbance to ca 120 ft. East side: 15% obvious disturbance; but surface is rough and may indicate older disturbances there.

2.5 miles

Back into a wash channel—a broad channel running next to another small east-west ridge. Roadbed is at channel level; little effect on vegetation. Vegetation is plentiful on both sides of road.   No apparent disturbance. At base of ridge the road rises somewhat above the channel bed.   Upstream (east) is deposition of clays and fines—presumably deposited when water slowed at road crossing. Downstream (west) is coarse material including road debris.

2.55 miles

Broad upland area with rills cutting fairly deeply into it.   Both sides of road: 70% disturbance on near sides of rills, no visible disturbance on far sides.

2.6 miles

Small wash area; road crossing is at same level with wash.   No apparent vegetation effect from road, but deposited fine soils are visible upstream (east) but not downstream, indicating some effect from the road slowing the water flow.   No visible disturbance.

2.65 miles

Broad, flat upland area with malapai. E side: 10% disturbance, W side 30%.   Disturbance consists of very shallow vehicle traffic impact, leaving malapai surface fairly much in place but creating surface roughness rather than the typical table-flatness of the malapai.

2.7 miles

Similar to previous stop. E side: 60% disturbance, deeper and more typical of vehicle churning.   W side: 60% disturbance, shallow, similar to previous location.

2.75 miles

Two small channels cross the road here, with a hump between them. 1st channel: ca 2 ft rise of road above channel bed, but only slight visible difference in size and density of vegetation up and downstream. Fine soil deposition upstream (east); road debris downstream (west).

2.8 miles

Here is hump and 2nd channel. Malapai on hump. 40% disturbance both sides. Roadbed is slightly raised above channel; slight visible difference in vegetation density and size up and downstream.

2.9 miles

Arrive back at road crossing in front of CM1 hill. General description of area: flat, malapai, no washes, varied disturbance but in general about 80%. Tests were due to start any minute so I did not linger to survey this area in more detail.

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1.	S. G. Hildebrand	5.	ORNL Central Research Library
2-4.	ESD Library	6.	ORNL Laboratory Records–RC

EXTERNAL DISTRIBUTION

7. Robert W. Holst, SERDP Program Office, 901 N. Stuart St., Suite 303, Arlington, VA 22203

8-9. Valerie Morrill, U.S. Yuma Proving Ground, Attn: CSTE-DTE-YP-CD-C, Building 3021, Yuma, AZ, 85365-9107

10. Susan Walsh, SERDP Support Office, c/o HydroGeoLogic, Inc., 1155 Herndon Parkway, Suite 900, Herndon, VA, 20170

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