



# **Environmental Effects of Off-Highway Vehicles on Bureau of Land Management Lands: A Literature Synthesis, Annotated Bibliographies, Extensive Bibliographies, and Internet Resources**

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# Conversion Factors

## Inch/Pound to SI (International System of Units)

	<b>Multiply</b>	<b>By</b>	<b>To obtain</b>
<b>Length</b>			
	inch (in.)	2.54	centimeter (cm)
	inch (in.)	25.4	millimeter (mm)
	foot (ft)	0.3048	meter (m)
	mile (mi)	1.609	kilometer (km)
	yard (yd)	0.9144	meter (m)
<b>Area</b>			
	square foot (ft <sup>2</sup> )	929.0	square centimeter (cm <sup>2</sup> )
	square foot (ft <sup>2</sup> )	0.09290	square meter (m <sup>2</sup> )
	square inch (in <sup>2</sup> )	6.452	square centimeter (cm <sup>2</sup> )
	square mile (mi <sup>2</sup> )	2.590	square kilometer (km <sup>2</sup> )
<b>Volume</b>			
	cubic inch (in <sup>3</sup> )	16.39	cubic centimeter (cm <sup>3</sup> )
	cubic yard (yd <sup>3</sup> )	0.7646	cubic meter (m <sup>3</sup> )
<b>Mass</b>			
	ounce, avoirdupois (oz)	28.35	gram (g)
	pound, avoirdupois (lb)	0.4536	kilogram (kg)
	ton, short (2,000 lb)	0.9072	megagram (Mg)
	ton, long (2,240 lb)	1.016	megagram (Mg)

## SI to Inch/Pound (English System of Units)

	<b>Multiply</b>	<b>By</b>	<b>To obtain</b>
<b>Length</b>			
	centimeter (cm)	0.3937	inch (in.)
	millimeter (mm)	0.03937	inch (in.)
	meter (m)	3.281	foot (ft)
	kilometer (km)	0.6214	mile (mi)
	meter (m)	1.094	yard (yd)
<b>Area</b>			
	square centimeter (cm <sup>2</sup> )	0.001076	square foot (ft <sup>2</sup> )
	square meter (m <sup>2</sup> )	10.76	square foot (ft <sup>2</sup> )
	square centimeter (cm <sup>2</sup> )	0.1550	square inch (in <sup>2</sup> )
	square kilometer (km <sup>2</sup> )	0.3861	square mile (mi <sup>2</sup> )
<b>Volume</b>			
	cubic centimeter (cm <sup>3</sup> )	0.06102	cubic inch (in <sup>3</sup> )
	cubic meter (m <sup>3</sup> )	1.308	cubic yard (yd <sup>3</sup> )
<b>Mass</b>			
	gram (g)	0.03527	ounce, avoirdupois (oz)
	kilogram (kg)	2.205	Pound, avoirdupois (lb)
	megagram (Mg)	1.102	ton, short (2,000 lb)
	megagram (Mg)	0.9842	ton, long (2,240 lb)



## Glossary

**ATV (All-Terrain Vehicle)** Small, motorized 3- or 4-wheeled vehicles specifically designed for off-road use. The American National Standards Institute (ANSI) further defines an ATV as a vehicle that travels on low-pressure tires, with a seat that is straddled by the operator, and with handlebars for steering control. By the current ANSI definition, it is intended for use by a single operator, although a change to include 2-seaters (in tandem) is under consideration. Herein, the definition of ATV coincides with the description above and does not include passenger vehicles, including sport-utility vehicles or 4-wheel-drive jeeps.

**fugitive dust** Dust raised by mechanical (anthropogenic) disturbance of granular material exposed to and becoming suspended in the air, then carried by wind. Arises from “nonpoint” sources—such as unpaved roads, agricultural tilling operations, aggregate storage piles, and heavy construction—rather than “point” sources—such as confined flow streams discharged to the atmosphere from a stack, vent, or pipe.

**indicator threshold** For a given land health indicator (or set of indicators), the value(s) at or above which management action may be triggered or required.

**land health** The condition of natural resource attributes, including soils and site stability, hydrologic function, and biotic integrity.

**OHV** Defined herein as any civilian off-highway vehicle, including motorcycles, motorized dirt bikes, ATVs (see definition above), snowmobiles, dune buggies, 4-wheel-drive jeeps, sport-utility vehicles, and any other civilian vehicles capable of off-highway, terrestrial travel (including utility vehicles [UTVs] and ATVs with more than 4 wheels).

**OHV route** Defined herein as any unpaved route created for OHV travel, including single-track paths or trails, two-tracks, and unimproved or improved dirt/gravel roads. Herein, this term is also applied to “rogue” (undesignated or unauthorized) routes created by OHV users in closed or limited areas.

**population dynamics** Herein, used broadly to include wildlife or vegetation population size, density, and/or distribution (both spatial and temporal); rates of birth/germination, death, and/or survivorship; population gender/age-class structure; population genetics; and/or the rates/directions of change in all these parameters.

**right-of-way habitat** Habitat provided within the legal description of a given transportation corridor.

**sink population** For a given metapopulation, a population sink is a local area or habitat where the local population’s reproductive rate is lower than the required replacement rate (in other words, a sink population is eventually extirpated without immigration of individuals from other areas). Population sinks often occur where there is excessive predation pressure and/or poor habitat quality.

**source population** For a given metapopulation, a population source is a local area or habitat where the local population’s reproductive rate is greater than the required replacement rate. Excess individuals produced from a source population may emigrate to join sink populations, thereby keeping the sink populations from becoming extirpated.

**stream order** A stream’s order is determined by its confluence with other streams: first-order streams are headwaters, the confluence of two first-order streams forms a second-order stream, the confluence of two second-order streams forms a third-order stream, and so on.

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## Executive Summary

This report and its associated appendixes compile and synthesize the results of a comprehensive literature and Internet search conducted in May 2006. The literature search was undertaken to uncover information regarding the effects of off-highway vehicle (OHV) use on land health, or “natural resource attributes,” and included databases archiving information from before OHVs came into existence to May 2006. Information pertaining to socioeconomic implications of OHV activities is included as well. The literature and Internet searches yielded approximately 700 peer-reviewed papers, magazine articles, agency and non-governmental reports, and internet websites regarding effects of OHV use as they relate to the Bureau of Land Management’s (BLM) standards of land health. Discussions regarding OHV effects are followed by brief syntheses of potential indicators of OHV effects, as well as OHV-effects mitigation, site-restoration techniques, and research needs.

## Terminology Used in This Report

The BLM has definitions for several road and trail types; however, the OHV literature often uses somewhat different definitions. Whereas all terms are useful within their own contexts, herein the general term “OHV routes” is used to simplify discussions concerning all types of unpaved roads and trails, whether designated or unauthorized, and “roads” or “highways” are used to simplify discussions concerning paved roads. The definition of OHV also varies by agency and author, and to simplify discussions herein, OHV may include off-highway motorbikes, ATVs, dune buggies, snowmobiles, 4-wheel drive jeeps, motorcycles, some types of 4-wheel drive automobiles (including sport-utility vehicles), and any other civilian vehicle specifically designed for off-road travel. OHV type or route/road type are specified if a given discussion warrants and if the literature cited in that discussion specified OHV type or route/road type.

## How to Use This Report

Major sections of this document comprise a “manager’s report,” which includes a literature synthesis and related discussions of (1) OHV effects on natural resource attributes and socioeconomics; (2) indicators described in the literature to evaluate/monitor OHV effects on natural resource attributes and could serve as potential indicators in future research or monitoring programs; (3) mitigation and site-restoration techniques used for OHV-use areas; and (4) research and monitoring needs pertaining to OHV-effects. This document also includes extensive bibliographies pertaining to OHV effects on natural resources. It is recommended that readers focus first on the manager’s report, as it provides the basic understanding of OHV effects and potential approaches to researching, monitoring, and/or managing OHV effects. Reading the Executive Summary, the summaries provided in each section, and the conclusion may suffice for those seeking a quick overview. **To facilitate a rapid review, section summaries are placed at the beginning of their respective sections and do not contain in-text citations. For a more in-depth review (with in-text citations), the entire manager’s report should be read.** Appendix 1 provides the extensive bibliographies, and Appendix 2 details the literature/Internet search methods and summarizes the search results (including tables and graphs).

## **OHV Effects**

### **OHV Effects on Soils and Watersheds**

The primary effects of OHV activity on soils and overall watershed function include altered soil structure (soil compaction in particular), destruction of soil crusts (biotic and abiotic) and desert pavement (fine gravel surfaces) that would otherwise stabilize soils, and soil erosion. Indicators of soil compaction discussed in the OHV effects literature include soil bulk density (weight per unit of volume), soil strength (the soil's resistance to deforming forces), and soil permeability (the rate at which water or air infiltrate soil). Generally, soil bulk density and strength increase with compaction, whereas permeability decreases with compaction. As soil compaction increases, the soil's ability to support vegetation diminishes because the resulting increases in soil strength and changes in soil structure (loss of porosity) inhibit the growth of root systems and reduce infiltration of water. As vegetative cover, water infiltration, and soil stabilizing crusts are diminished or disrupted, the precipitation runoff rates increase, further accelerating rates of soil erosion.

### **OHV Effects on Vegetation**

Plants are affected by OHV activities in several ways. As implied above, soil compaction affects plant growth by reducing moisture availability and precluding adequate taproot penetration to deeper soil horizons. In turn, the size and abundance of native plants may be reduced. Above-ground portions of plants also may be reduced through breakage or crushing, potentially leading to reductions in photosynthetic capacity, poor reproduction, and diminished litter cover. Likewise, blankets of fugitive dust raised by OHV traffic can disrupt photosynthetic processes, thereby suppressing plant growth and vigor, especially along OHV routes. In turn, reduced vegetation cover may permit invasive and/or non-native plants—particularly shallow-rooted annual grasses and early successional species capable of rapid establishment and growth—to spread and dominate the plant community, thus diminishing overall endemic biodiversity.

### **OHV Effects on Wildlife and Habitats: Native, Threatened, and Endangered Species**

Habitats for native plants and animals, including endangered and threatened species, are impacted by OHVs in several ways. A salient effect is habitat fragmentation and reduced habitat connectivity as OHV roads and trails proliferate across the landscape. Reduced habitat connectivity may disrupt plant and animal movement and dispersal, resulting in altered population dynamics and reduced potential for recolonization if a species is extirpated from a given habitat fragment. Wildlife is also directly affected by excessive noise (decibel levels/noise durations well above those of typical background noise) and other perturbations associated with OHV activities. Disturbance effects range from physiological impacts—including stress and mortality due to breakage of nest-supporting vegetation, collapsed burrows, inner ear bleeding, and vehicle-animal collisions—to altered behaviors and population distribution/dispersal patterns, which can lead to declines in local population size, survivorship, and productivity.

### **OHV Effects on Water Quality**

The effects of OHV activities on water quality can include sedimentation (deposited solids), turbidity (suspended solids), and pollutants within affected watersheds. Sedimentation increases because compacted soils, disrupted soil crusts, and reduced vegetation cover can lead to increased amounts and velocities of runoff; in turn, this accelerates the rates at which

sediments and other debris are eroded from OHV-use areas and flushed to aquatic systems downslope. Pollutants associated with deposition of OHV emissions and spills of petroleum products may be adsorbed to sediments, absorbed by plant material, or dissolved in runoff; once mobilized, these contaminants may enter aquatic systems.

### **OHV Effects on Air Quality**

Air quality is affected when OHV traffic raises fugitive dust and emits by-products of combustion. Because wind can disperse suspended particulates over long distances, dust raised by OHV traffic can blanket plant foliage and disperse dust-adsorbed contaminants well beyond a given OHV-use area. Primary combustion by-products potentially affecting air quality in OHV-use areas include (but are not limited to) polycyclic aromatic hydrocarbons, sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), and ozone (O<sub>3</sub>). Although leaded gasoline has not been used in the United States since 1996, lead emissions deposited prior to the ban on leaded gasoline may persist for decades and continue impacting ecosystems as wind and water erosion continue to mobilize lead and other contaminants downwind (or downslope) of contaminated soils.

### **Socioeconomic Implications of OHV Use**

For the purposes of this document, the socioeconomics of OHV use include (1) OHV user demands, concerns, and attitudes; (2) the economic effects of OHV use on communities near OHV-use areas; (3) and the effects of OHV use on other land users. Although not one of BLM's land health considerations, the socioeconomic implications of OHV use have significant direct and indirect effects on land health. As the popularity of OHV recreation increases, socioeconomic factors become increasingly important considerations in understanding and mitigating the overall effects of OHV use on land health. OHV recreation can have significant economic value to local communities where and when OHV use is popular; however, the economic costs to those communities remain unknown. OHV use also can lead to conflicts among different land users—both OHV users and people seeking non-motorized forms of recreation—within OHV-use areas and nearby areas. Crowding of designated OHV areas may encourage unauthorized use in closed areas, and adjacent or overlapping use types may cause dissatisfaction or discourage recreation altogether, which can diminish public support for land-management programs.

### **Potential Indicators (Both Direct and Indirect) for Evaluating and Monitoring OHV Effects**

#### **Soil Health and Watershed Condition**

- Soil strength
- Soil bulk density
- Soil permeability (rates of air and water infiltration)
- Erosion rate
- Level of sedimentation or turbidity in wetlands
- Surface changes (for example, gully erosion)
- Presence/condition of soil crusts

#### **Vegetation Health**

- Plant community composition (including species and structural diversity, ratio of native to non-native or invasive species)
- Abundance of individuals and/or stem density

- Percent vegetation cover
- Plant size
- Growth rate
- Biomass

**Habitat Condition and Health of Wildlife Populations** (including indirect indicators)

- Habitat patch size and connectivity
- Community composition (including species diversity, ratio of native to non-native or invasive species)
- Population size, density, and trend
- Spatiotemporal distribution of populations
- Survivorship and mortality rates
- Productivity and body mass
- Age-class and gender structure
- Frequency of OHVs passing through a given area and associated wildlife mortalities rates
- Road or trail type and width
- Level (decibels), duration, and timing of traffic noise

**Water Quality**

- Sedimentation rate
- Levels of turbidity and suspended solids
- Contaminant levels, including petroleum-derived compounds from spills and emissions, such as benzene; ethylbenzene; m-, p-, and o-xylene; toluene; 1,3-butadiene; and lead

**Air Quality**

- Level of dust particulates
- Particulate levels of OHV emission by-products, such as polycyclic aromatic hydrocarbons, aldehydes, carbon monoxide, nitrogen oxides, ozone, and sulfur oxides

**Socioeconomics**

- User satisfaction with recreation experiences
- User compliance with OHV (or other) regulations
- User knowledge regarding effects of recreation activities on various aspects of land health
- Distribution and intensity of OHV versus non-motorized recreation and other land uses
- Extent to which unauthorized trails are created and damage to vegetation occurs
- Trends in local economic indicators associated with OHV and non-motorized recreation and other land uses, such as sales of camping equipment, gasoline, restaurants, lodging facilities

**Mitigation and Site-Restoration Techniques**

Balancing OHV-user preferences with protecting land health and the needs of other land users requires careful study and planning, as well as appropriate management strategies. Prior planning for locating OHV areas before they are opened to the public can preclude undesirable

effects of OHV use and costly site restoration. Once a site has been used, however, trail/area closures, signage, and other visual cues, as well as enforcement and limiting visitor numbers through “rationing,” are among the tools used to preclude additional effects.

Because habitat fragmentation is particularly difficult to repair, planning and management designed to maintain habitat connectivity are crucial to minimize fragmentation. Variation in impacts requires various restoration techniques. Whereas a single OHV pass on a xeric landscape may cause long-lasting damage, a similar single pass on a mesic landscape may require no treatment at all. Restoration approaches may include replacing native soil where erosion has removed the topsoil and exposed the underlying bedrock, seeding with indigenous plants, inoculating soils with native microbes and mycorrhizae, scarifying, and/or mulching. Ultimately, the success of such measures depends on the nature and intensity of the disturbance, topography, soil type, climate, and the ability of land managers to enforce closures and prevent the proliferation of new routes.

### **Monitoring and Research Needs to Support OHV Management Decisions**

Elucidating OHV impacts on soils and watersheds, vegetation, wildlife and their habitats, water and air quality, and/or socioeconomics, whether through monitoring or experimental research studies, will require careful planning and appropriate, rigorous study design. Results of many past ecological studies on the effects of OHVs may be regarded as preliminary, particularly for those that lacked comparable treatment and control sites and site replication. Overall, the reliability and value of monitoring and research results would increase significantly by including a broad range of spatial and temporal scales—from microhabitat to landscape or ecosystem scale, and from short-term (seasonal) to long-term (decades)—within the full range of impacted habitat types represented on BLM lands. The full array of site types also needs evaluation, including designated OHV-use sites, undesignated (rogue) OHV-use sites, unused areas, and restoration sites. Multiple- and simultaneous-assessment techniques that take advantage (and push the advancement) of existing and emerging technologies are needed to fully represent the scale and diversity of OHV impacts on the abiotic and biotic components of affected lands and communities, and to ascertain indicator thresholds as they pertain to BLM’s land health standards. More specifically, monitoring and research needs pertaining to OHV use and impacts include (but are not limited to)

- well-designed monitoring programs and experimental studies that incorporate planned comparisons of treatment (OHV-impacted) and control (unimpacted/reference) sites;
- before and after OHV-impact studies;
- studies at various spatial and temporal scales across all impacted habitat types;
- studies on habitat fragmentation and road-edge effects caused by OHV activities;
- studies on various gradients in OHV disturbance at various distances from OHV routes;
- studies to improve the understanding of the physical and chemical dynamics of soil compaction;
- studies evaluating the effects of erosion, sedimentation, and turbidity at both local (immediately downslope of OHV-affected sites) and landscape (throughout impacted watersheds) scales;
- studies of OHV effects on plant and animal population dynamics;
- simultaneous evaluations of wildlife responses and OHV route-specific variables;
- improvements in techniques for successful site restoration;

- improvements in techniques and technologies for assessing OHV impacts over large areas and long periods of time;
- effectiveness evaluations of various techniques to manage OHV use and its ecological and socioeconomic effects while simultaneously providing the greatest satisfaction among all land users; and
- studies that determine the economic and sociological costs of OHV use.



# 1.0 Introduction

## 1.1 Issue Context: Bureau of Land Management Land Health and Off-highway Vehicle Use

### 1.1.1 Bureau of Land Management Land Health Standards

In the mid-1990s, *Rangeland Health: New Methods to Classify, Inventory, and Monitor Rangelands* was published to examine the scientific basis and success of methods used by federal agencies to inventory, classify, and monitor rangelands, and to make recommendations for improvements to these methods (Committee on Rangeland Classification, Board on Agriculture, and National Research Council, 1994). Therein, rangeland health was defined as "...the degree to which the integrity of the soil and the ecological processes of rangeland ecosystems are sustained." In 2001, the BLM published *Rangeland Health Standards*, a process framework for assessing rangeland health via interdisciplinary teams that, at a minimum, would evaluate (1) watershed function; (2) nutrient cycling and energy flow; (3) water quality; (4) habitat for endangered, threatened, proposed, candidate, or special status species; and (5) habitat quality for native plant and animal populations (U.S. Bureau of Land Management, 2001). Subsequently, it was clarified that the term "rangeland" is interchangeable with "land" and that "... 'the rangeland health standards' really apply to the condition of the land itself regardless of the uses that may influence the health of that land" (U.S. Bureau of Land Management, 2007). In other words, the standards for rangeland health apply to all BLM lands, whether used for grazing, off-highway vehicle (OHV) recreation, or any other use permitted to occur on BLM lands.

The standards of rangeland health establish minimum resource conditions that must be achieved and maintained to ensure the "proper functioning condition" (see Barrett and others, 1995)—both physical and biological—and sustainability of BLM lands. These standards, however, must be relative to the native conditions for a given "reference site," as native conditions vary widely among sites on BLM lands. For example, the BLM defines healthy soils in northwest California as "exhibit[ing] characteristics of infiltration, fertility, permeability rates, and other functional and physical characteristics that are appropriate to soil type, climate, desired plant community, and land form" (personal communication from M. Karl to V. Josupait, U.S. Bureau of Land Management, Denver, Colorado, May 2001).

The BLM's technical reference on *Interpreting Indicators of Rangeland Health* recognizes three broad categories of natural resource attributes for assessing land health: (1) soils and site stability, (2) hydrologic function, and (3) biotic integrity (Pellant and others, 2005). Relative to off-highway vehicle (OHV) impacts on ecosystem health, soil/site stability and hydrologic or watershed function pertain (but are not limited) to erosion and extent of surface changes and patterns of water flow, including infiltration. Biotic integrity pertains to community structure and functionality of plants. Within these three categories, overall land health is qualitatively assessed via 17 parameters (or indicators) that indicate the presence, number, extent, percent, and/or depth or height of (1) rills, (2) water flow patterns, (3) erosional pedestals/terraces, (4) bare ground, (5) gullies and gully erosion, (6) wind scoured blowouts and/or depositional areas, (7) litter movement, (8) soil surface resistance to erosion, (9) soil surface structure and content of soil organic matter (SOM), (10) effect of plant community composition and spatial distribution on infiltration and runoff, (11) compaction layer, (12) dominance hierarchy of functional/structural groups in plant communities, (13) mortality and

decadence among plant functional groups, (14) litter cover, (15) expected above-ground annual production, (16) potential invasive species, and (17) perennial plant reproductive capability (Pellant and others, 2005). Many of the indicators listed above may be assessed in terms of the condition and extent of abiotic (chemical) and biotic soil crusts, and soil surfaces of small stones known as “desert pavement,” as they help stabilize soils and/or cycle nutrients through the system. Indicators 1-11 largely pertain to soil/site stability and hydrologic/watershed function, whereas parameters 12-17 are primarily indicators of biotic integrity, although there is overlap among the two groups.

### **1.1.2 Increasing OHV Use**

An important factor affecting the health of BLM lands is the use of OHVs. In 1993, 2,920,000 all-terrain vehicles (ATVs) and off-highway motorcycles were estimated to be in use (Cordell and others, 2005). Between 1995 and 2003, sales of ATVs and off-highway motorcycles tripled, increasing the number of ATVs and off-highway motorcycles in use to 8,010,000 (Cordell and others, 2005). Because the popularity of OHV-based recreation is relatively recent and still increasing (see Matchett and others, 2004), the full range of short- and long-term impacts has yet to be fully realized or understood. Overall, it is clear that OHV use on public lands is and will continue to be an important management issue.

## **1.2 Objectives, Scope, Organization, and Use of This Report**

### **1.2.1 Objectives**

The objectives of this report are twofold. This first is to synthesize the results of a comprehensive literature search on what is currently known about the effects of OHV activities as they relate to the BLM’s land health standards (U.S. Bureau of Land Management, 2001). These discussions include socioeconomic implications of OHV use—including preferences of OHV users, effects of OHV activities on other land users, and the economic impacts of OHV recreation on local economies—because understanding these factors and incorporating that knowledge into management plans and policies will be crucial to management success. The second objective is to discuss the indicators of land health and socioeconomics described in the OHV effects literature, as they have potential usefulness for evaluating or monitoring lands and land users affected by OHV use. This report also contains brief overviews of mitigation approaches, site-restoration techniques, and monitoring and research needs described in the OHV-effects literature.

### **1.2.2 Geographical Scope**

Although the vast majority of literature and other sources consulted address OHV impacts on ecosystems in the western United States, there are a number of useful references that address OHV use or impacts of roads in other parts of the United States and in other countries. Some of these sources have been included to provide additional information not provided elsewhere and/or to broaden the scope and relevance of this document.

### **1.2.3 Organization**

The main body of this document—referred to herein as the “manager’s report” (Executive Summary and Sections 1-7)—includes the literature synthesis of OHV effects; annotated bibliographies that typify the body of research regarding effects of OHV activities on BLM’s land health standards; sections regarding indicators of OHV effects, mitigation and site-

restoration techniques, and monitoring and research needs; and a listing of all literature cited in the manager's report. To facilitate the logical flow of information, the natural resource attributes addressed in BLM's land health standards serve as the underlying organizational structure of all major sections in the report, as indicated by parallel subsection headings pertaining to (1) soils and watersheds, (2) vegetation, (3) habitat for native plants and wildlife, (4) water quality, and (5) air quality. Although not part of the BLM's land health agenda, a sixth subsection has been included in each major section to address the socioeconomic considerations of OHV use, because, ultimately, it is socioeconomic factors (including conflicts among land users, preferences of OHV users, and economics of OHV use) that drive changes in overall land health.

#### 1.2.4 Tips on Navigating This Document

It is recommended that readers focus first on the manager's report, as it provides the basic understanding of OHV effects and possible indicators to use in research, monitoring, and/or management programs. Reading the Executive Summary, subsection summaries, and the overall conclusion may suffice for those seeking a quick overview. **For quick and easy reference, subsection summaries on OHV effects are placed at the top of their respective subsections. In-text citations were purposely left out of all summaries to enhance readability. For a more in-depth, fully cited review, reading the entire manager's report is recommended.**

Appendixes 1 and 2 provide further information and more extensive resources for those needing high levels of detail. The Extensive Bibliographies (Appendix 1) includes the approximately 700 publications and reports uncovered through the literature search (from 1960 to May 2006) that pertain to effects of OHV use. Appendix 2 details the literature- and Internet-search methods and provides tabular and graphical summaries of literature, websites, and associated resources, as they pertain to OHV effects on natural resources and related policies.

### 1.3 Definitions of OHV Routes/Roads, Vehicles, and Activities

#### 1.3.1 Definitions of Roads and Trails Used in This Report

BLM's *Roads and Trails Terminology* document (U.S. Bureau of Land Management, 2006) defines (1) a road as "a linear route declared a road by the owner, managed for use by low-clearance vehicles having four or more wheels, and maintained for regular and continuous use;" (2) a primitive road as "a linear route managed for use by four-wheel drive or high-clearance vehicles;" and (3) a trail as "a linear route managed for human-powered, stock, or off-highway vehicle forms of transportation or for historical or heritage values." Bolling and Walker (2000) offer more detailed definitions of unpaved roads and trails: (1) graded, improved roads are those from which the topsoil has been removed by bulldozer and characterized by the presence of lateral berms; (2) unimproved roads are those not graded consistently; (3) jeep trails are four-wheel drive tracks impacted only by vehicular traffic and generally characterized by a center berm; and (4) single tracks are severely compacted trails generated by OHVs.

The literature includes numerous reviews on the ecological effects of paved as well as unpaved roads (see Andrews, 1990; Forman and Alexander, 1998; Spellerberg, 1998; Trombulak and Frissell, 2000). Ecosystems of the West, however, are especially vulnerable to OHV-related activities on unpaved (gravel or dirt) roads and trails due to the effects they impose on soils and vegetation, which may take centuries to recover (Webb, 1982; Lovich and Bainbridge, 1999). Furthermore, unpaved roads comprise the majority of OHV routes used throughout public lands in the western United States. Therefore, the primary considerations in this report are unpaved

roads and trails. References and discussions regarding effects of paved roads are not entirely excluded, however, as they often inform the potential scope of OHV effects not otherwise addressed. When necessary to do so, the type of road is specified.

All of terms described above for roads and trails are useful within their own contexts, but to distinguish between them and those used in the OHV literature would unnecessarily complicate discussions herein. Therefore, except where there is a need to specify in more detail, unpaved roads, primitive roads, and unpaved trails, are referred to as “routes,” regardless of their intended purpose or how they are maintained. “Routes” also include unauthorized or “rogue” roads and trails created by OHV users traveling off officially designated roads, primitive roads, and trails. Paved roads are referred to as “roads.”

### **1.3.2 Definitions of OHVs and OHV Activities Used in This Report**

BLM’s *Roads and Trails Terminology* document (U.S. Bureau of Land Management, 2006) defines an OHV as “any motorized vehicle capable of—or designated for—travel on or immediately over land, water, or other natural terrain” (excluding nonamphibious registered motorboats; military, fire, emergency, or law enforcement vehicles used for emergency purposes; official vehicles used expressly by an authorized officer; and military vehicles). Cordell and others (2005) further specify that OHVs may include motorcycles and off-highway motorbikes, ATVs, dune buggies, snowmobiles, most 4-wheel drive automobiles (jeeps, sport utility vehicles), and any other civilian vehicle specifically designed for off-road travel. For the purpose of this document, OHV is defined in accordance with BLM terminology and includes those vehicles listed by Cordell and others (2005), as well as utility vehicles (UTVs) and ATVs with more than 4 wheels.

There are numerous activities and outcomes directly and indirectly associated with OHV use. To simplify discussions of OHV activities herein, the term “OHV activities” largely refers to driving OHVs for recreation. In certain contexts, OHV activities also may include driving and parking vehicles that tow trailers carrying OHVs and loading and unloading OHVs from trailers. Whereas the use of 4-wheel drive jeeps, automobiles, and sport utility vehicles is largely restricted to unpaved roads and jeep trails, the effect of ATVs and off-highway motorcycles extends well beyond them to double- and single-track trails, as well as unauthorized roads and trails. Thus, “OHV activities” may include driving OHVs on authorized roads/routes and on (or creating) unauthorized routes.

## **2.0 Effects of OHV Travel on Natural Resource Attributes and Socioeconomics**

### **2.1 Scale and Patterns of OHV Activities and Their Effects**

Temporal and spatial scales are crucial considerations when evaluating or monitoring effects of any factor on ecosystems (Noon, 2003; Ringold and others, 2003). In discussing OHV effects on desert ecosystems, Brooks and Lair (2005) and Matchett and others (2004) describe the impacts of OHV activities at various spatial and temporal scales. At the highly localized spatial scale, one might find soil compaction taking place within the confines of a single OHV route, the effects of which might be limited to poor infiltration of water and reduced plant cover in the route itself. Brooks and Lair (2005) go on to explain, however, that the cumulative impacts of any one effect at many sites can result in impacts at much greater scales. For example, if

networks of OHV routes criss-cross large areas, the habitat connectivity that previously facilitated animal movements within that landscape may be disrupted (Forman and others, 2003: p. 129-134). Similarly, a single pass by one OHV probably has negligible effects on animal distributions, but if OHV traffic is intense and chronic, animal densities may decline (Reijnen and others, 1995, 1997) as cumulative impacts of this one effect occurring at many sites across a landscape disrupt entire populations. Furthermore, any **direct** effect of OHV use is also likely to have **indirect** effects that go beyond the site of disturbance. For example, reduced plant cover (direct effect) can result in greater rates of erosion in and around an OHV route, which, in turn, might increase sedimentation and turbidity in wetlands downslope of the route (indirect effect). Overall, Brooks and Lair (2005) conclude that effects of OHV use need to be evaluated at appropriate scales, which must take into account the scale at which OHV activities and ecosystem responses occur (Brooks and Lair, 2005). Overall, most, if not all, effects of OHV activities described in sections 2.2 through 2.6 can occur from the very localized and/or ephemeral scale to the landscape and/or long-term scale. By the same token, any direct effect may have a number of indirect effects, the magnitude of which may depend on the spatial and temporal scales at which a direct effect occurs.

At an OHV site in California, Matchett and others (2004) classified OHV routes in terms that describe intensity and pattern of use. First, OHV lines (routes) were categorized as either *dirt* (lines most likely created for or by OHV use) or as *wash* (lines most likely created by water flow, but possibly used by OHVs). They went on to define levels of OHV use that also imply patterns of use: (1) densely tracked reticulate (OHV lines evident in a web-like pattern, but too dense and overlapping to distinguish individually); (2) densely tracked hill-climb (OHV lines evident on slopes, but too dense and overlapping to distinguish individually); (3) densely tracked intersection (OHV lines evident at intersections, but too dense and overlapping to distinguish individually); (4) densely tracked right-of-way (OHV lines evident near pipelines, transmission lines, and highway right-of-ways, but too dense and overlapping to distinguish individually); (5) densely tracked wash (OHV lines evident within washes, but too dense and overlapping to distinguish individually); (6) denuded hill-climb (OHV lines not readily evident on hill-climbs, but the preponderance of densely tracked areas in the vicinity indicate that OHV use was probably high within that area); and (7) denuded staging (OHV routes not readily evident in relatively flat camping areas, but the preponderance of densely tracked areas in the vicinity indicated that OHV use was probably high within that area) (Matchett and others, 2004). Overall, these categories indicate that OHV use often entails many criss-crossing routes as opposed to a single route. They also point out that OHV use may be heaviest on slopes, along right-of-ways, in washes, and in the vicinity of camping facilities.

## **2.2 OHV Effects on Soils and Watersheds**

### **2.2.1 Section Summary**

Important effects of OHV activities on soils and watershed function include soil compaction, diminished water infiltration, diminished presence and impaired function of soil stabilizers (biotic and abiotic crusts, desert pavement), and accelerated erosion rates. Compacted soil inhibits infiltration of precipitation. In turn, soil moisture available to vegetation is diminished, volumes and velocities of precipitation runoff increase, and soil erosion accelerates, leading to the formation of gullies and other surface changes. Additionally, soil compaction may inhibit root growth among plants, in which case organic matter, litter, soil fertility, and vegetative cover are diminished, further exacerbating the soil's susceptibility to erosion. Where

biotic and chemical crusts or other soil stabilizers are disturbed or destroyed, soil erosion from water and wind may increase beyond rates found in undisturbed sites with similar soils and conditions; nutrient-cycling processes also are likely to be disrupted, potentially leading to declines in soil fertility.

### 2.2.2 Soil Compaction and Reduced Water Infiltration

One of the most common and important effects of OHV activities is soil compaction (Liddle, 1997), which diminishes water infiltration, destroys soil stabilizers (biotic and abiotic crusts, desert pavement), and promotes greater rates of erosion from water and wind. In turn, soil moisture available for plant growth is diminished, precipitation runoff increases in volume and velocity, and soil erosion accelerates, which leads to surface changes, including the formation of rills, gullies, terracettes, and pedestals (Webb and others, 1978; Iverson and others, 1981; Webb, 1982; Hinckley and others, 1983; Wilshire, 1983b). The extent of soil compaction may be measured in terms of soil bulk density, soil strength, and/or permeability. Soil bulk density, calculated as oven-dried soil weight per unit of volume, is typically expressed as  $\text{g/cm}^3$  or  $\text{g/cc}$ . Soil strength, measured as the soil's resistance to deforming forces—or the amount of energy required to break apart aggregates or move implements through the soil—is typically expressed as  $\text{kg/cm}^2$  or pounds per square inch (PSI). Soil permeability is the rate at which water (or air) infiltrates the soil, expressed as  $\text{cm/hr}$  or  $\text{inches/hr}$  (Leung and Meyer, 2004). Generally, soil bulk density and strength increase with increasing compaction, whereas permeability decreases with increasing compaction (Adams and others, 1982; Webb, 1982; Cole, 1990).

Important factors affecting a soil's susceptibility to compaction include its (1) texture (relative proportions of sand, silt, and clay); (2) structure (the grouping of sand, silt, and clay particles into aggregates), including its porosity (a measure of pore space, which affects the amount of air or water a soil can hold) and aggregate stability (the ability of soil aggregates to resist disruption from outside forces—water in particular); (3) type (series) and depth; and (4) antecedent moisture (the soil's water content prior to compaction). Sandy or clayey soils relatively uniform in texture and structure are less vulnerable to compaction than loamy sands or coarse-textured, gravelly soils characterized by variability in particle size (Lovich and Bainbridge, 1999). In addition, soils with greater water content are more susceptible to compaction than those containing less moisture (Webb, 1982), although even in semi-arid and arid lands soil compaction is problematic because the texture of these soils is slow to recover (Webb, 1982) through natural soil-loosening processes (including shrinking, swelling, drying, wetting, freezing, and thawing).

As the number of vehicle “passes” (one pass is the equivalent of one OHV passing over a given area one time) increases, soil bulk density and soil strength increase and permeability (as indicated by water infiltration rate) decreases (Lovich and Bainbridge, 1999). Soil compaction may become evident after only a few vehicle passes. In fact, Iverson and others (1981) found that soil bulk density increased logarithmically with the number of vehicle passes. Similarly, Adams and others (1982) report that soil strength on routes subjected to a single vehicle pass was 5.3 to 28.4  $\text{kg/cm}^2$  (75.366 to 403.848 PSI) greater (depending on the percent soil moisture) than that of nearby undisturbed soils; after 10 to 20 passes, soil strength was too great (impenetrable) to measure with a penetrometer, indicating that a few passes were enough to cause soil “cementation.” After initial disturbance, the effects of soil compaction can persist for years, even centuries, before natural soil-loosening processes can restore the soil's texture (Webb and Wilshire, 1980; Webb, 1982; Froehlich and others, 1985; Prose, 1985; Lovich and Bainbridge, 1999). For example, one year after impact, a one-pass trail was still faintly visible, as indicated

by slightly more surface gravel and growth of annual plants (the first to grow in disturbed sites) than on surrounding land, and trails impacted by 100 and 200 passes had notable side berms (Prose, 1985).

Other effects of soil compaction include changes to soil horizons and increased compaction in deeper strata. The OHV traffic associated with the annual Johnson Valley-Parker OHV race (1980-1983) near Joshua Tree National Park on the Colorado River compacted 2 to 5 cm (0.8 to 2.0 in) of the underlying vesicular soil horizon (composed of fined-grained, wind-blown material occurring about 20 cm [7.9 in] deep near surface soil horizons, often immediately under desert pavement, and characterized by small pores, or vesicles, of air space; typical of arid regions) and caused excavation (mechanical erosion) of the A and B soil horizons to depths of 20 cm (7.9 in) (Wilshire, 1983a). Prose (1985) found that resistance (to a penetrometer) of soil affected by military maneuvers (including tanks, tracked equipment and personnel carriers, and support vehicles) was 50 percent greater than that of undisturbed soils. Overall, traffic typically causes significant changes to soils, which may take years, if not decades, to recover.

### 2.2.3 Effects on Soil Stabilizers and Rates of Soil Erosion

A significant effect of soil compaction is the soil's inability to support vegetation after disturbance, thus increasing its susceptibility to erosion (Webb and others, 1978). Soil erosion resulting from soil compaction is caused by two main factors (Hinckley and others, 1983): reduced infiltration rates and destruction of soil stabilizers. Infiltration of water into soils depends, to a large extent, on the soil's porosity, which is reduced by compaction. Soil stabilizers, which are characteristic of undisturbed desert substrates, may include cryptobiotic crusts of lichen, fungi, bacteria, mosses, and/or algae; chemical or mechanical crusts (thin upper coating of clay particles oriented parallel to the surface); and desert pavements (closely packed, interlocking fragments of pebble- and/or cobble-sized rocks from which fine-grained materials have been removed by wind or water erosion) (Lovich and Bainbridge, 1999). Cryptobiotic organisms facilitate accumulation of organic materials and nutrients, including nitrogen and carbon, thereby increasing soil fertility (Johansen, 1993). Since they occur in the soil's upper layer, they also promote water infiltration and enhance retention of soil moisture (Belnap and Gardner, 1993). Their proximity to the surface, however, makes them susceptible to destruction by vehicular and foot traffic.

Cole (1990) documented destruction of cryptogamic soil crusts after only 15 passes by hikers wearing lug-soled boots. Traffic from the Johnson Valley-Parker OHV race mentioned in section 2.2.2 not only destroyed the vesicular soil horizon, it destroyed the overlying desert pavement (Wilshire, 1983a). Webb (1982), who evaluated soil surfaces (shape; another measure of soil compaction) after 1, 10, 100, and 200 motorcycle passes, found changes occurring after the first few passes, although the effects of subsequent passes were more severe due to their cumulative effects: routes subjected to 100 and 200 passes were characterized by berms and lateral edges, and route midlines were 10-30 mm below the level of surrounding undisturbed ground. Once damaged or destroyed, it may take 300-500 years per inch for soil stabilizers to recover or return to their original state (Hudson, 1971).

Typically, undisturbed soil surfaces are very important in controlling the soil's response to precipitation runoff, particularly where the soil surface is covered with fine gravel that overlays soils with large pores (Webb, 1982). In the Mojave Desert, surface runoff was typically five times greater and sediment yield (in runoff) was 10-20 times greater in OHV-impacted areas than in undisturbed areas (Iverson and others, 1981). For various reasons, certain portions of the desert, including dunes, playas, and areas covered with coarse surface material, are fairly

resistant to erosion from runoff (Hinckley and others, 1983), whereas vulnerable areas are those where initial infiltration rates are low, slopes are high, and ratios of surface sand/gravel to smaller particles are low (Iverson and others, 1981). The character of precipitation also influences the susceptibility of denuded soil to erosion; erosion rates are typically greater when rainfall events are of long duration and high intensity (Iverson and others, 1981). Disturbed soils also increase the likelihood of debris eroding from areas disturbed by OHV activities (Lovich and Bainbridge, 1999). Indeed, debris flow has been documented to bury plants growing outside the area impacted (Nakata, 1983).

#### 2.2.4 Annotated Bibliography for OHV Effects on Soils and Watersheds

**Adams, J.A., Endo, A.S., Stolzy, L.H., Rowlands, P.G., and Johnson, H.B., 1982**, Controlled experiments on soil compaction produced by off-road vehicles in the Mojave Desert, California: *Journal of Applied Ecology*, v. 19, no. 1, p. 167–175.

Under controlled conditions, soil crust properties were measured to determine how rapidly they were altered by passing vehicles. Routes impacted by a single vehicle pass had soil strengths 5.3 to 28.4 kg/cm<sup>2</sup> (75.366 to 403.848 lb/in<sup>2</sup> [or PSI], depending on the percent soil moisture) greater than undisturbed soil, indicating that just a single pass can begin to affect soil strength. Mean soil strength on routes exposed to 10 and 20 passes was too high to measure. Drying caused the soil in the slightly compacted track to become much harder (increased soil strength) than the undisturbed soil.

**Belnap, Jayne, 1993**, Recovery rates of cryptobiotic crusts— inoculant use and assessment methods: *Great Basin Naturalist*, v. 53, no. 1, p. 89–95.

Rates of recovery of cyanobacterial-lichen soil crusts from disturbance were examined. Plots were either undisturbed or scalped, and scalped plots were either inoculated with surrounding biological crust material or left to recover naturally. Natural recovery rates were found to be very slow. Inoculation significantly hastened recovery of the cyanobacterial/green algal component, lichen cover, lichen species richness, and moss cover; even with inoculation, however, lichen and moss recovery was minimal.

**Belnap, Jayne, 2002**, Impacts of off-road vehicles on nitrogen cycles in biological soil crusts—resistance in different U.S. deserts: *Journal of Arid Environments*, v. 52, no. 2, p. 155–165.

This study was conducted to evaluate short-term impacts of OHVs on lichen cover and the nitrogenase activity (NA) of biological soil crusts on various soil types in the Great Basin, Colorado Plateau, Sonoran, Chihuahuan, and Mojave deserts. Lichen cover was significantly correlated with percent silt in soil (and negatively correlated with percent sand and clay). Disturbance reduced NA at all 26 sites, but significantly at 12; declines were greatest in soils of cooler regions than hotter ones, possibly indicating that non-heterocystic cyanobacterial species are more susceptible to disturbance than heterocystic species. Sandy soils showed greater reduction of NA as sand content increased, while fine-textured soils showed a greater decline as sand content increased. At all sites, higher NA before the disturbance resulted in less impact to NA post-disturbance. These results may be useful in predicting the impacts of off-road vehicles in different regions and different soils.

**Cole, D.N., 1990**, Trampling disturbance and recovery of cryptogamic soil crusts in Grand Canyon National Park: *Great Basin Naturalist*, v. 50, no. 4, p. 321–325.



Under controlled conditions, cryptogamic soil crusts in Grand Canyon National Park were trampled by hikers to determine how rapidly they were pulverized and how rapidly they recovered. Only 15 passes were required to destroy the structure of the crusts; visual evidence of bacteria and cryptogam cover was reduced to near zero after 50 passes. It took soil crusts one to three years to redevelop, and after 5 years the extensive bacteria and cryptogam cover left little visual evidence of disturbance. Surface irregularity remained low after 5 years, however, suggesting that recovery was incomplete.

**Eckert, R.E.J., Wood, M.K., Blackburn, W.H., and Peterson, F.F., 1979**, Impacts of off-road vehicles on infiltration and sediment production of two desert soils: *Journal of Range Management*, v. 32, no. 5, p. 394–397.

This project staged a series of controlled motorcycle and 4-wheel drive vehicle passes, followed by simulated rainfall. Two sites were chosen to represent two different soil types. Infiltration rates were lower and sediment yield was higher after soil was disturbed by vehicular traffic. High sediment yield was attributed to reduced infiltration after 10 minutes; the remaining 20 minutes of the test period were characterized by particles being carried away in runoff water.

**Folz, R.B., 2006**, Erosion from all terrain vehicle (ATV) trails on National Forest lands (abs.): Proceedings of the 2006 American Society of Agricultural and Biological Engineers, Portland, Oregon, July 9–12, 2006: St. Joseph, Michigan, 2006 American Society of Agricultural and Biological Engineers, <http://asae.frymulti.com/abstract.asp?aid=21056&t=2>.

Concern about unmanaged use of all terrain vehicles (ATV) on U.S. Forest Service lands prompted an experimental study to test the relative effects of low-, medium-, and high-disturbance trails (based on traffic levels), as measured by reduced litter/vegetation and the width and wheel-rut depth of trails. Trail condition was assessed and then subjected to simulated rainfall. A negative relationship between levels of ATV traffic and rainfall infiltration was not statistically significant among disturbance levels; however, there were significant differences in infiltration and measures of erosion between undisturbed and disturbed conditions. Data from this study will be used to estimate ATV traffic-induced erosion and make decisions regarding management of ATV use.

**Iverson, R.M., Hinckley, B.S., and Webb, R.M., 1981**, Physical effects of vehicular disturbances on arid landscapes: *Science*, v. 212, no. 4497, p. 915–917.

In 50 rainfall simulation tests, vehicle-use plots had about five times more runoff and 10–20 times greater sediment yield than adjacent unused plots. In a desert environment, such effects may occur even when use of off-road vehicles is light. Recovery times from vehicular traffic were estimated to be nearly 100 years. Erosion rates were calculated from multivariate statistical analyses using 22 experimental factors. The character of the rainfall was identified as the most important variable in predicting increases in erosion.

**Sparrow, S.D., Wooding, F.J., and Whiting, E.H., 1978**, Effects of off-road vehicle traffic on soils and vegetation in the Denali Highway region of Alaska: *Journal of Soil and Water Conservation*, v. 33, no. 1, p. 20–27.

This study examined the effects of vehicles on trails. The surface layer of living material was killed on all main trails, although soil morphology was not generally altered except in the surface horizon. Varying amounts of organic matter were lost from the heavily used trails,

depending on slope and vehicle type. Soil depth and drainage were the most important factors influencing the condition of the trail. The greatest effects on soils occurred in poorly drained areas or on loose, gravel-free soils that were highly susceptible to erosion.

**Tuttle, M., and Griggs, G., 1985**, Accelerated soil erosion at three State Vehicular Recreation Areas: central and southern California, *in* Erosion control: A challenge in our time, proceedings of the 16th annual International Erosion Control Association, February 21–22, 1985, San Francisco, California: San Francisco, California, International Erosion Control Association, p. 105-115.

Soil erosion rates were evaluated at three State Vehicular Recreation Areas, with a particular focus on hillclimbs. The key factors contributing to erosion rates were slope, length of climb, soil type, and weather. Based on monitoring and catchment basin yield, erosion in open areas dedicated to OHV use was 10 to 25 times greater than in undisturbed areas.

**Webb, R.H., 1982**, Off-road motorcycle effects on a desert soil: *Environmental Conservation*, v. 9, no. 3, p. 197–208.

The effects of controlled motorcycle traffic on a Mojave Desert soil in California were studied in order to quantify soil compaction. Four experimental trails treated with 1, 10, 100, and 200 passes with an off-road motorcycle were established in loamy sand at 6.2 percent (by weight) moisture content. Soil penetration resistance, bulk density, infiltration rate, and response to rainfall were measured for undisturbed soil and the experimental trails immediately after the impact, and soil cores were measured in the laboratory to determine pore-size distributions. Soil bulk density was remeasured one year after the impact to ascertain the amount of recovery. The 1-pass trail had a slight surface indentation with knob imprints from the tires. Along the 100- and 200-pass trails, there were berms and lateral edges, and their centers were 10–30 mm below the level of undisturbed soil adjacent to the trail.

**Wilshire, H.G., and Nakata, J.K., 1976**, Off-road vehicle effects on California's Mojave Desert: *California Geology*, June 1976, p. 123–132.

This study was designed to evaluate long-term effects of an off-road vehicle race on the desert landscape, in particular the landscape condition after vehicular use (specifically motorcycles), whether or not effects were confined to the areas of direct impact, and how long the physical effects of such activities remained. Visual observations and penetrometer measurements were recorded in five ground types. Soil compaction was the dominant consequence of motorcycle use: penetrometer data revealed decreases in mean penetration depths. Combined with a notable reduction in plant cover, soil compaction significantly increased the potential for erosion. Initial vehicle impact resulted in substantial, immediate mechanical erosion, followed by wind erosion, culminating in the increased potential for water erosion over longer periods of time.

**Wilshire, H.G., Nakata, J.K., Shipley, Susan, and Prestegard, Karen, 1978**, Impacts of vehicles on natural terrain at seven sites in the San Francisco Bay area: *Environmental Geology*, v. 2, no. 5, p. 295–319.

Vegetation and soil properties were measured at seven sites exposed to off-road vehicle activities. Impacts on loamy soils included greater soil surface strength and bulk density, lower infiltration rates and soil moisture, extended diurnal temperature ranges, and reduced organic

carbon. These effects, combined with the associated loss in vegetative cover, promoted erosion, the rates of which significantly exceeded Federal and local standards, and the increased sediment yield and runoff caused adverse effects on neighboring properties.

## 2.3 OHV Effects on Vegetation

### 2.3.1 Section Summary

Relative to plant communities in OHV-impacted areas, those in undisturbed sites are dominated by native plants, invasive species are not increasing, plant growth and reproduction are vigorous, age-classy structures are appropriate to the species, and canopy cover and vertical structure are adequate for dispersing the energy of precipitation runoff and promoting water infiltration. Direct impacts of OHV activities on vegetation include reduced vegetation cover and growth rates, and increased potential for non-native grasses and pioneering species to become established, thus altering vegetation communities. In certain instances, however, the impervious nature of compacted route and paved road surfaces could result in significant runoff that generates greater moisture availability immediately along OHV routes. In turn, this would promote increased vegetation cover and plant abundance than one might find in surrounding areas farther away from OHV routes.

Some important indirect effects of OHV activities on vegetation are tied to soil properties altered by OHV traffic, as soil properties typically influence vegetation growth. OHV roads and trails also create edge habitats, which can generate conditions that promote the encroachment of non-native and invasive plant species. Other indirect effects include increased amounts of airborne pollutants and dust raised by OHV traffic. A blanket of fugitive dust on plant foliage can inhibit plant growth rate, size, and survivorship.

### 2.3.2 Overall Effects on Vegetation Cover and Community Composition

When soils are severely disturbed, vegetation cover can be reduced significantly (Adams and others, 1982; Prose and others, 1987; Bolling and Walker, 2000) and growth can be impaired (Spencer and Port, 1988; Angold, 1997). As stated in the previous section, even a few passes by vehicles can cause significant changes in soil properties. Adams and others (1982) found reduced cover of desert annuals in tracks created by as few as 1 (on wet loamy sand) to 20 (on dry loamy sand) vehicle passes; the reduction in cover, however, was not due to fewer plants, but to smaller plant sizes. Similarly, Bolling and Walker (2000) found that in OHV routes there were many small individuals of creosote bush (*Larrea tridentata*), but larger plants were few or absent; in control plots, however, there were more large plants and fewer small ones.

Reduced plant sizes are typical where the extent of soil compaction inhibits their roots from penetrating to deeper soil levels. In fact, Adams and others (1982) determined that root growth is precluded at soil strengths of about 20 kg/cm<sup>2</sup> (284.4 lb/in<sup>2</sup>). Within tracks made by 1, 3, 10, and 20 vehicle passes, Adams and others (1982) found that annuals with large taproots (for example, pincushion flower [*Chaenactis fremontii*]) decreased, whereas there was significantly greater cover of common Mediterranean grass (*Schismus barbatus*), a non-native grass with a fibrous root system. The fibrous root system of plants that characterized by single cotyledons, such as common Mediterranean grass, allows for easier germination and root growth than is possible for taprooted dicotyledons.

Soil compaction also increases the potential for invasive, non-native annuals and other early successional plants to establish rapidly in OHV routes, whereas native perennials may require at least 5 years to become established (Adams and others, 1982; Prose and others, 1987;

Lovich and Bainbridge, 1999). This is due, in part, to the increased surface moisture availability within the tracks of OHV routes after compaction has reduced the rate of water infiltration, which may favor the rapid germination and growth of non-native and invasive annuals (Adams and others, 1982). In disturbed areas, pioneering species, such as burrobrush (*Ambrosia dumosa* and *Hymenoclea salsola*—now *Ambrosia salsola*; see [http://ucjeps.berkeley.edu/cgi-bin/get\\_cpn.pl?3578](http://ucjeps.berkeley.edu/cgi-bin/get_cpn.pl?3578)), often dominate the plant community and typically their percent cover is similar to, or greater than, that of undisturbed areas (Prose and others, 1987). Davidson and Fox (1974) also found that non-native, early-successional species, such as redstem stork's bill (*Erodium cicutarium*) and common Mediterranean grass were common at sites disturbed by OHVs. When comparing vegetation in disturbed versus protected plots, Brooks (1995) found that common Mediterranean grass was the only species with greater biomass in the disturbed plots.

OHV traffic also causes direct impacts to vegetation structures (breakage, smashing), although population-level effects may be difficult to discern in the short term. Overall, the extent of immediate effects increases with the frequency of OHV passes. For example, Webb (1983) found that after a single pass, annual plants on an OHV route remained intact, but most were destroyed after 10 passes. Likewise, a series of studies to evaluate the impacts of OHV traffic on the Federally listed Peirson's milkvetch (*Astragalus magdalenae peirsonii*) indicated that this plant was more likely to occur at sites closed to OHV activity than at OHV sites that have been rested from OHV activity (Groom and others, 2005); however, additional study indicated that the number of reproducing plants (and the seedbank) was adequate to maintain the milkvetch population (Phillips and Kennedy, 2006; for more reports, go to [http://www.fws.gov/carlsbad/PMV\\_Docs.htm](http://www.fws.gov/carlsbad/PMV_Docs.htm)). It remains unclear, however, whether research conducted over longer time scales would yield different results.

### 2.3.3 Edge Effects Along OHV Routes

Roads and trails also create edge habitats (Johnson and others, 1975; Vasek and others, 1975; Adams and Geis, 1983; Andrews, 1990; Holzapfel and Schmidt, 1990; Lightfoot and Whitford, 1991; Reed and others, 1996), resulting in a variety of effects, including changes in vegetation and encroachment of non-native and invasive species (Huey, 1941; Lovich and Bainbridge, 1999). As mentioned in section 2.3.2, the impermeable surfaces of roads and OHV routes shed precipitation, thereby increasing overall moisture availability in the immediate vicinity of the road or route. Additionally, the coarse-textured soils typically found in association with paved roads (roadbed materials laid down prior to paving) permit good water infiltration along road edges (Hillel and Tadmor, 1962); similar conditions may occur along improved gravel routes. The increased moisture availability may promote greater plant vigor along roadsides than in surrounding areas (Johnson and others, 1975), and Angold (1997) indicated that such effects may extend as far as 200 m from road edges. Indeed, several studies have shown that there can be more vegetation cover along roadsides and right-of-ways than in adjacent areas (Johnson and others, 1975; Vasek and others, 1975; Holzapfel and Schmidt, 1990; Lightfoot and Whitford, 1991). Perennial shrubs, in particular, may grow larger and attain greater vigor and density along road edges (Johnson and others, 1975; Lightfoot and Whitford, 1991). Likewise, Johnson and others (1975) found that the standing crop (a measure of primary productivity) was 6 times greater along unpaved roads (17 times greater along paved roads) than it was in nearby undisturbed areas.

The greater vegetation cover typically observed along roadsides also is often due, in part, to greater species richness in those areas (Holzapfel and Schmidt, 1990); however, much of this diversity may be represented by non-native species easily dispersed along roads and trails

(Wilcox, 1989; Tyser and Worley, 1992; Parendes and Jones, 2000). Furthermore, local-scale increases in species richness can be associated with decreases in species richness at the landscape scale, thus creating a relatively impoverished and anthropogenic vegetation community (Holzapfel and Schmidt, 1990). Interestingly, increased vegetation cover along roadsides may attract more invertebrates and other organisms. For example, Lightfoot and Whitford (1991) found that shrubs along a road supported greater numbers of foliage arthropods. What is not clear, however, is whether high densities of animals in roadside habitats represent improved conditions for native fauna or dominance by invasive and/or non-native organisms. Furthermore, high densities do not necessarily represent population sources (that is, where survivorship and productivity are high enough to contribute to the species' overall population); instead, high densities can indicate poor-quality habitat into which subordinate animals may crowd and experience poor survivorship if they cannot find or defend better habitat (population sinks). In other words, density can be a misleading indicator of habitat quality (Van Horne, 1983). It is important to note, however, that the greater vegetation cover along roadsides compared to plots away from roads may be a phenomenon found only in arid environments (Hillel and Tadmor, 1962; Holzapfel and Schmidt, 1990).

Fugitive dust raised by OHV traffic also affects vegetation in the vicinity of roads. Along Alaskan roads heavily traveled by various types of vehicles, Walker and Everett (1987) found significant dust impacts up to 10 m (10.9 yd) from the roadside and dust blankets up to 10 cm (3.9 in) thick on mosses and other vegetation of low stature. Several morphological factors contribute to plant susceptibility to heavy dust loads, including mat or prostrate growth form, lack of a protective stem cortex or leaf cuticle, and intricate branching or closely spaced leaves that tend to trap dust (Walker and Everett, 1987; Spellerberg and Morrison, 1998). Processes that may be affected by dust include photosynthesis, respiration, and transpiration due to blocked stomata and cell destruction (Spellerberg and Morrison, 1998), all of which could result in reduced plant growth, size, productivity, and/or survivorship.

### 2.3.4 Annotated Bibliography for OHV Effects on Vegetation

**Adams, J.A., Stolzy, L.H., Endo, A.S., Rowlands, P.G., and Johnson, H.B., 1982**, Desert soil compaction reduces annual plant cover: *California Agriculture*, v. 36, no. 9–10, p. 6–7.

Soil crust properties and associated changes in vegetation composition were measured under controlled conditions over two 6-month wet seasons to determine how rapidly they were altered by vehicle passes. Reductions in annual plant cover occurred in tracks created by as few as 1 (on wet loamy sand) to 20 vehicle passes (on dry loamy sand). This cover reduction, however, was not due to fewer plants; rather, the plants were smaller, and their size depended on the duration of drying periods, during which the soil strength intensified in impact/track areas. Cover of annuals with large taproots (for example, *Chaenactis fremontii*) decreased in vehicle tracks, whereas the cover of *Schismus barbatus*, a grass with a fibrous root system, was significantly greater in tracks generated by 1, 3, 10, and 20 vehicle passes. It was determined that root growth for plants stops at soil strengths of about 20 kg/cm<sup>2</sup> (284.4 lb/in<sup>2</sup> [or PSI]). Soil disturbance also increased the potential for grasses and pioneering annual species to become established, whereas perennial species would take at least 5 years to return. A possible reason for this may be greater water availability in the track.

**Angold, P.G., 1997**, The impact of a road upon adjacent heathland vegetation—Effects on plant species composition: *Journal of Applied Ecology*, v. 34, no. 2, p. 409–417.

The effect of a road on heathland vegetation was investigated at five sites adjacent to the main trunk road through the New Forest, Hampshire, United Kingdom, and nine supplementary sites adjacent to five minor roads. There was enhanced growth of vascular plants near the road, notably heather and grasses, which was probably due to nitrogen oxides from vehicle emissions. There was a decrease in the abundance and health of lichens near the road. There was an increase in the abundance of grasses in the heathland near roads, which may be due to the changes in relative competitive ability of plant species under conditions of eutrophication. The extent of the edge effect in the heath was closely correlated with traffic intensity, with a maximum edge effect of 200 m adjacent to a dual carriageway.

**Benninger-Traux, M., Vankat, J.L., and Schaefer, R.L., 1992**, Trail corridors as habitat and conduits for movement of plant species in Rocky Mountain National Park, Colorado, USA: *Landscape Ecology*, v. 6, no. 4, p. 269–278.

Ground-layer vegetation was sampled along selected trail corridors to determine whether corridors provide habitat for certain species and serve as conduits for species dispersal. Patterns of plant species composition were analyzed in relation to distance from trail edge, level of trail use, and distance from trailheads, junctions, and campgrounds. Species composition was significantly affected by distance from trail edge and level of trail use, as species were favored or inhibited by the corridor, depending upon their growth habits. Species composition also was affected by distance from trailheads. These findings, along with the presence of exotic species, indicate that trail corridors in Rocky Mountain National Park function as habitat and conduits for dispersal of plant species.

**Bolling, J.D., and Walker, L.R., 2000**, Plant and soil recovery along a series of abandoned desert roads: *Journal of Arid Environments*, v. 46, no. 11, p. 1–24.

To elucidate factors controlling desert succession, soil and vegetation dynamics were examined along roads abandoned for 5, 10, 21, 31, 55 and 88 years in southern Nevada. None of the measured soil or vegetation parameters varied significantly with road age. Differences were found, however, between soils and vegetation on roads compared to those on nearby control sites, and soils differed between roads created by surface vehicular traffic and those made by bulldozing. Studies of recovery following disturbance in deserts must take into account natural patterns of plant and soil heterogeneity and initial disturbance type.

**Brooks, M.L., 1995**, Benefits of protective fencing to plant and rodent communities of the western Mojave Desert, California: *Environmental Management*, v. 19, no. 1, p. 65–74.

This paper documents the response of plant and small mammal populations to fencing constructed to preclude OHV activities between 1978 and 1979 at the Desert Tortoise Research Natural Area, Kern County, California. Aboveground live annual plant biomass was generally greater inside than outside the fenced plots during April 1990, 1991, and 1992. The non-native grass, *Schismus barbatus*, was a notable exception, producing more biomass in the unprotected area. Forb biomass was greater than that of non-native annual grasses inside the fence during all 3 years of the study. Outside the fence, forb biomass was significantly greater than that of non-native grasses only during spring 1992. Percent cover of perennial shrubs was greater inside the fence than outside, while no significant trend in density was detected. There was also more seed biomass inside the fence, which may have contributed to the greater species diversity and density of Merriam's kangaroo rats (*Dipodomys merriami*), long-tailed pocket mice (*Chaetodipus*

*formosus*), and southern grasshopper mice (*Onychomys torridus*) in the protected area. These results show that protection from OHV disturbance has many benefits, including greater overall community biomass and diversity.

**Holzappel, C., and Schmidt, W., 1990**, Roadside vegetation along transects in the Judean Desert: Israel Journal of Botany, v. 39, p. 263–270.

Vegetation was studied on comparable plots along roadsides and in the surrounding area. The uniqueness of roadside vegetation was shown using indices and measurements that allowed comparison along a climatic gradient. Near roads, biomass and species diversity were notably greater than in surrounding areas, and the chorological composition was different, at least under arid conditions. The reasons for these differences are discussed based on investigations of site conditions. Increased water runoff and more favorable soil conditions seem to have had important influences on the vegetation community.

**Kutiel, P., Eden, E., and Zhevelev, Y., 2000**, Effect of experimental trampling and off-road motorcycle traffic on soil and vegetation of stabilized coastal dunes, Israel: Environmental Conservation, v. 27, no. 1, p. 14–23.

The aim of this study was to assess the response of soil and annual plants of stabilized Mediterranean coastal dunes in Israel to various intensities of short-duration pedestrian and motorcycle traffic. Experimental procedures entailed 0, 20, 50, 100, and 200 straight and 150 turn motorcycle passes. The response of annual plants was assessed by measuring ground cover, height, and species richness and diversity, and soil response was assessed by measuring penetrable depth, organic matter, and moisture content. Motorcycle passage had an immediate significant impact on annual plants at all traffic intensities. The maximum effect on plants was observed in the wheel tracks and in the turn lanes. Mean annual ground cover and height were less sensitive measures than species richness and diversity for determining the overall impact of motorcycles on the area.

**Prose, D.V., Metzger, S.K., and Wilshire, H.G., 1987**, Effects of substrate disturbance on secondary plant succession—Mojave Desert, California: Journal of Applied Ecology, v. 24, no. 1, p. 305–313.

The effects of substrate disturbance on perennial plant succession in the Mojave Desert were assessed at three military camps abandoned for 40 years. Soil compaction, removal of the top layer of soil, and altered drainage channel density caused significant changes in perennial plant cover, density, and relative species composition. Long-lived species, predominantly *Larrea tridentata*, were dominant in all control areas, but percent cover and density were greatly reduced in areas where substrate alterations were significant. At one camp where substrate alterations were insignificant in disturbed areas, *Larrea* was the dominant species (as it was in the control areas).

**Schultink, G., 1977**, Impact analysis of off-road-vehicle use on vegetation in the Grand Mere Dune environment: East Lansing, Michigan, Michigan State University, Report no. NASACR155764, 10 p.

A linear regression of percent unvegetated land in OHV-impacted areas versus time for two sample areas indicated that the areas underwent average declines of 1.9 and 5.9 percent per year in vegetation cover. Two factors were assumed to play roles in the difference: the difference

in accessibility and the extent of vegetation fragmented during the first year of the study (one sample area was located closer to potential access points and was more fragmented initially).

*Wilshire, H.G., Shipley, Susan, and Nakata, J.K., 1978*, Impacts of off-road vehicles on vegetation: Transactions of the North American Wildlife and Natural Resources Conference, v. 43, p. 131–139.

Observations of the impacts of off-road vehicles on soils and vegetation were made at more than 400 sites in seven western states during 3 years. This type of land use had both direct and indirect effects on vegetation. Direct effects included crushing and uprooting plants. Indirect effects included modification of the soil, which affected plants beyond the areas directly impacted by vehicles, and restoration of the plant cover was inhibited. This paper covers the erosional effects on vegetation, depositional effects on vegetation, and the effects of physical and chemical modification of remnant soils on revegetation.

## **2.4 OHV Effects on Wildlife and Habitats: Native, Threatened, and Endangered Species**

### **2.4.1 Section Summary**

The impacts of OHV activities on wildlife and their habitats are numerous and well documented. Networks of roads and trails fragment habitat, reduce patch size, and increase the ratio of edge to interior. This may have serious consequences for area-sensitive species (those that cannot carry out certain aspects of their life cycles without large blocks of habitat or corridors linking habitat patches), predator-prey relationships, and overall population dynamics. In particular, fragmentation and edges created by OHV routes may have strong effects on animal movement patterns. Precluding or inhibiting animal movements effectively diminishes dispersal to and recolonization in other areas, thus increasing the likelihood of local extirpations. Overall, studies demonstrate that even narrow roads (paved and unpaved) and trails can represent significant barriers to the movements of animals. Reluctance to cross even narrow trails similar in width to routes created by OHV travel may alter or preclude the movements of various species. The cumulative effects of OHV-route networks proliferating across the landscape may have serious ecological consequences for species reluctant to cross OHV routes. Where threatened and endangered species are at risk, understanding their particular responses to roads of varying types, widths, use intensities, and habitat contexts is crucial.

OHV routes also generate conditions unlikely to occur in environments unaffected by OHV activity; in turn, these conditions can facilitate range extensions and invasions of non-native and/or opportunistic species. In addition, OHVs can contribute directly to mortality (and possible population declines) of wildlife species through collisions with vehicles, nest destruction, and collapsing burrows. Noise generated by OHVs also has been found to cause inner ear bleeding. In particular, noise may alter animal behaviors, breeding populations, the abilities of some species to detect predators (through auditory cues), and it can stimulate estivating animals to emerge from their underground burrows at inappropriate times. These factors may result in diminished body mass, reduced productivity, and/or poor survivorship.

### **2.4.2 Loss of Habitat Connectivity: Fragmentation and Barrier Effects**

Creating roads and trails (of any kind) diminishes habitat connectivity, increases the proportion of edge to interior habitat, and decreases patch size of habitats (Reed and others, 1996; Forman and others, 2003). In fact, roads, including OHV routes, represent a principal



factor contributing to habitat fragmentation at various scales (Meffe and Carroll, 1997). Furthermore, both paved roads and OHV routes—ranging from 4-lane paved highways to two-track routes less than 3 m (3.3 yards) wide—that separate once-continuous habitat can disrupt the movement and dispersal of many wildlife species between and within habitats (Swihart and Slade, 1984; Brody and Pelton, 1989; Yanes and others, 1995; Lovallo and Anderson, 1996; Clevenger, 1998; Forman and Alexander, 1998; Jackson and Griffen, 1998). In turn, these effects can have consequences for area-sensitive species and may encourage non-native and/or invasive species. Special-status wildlife species known to occur on BLM lands and whose long-term persistence is threatened by habitat fragmentation and diminished habitat connectivity include grizzly bear (*Ursus arctos horribilis*; Gibeau and Herrero, 1998; Servheen and others, 1998), black bear (*Ursus americanus*; Brody and Pelton, 1989), gray wolf (*Canis lupus*; Paquet and Callahan, 1996), mountain lion (*Felis concolor*; Beier, 1993), lynx (*Felis lynx*; Ruediger, 1998), ocelot (*Leopardus pardalis*; Tewes and Blanton, 1998), and desert tortoise (*Gopherus agassizii*; Boarman and Sazaki, 1996). The resulting isolation of subpopulations (Dobson and others, 1999) can promote increased inbreeding and a lack of genetic exchange with other subpopulations, ultimately leading to declines in the genetic diversity required for adaptation to variable conditions and possible founder effects (Hanski and Simberloff, 1997; Hanski, 1999). Another consequence of subpopulation isolation is the reduced potential for recolonization when extirpations occur as a result of localized population fluctuations and catastrophic events (Yanes and others, 1995).

Until recently, only wide, multi-lane, paved roads have been considered significant barriers to animal movements. More recent lines of evidence from fragmentation studies, however, indicate that the ability or willingness of an animal to cross a given road type varies widely by species (Brody and Pelton, 1989; Lovallo and Anderson, 1996). For example, rodents in a desert habitat were found to avoid crossing a 4-lane highway, although they lived alongside the road in the right-of-way vegetation (Garland and Bradley, 1984). Likewise, in forested habitats divided highways wider than 90 m (98.4 yd) served as total barriers to dispersal by small forest mammals (Oxley and others, 1974). However, improved gravel roads have been found to inhibit crossings by mountain lions (*Puma concolor*; van Dyke and others, 1986), and even infrequently traveled, single-lane dirt roads have been found to alter movements by some species (Andrews, 1990). For example, Swihart and Slade (1984) report that prairie voles (*Microtus ochrogaster*) and cotton rats (*Sigmodon hispidus*) were strongly inhibited from crossing a route less than 3 m (3.3 yd) wide and composed of two dirt tracks created by the passing of 10 to 20 vehicles per day. Oxley and others (1974) evaluated small mammal responses to roads and routes ranging from 4-lane paved highways to country gravel roads in forested systems of southeastern Canada and found that they were not willing to cross roads or other routes with a total clearance (the distance between forest margins, including road surfaces and immediately adjacent strips of vegetation kept very short via spraying and/or mowing) of 30 m (32.8 yd) or greater; road surface apparently was unimportant. Likewise in Germany, forest mice (*Apodemus flavicollis*) did not cross roads 6 m (6.6 yd) wide, and very few mice returned to the side of the road from which they were captured after being translocated to the opposite side within the same habitat type (Mader, 1984). Areas characterized by high densities of roads also are characterized by low probabilities that amphibian species will occupy breeding pools (Vos and Chardon, 1998), most likely because the edges were relatively impermeable (whether due to behavioral avoidance or direct mortality) to critical amphibian movements (dispersal, seasonal movements; Gibbs, 1998). On the other hand, some small mammals are known to cross paved and gravel roads (Bakowski

and Kozakiewicz, 1988), particularly where vegetated highway right-of-ways resemble those of adjacent habitats (Wilkins, 1982). These studies indicate that road surface type is not always the critical inhibiting factor; however, it does influence traffic speed, which can directly affect mortality rates (Oxley and others, 1974; Bakowski and Kozakiewicz, 1988).

Invertebrates also may be precluded from crossing various road types, including those considered relatively narrow; again, however, there are species differences that may be influenced by their ecologies and physical capabilities. For example, Samways (1989) found that both “tarred” (paved) and “untarred” roads were almost complete or partial barriers to three species of bush crickets (*Decticus varrucivorus monspeliensis* and *Platycleis fedtschenkoi azami*, both wingless, and *P. tessellate*, the flight range of which is less than [ $\leq$ ] 5m [5.5 yd]), but roads were only minor, very minor, or did not serve as barriers to the movements of six other bush cricket species, five of which can readily fly across roads (flight ranges from  $<30$  to 150 m [32.8–164.0 yd]). On the other hand, Munguira and Thomas (1992) found that wide highways did not affect the movements of butterflies in open populations; movements of butterflies in closed populations, however, were slightly impeded by roads. Other butterfly species may not even attempt to fly across roads (described by authors as two-lane highways and secondary roads), possibly due to the extreme changes in microclimate over roads (including columns of warm air rising above roads; Boer Leffef, 1958, as interpreted and translated by van der Zande, 1980). Mader (1984) reported that in a five-year mark-recapture-release study involving 10,186 carabid beetles representing nine species, three species were never recaptured on the opposite side of study area roads (one- or two-lane paved roads) or parking loops, and the remainder were recaptured across the road only rarely. However, some individuals of a Swedish snail species (*Arianta arbustorum*) that were captured and translocated to the opposite sides of narrow paths or relatively wider roads did return to the capture sides of paths (Baur and Baur, 1990).

### 2.4.3 Edge Effects

Aside from fragmenting habitat, roads and trails of any kind also create habitat edges (Reed and others, 1996). In many instances, these edge effects extend well beyond the road’s actual footprint and for some species the effects may extend well into the desert interior. Therefore, assessing edge effects of roads and trails on wildlife may entail determining distributions of wildlife in reference to the extent of any one edge effect (Yahner, 1988). Even then there may be an array of factors that vary the distances from roads/trails at which edge effects may be apparent. For example, Nicholson (1978) indicates that metapopulations of desert tortoises may be depleted within 0.8 km (0.5 mi) of highway edges, and von Seckendorff Hoff and Marlow (1997) indicate that this effect may extend as far as 3.5 km (2.2 mi) from the highway edge.

Given the frequent incidence of significant vegetation cover along road edges, many organisms may be attracted to right-of-way habitats. For example, Adams and Geis (1983) found greater small mammal density within interstate right-of-way habitats than in adjacent habitats. Density, however, can indicate habitats sinks to which animals retreat when more desirable habitats are occupied (Van Horne 1983). Alternatively, road edges may serve as ecological traps (Andrews, 1990) that are attractive and replete with necessary resources on the one hand, but impose unusually high mortality rates on the other hand. For example, birds may be attracted to lush roadside vegetation for breeding, nesting, or foraging (Clark and Karr, 1979), but they may be at great risk of mortality due to being hit by vehicles (Mumme and others, 2000). Similarly, avian eggs and nestlings can experience increased mortality due to high rates of predation (Yahner and others, 1989) in edge habitats. As mentioned in the section above, edge effects

along roads can alter or preclude the seasonal movements of amphibians to their breeding pools (Gibbs, 1998; Vos and Chardon, 1998).

In the same ways that travel routes promote increased dispersal of non-native and invasive plant species, they also promote increased distributions of wildlife species otherwise unlikely to be common in a given area; in turn, this exerts additional competitive pressures on native species. Huey (1941) documented pocket gophers (*Thomomys umbrinus*) extending their ranges across the Mojave Desert via roads and canal systems. Although much of the surrounding desert landscape contained soils unsuitable for gophers, the attractive habitat (greater cover of vegetation resulting from increased moisture availability) along roadsides and canals facilitated the spread of these animals (Huey, 1941). An additional important edge effect associated with roads of many types is the presence of utility infrastructures, which can contribute to significantly altered predator-prey relationships along roads. For example, raven species (*Corvus* spp.) have increased their distribution throughout the Mojave Desert, primarily due to the fact that they can perch along utility structures to scan for carcasses on adjacent roads (paved and unpaved) (Knight and Kawashima, 1993), a significant concern in light of the fact that Berry and others (1986) reported ravens as being responsible for 68 and 75 percent of mortality among juvenile desert tortoises on two study plots.

#### 2.4.4 OHV Disturbance and Noise

Vehicular traffic is also a source of noise and other stimuli that have the potential for disturbing wildlife along any type of road or trail (Singer, 1978; van der Zande, 1980; Brattstrom and Bondello, 1983; Bowles, 1995; Reijnen and others, 1995, 1996; Bowles, 1995; Kaseloo and Tyson, 2004). Veen (1973; as interpreted and translated by van der Zande, 1980) found that four shorebird species inhabiting open grassland areas were disturbed within 500–600 m of a “quiet rural road” and within 1600–1800 m of a “busy highway;” van der Zande (1980) reanalyzed Veen’s data and yielded similar results for three of the four species, and went on to conclude that populations of these birds were diminished by as much as 60 percent over those distances. Forman and Alexander (1998) found that noise levels generally increase with traffic intensity, and Reijnen and others (1995, 1997) concluded that traffic noise can lead to significant reductions in breeding bird densities. Larger animals also exhibit responses to the intensity of traffic and traffic noise. Lyren (2001) found that coyotes changed their road-crossing periods in response to changes in traffic intensity throughout the day, and Singer (1978) reported that, in response to the shifting of truck gears, mountain goats ran away from a road edge when the truck was 1 km (0.6 mi) away from them, and they ran away from a lick that was 400 m (437.4 yd) from the road.

Noise emitted from certain types of OHVs can be as high as 110 decibels, which is near the threshold of human pain (Lovich and Bainbridge, 1999). Although sounds from OHV motors are not the loudest anthropogenic sounds, in wildlife habitats they are emitted more frequently than other high-intensity sounds (Brattstrom and Bondello, 1983), and the effect on animals can be significant. For example, sand lizards (*Uma scoparia*) and kangaroo rats (*Dipodomys deserti*) experienced hearing loss that lasted for weeks after being exposed to less than 10 minutes of dune buggy playback recordings played intermittently at lower decibel levels than the animals would have been exposed to in the actual presence of a dune buggy (Brattstrom and Bondello, 1983); subsequently, both species were unresponsive to recordings of predator sounds. In two other studies, kangaroo rats (*Dipodomys spectabilis*) experienced inner ear bleeding when subjected to OHV noise (Berry, 1980b; Bury, 1980). Another issue is the way in which OHV noise (sound pressure) may simulate that of natural sounds (thunder, for example) to which many

animals may be adapted to respond. For example, in response to 30 minutes of taped motorcycle sounds, Brattstrom and Bondello (1983) documented a spadefoot toad (*Scaphiopus couchii*) emerging prematurely (wrong season, absence of rain) from its burrow, most likely because the sound mimicked that of thunder, to which the species would normally respond.

Noise, lights, and other disturbances associated with OHV activities also have the potential for eliciting stress responses from a broad spectrum of wildlife taxa. Indeed, studies have shown that ungulates, birds, and reptiles all experience accelerated heart rates and metabolic function during disturbance events; in turn, animals may be displaced and experience reproductive failure and reduced survivorship (see review in Havlick, 2002). For example, radio-collared mule deer disturbed by ATVs altered their patterns of foraging and spatial use of habitat; deer in undisturbed areas, however, exhibited no such changes (Yarmoloy and others, 1988). In addition, Yarmoloy and others (1988) found that harassment of deer resulted in diminished reproductive output in the following fawning season, whereas deer that were not harassed experienced no change in reproduction.

#### 2.4.5 Wildlife Mortality and Related Issues

Direct wildlife mortality can result from vehicular impact (Harris and Gallagher, 1989; Beier, 1993; Bruinderink and Hazebrook, 1996; Moore and Mangel, 1996), thus removing individuals from populations (Harris and Gallagher, 1989; Forman and Alexander, 1998); thus, habitats containing roads may represent population sinks for any species that commonly attempts to move from one habitat fragment to another by crossing roads (Kline and Swann, 1998). If mortality rates exceed rates of reproduction and immigration, wildlife populations decline (Beier, 1993; Bruinderink and Hazebrook, 1996; Moore and Mangel, 1996; Forman and Alexander, 1998). Previous studies indicate that mortality rates vary widely according to habitat and road or route characteristics (for example, road width, traffic density and speed, adjacent habitat) (Ward, 1982; Bashore and others, 1985; Foster and Humphrey, 1995; Evink and others, 1996, 1998), as well as taxa studied—invertebrates: Seibert and Conover (1991), Munguira and Thomas (1992); reptiles and amphibians: Rosen and Lowe (1994), Ashley and Robinson (1996), Boarman and others (1998), Rudolph and others (1998), Means (1999); birds: Dhindsa and others (1988), Moore and Mangel (1996), Mumme and others (2000); and mammals: Gilbert and Wooding (1996), Romin and Bissonette (1996), Lehnert and Bissonette (1997), Gunter and others (1998), Lyren (2001). Even where the frequency of wildlife mortality is relatively low most of the year, it may increase during certain seasons (Feldhammer and others, 1986; Bruinderink and Hazebrook, 1996) or when traffic frequency increases (McCaffery, 1973). Furthermore, population dynamics can be altered if low mortality rates nonetheless cause disproportionate mortality among specific sex and/or age classes (Beier, 1993; Moore and Mangel, 1996; Mumme and others, 2000).

Several researchers have conducted extensive monitoring at desert OHV sites and undisturbed sites to compare direct effects of OHV activity on mortality and abundance of certain reptile species (Bury and others, 1977; Berry, 1980a; Bury, 1980; Luckenbach and Bury, 1983; Brooks, 1999; Grant, 2005). Of important concern is the susceptibility of desert tortoises to mortality on all types of roads. Berry (1980a) found a link between OHV activity and population declines of the desert tortoise and Couch's spadefoot toad (*Scaphiopus couchii*); numbers of tortoises and active burrows in a 25-ha control plot were significantly greater than in a similar plot exposed to OHV activity, presumably the result of direct mortality from vehicles or the collapsing of burrows caused by OHV traffic (Lovich and Bainbridge, 1999). Additionally, the body masses of subadult and adult tortoises in the control plot were greater than those of

tortoises in the OHV area (Bury and Luckenbach, 1986, cited in Lovich and Bainbridge, 1999). When comparing lizards in OHV-impacted plots to control plots, controls supported 1.8 times more species, 3.5 times more individuals, and 5.9 times more biomass (Luckenbach and Bury, 1983). Similarly, Bury and others (1977) found more reptile species (1.63 times more) and greater reptile abundance (182 percent more individuals) at control sites than at OHV sites. In another study, the remains of 39 tortoises were recorded during three surveys over a 2.5-year period along a 24-km (14.9-mi) section of paved highway in the western Mojave Desert (Boarman and others, 1993). Snakes also experience high rates of mortality in the Mojave Desert due to their strategy for thermoregulation (lying on warm surfaces, such as roads; Sullivan, 1981). Rosen and Lowe (1994), who conducted nighttime snake surveys along a 2-lane paved road in the Sonoran Desert (primarily within Organ Pipe Cactus National Monument), documented a 72 percent rate of snake mortality (104 live, 264 dead); mortality peaked in spring—when snake activity was moderately high and automobile traffic had not yet reached its summer minimum—and during rain events in the monsoon season (July through early September). Overall snake mortality during the entire 4-year study was estimated at 2,383 snakes (13.5 snakes/km/year; 8.1 snakes/mi/year), although actual numbers were likely closer to 4,000.

Densities and species diversity of desert birds and small mammals also have been reported to decrease in areas where OHV use was extensive (Busack and Bury, 1974; Bury and others, 1977; Luckenbach, 1978; Luckenbach and Bury, 1983; Brooks, 1999). Direct and indirect effects of OHVs on these species include breaking shrubs containing nests (nests, eggs, or nestlings destroyed) and diminished cover when shrubs are reduced or eliminated, mortality due to vehicle impact (especially ground-dwelling animals), and collapse of burrows due to OHV traffic (Bury and others, 1977). Bury and others (1977) found greater small mammal species richness (1.25 times greater) and abundance (500 percent more individuals) at control sites than OHV sites. Similarly, Luckenbach and Bury (1983) found 1.5 times more small mammal species, 5.1 times more individuals, and 2.2 times more biomass in control plots than in OHV-impacted plots; the number of desert kangaroo rats recorded in OHV plots was 53 percent lower than the number in control plots. Luckenbach and Bury (1983) found that overall animal activity—as measured by track frequencies—was greater in control areas than it was in OHV-use areas: arthropod tracks were 24 times more abundant, kangaroo rat tracks were 5 times more abundant, kit fox tracks were 2 times more abundant, and cottontail rabbit tracks were 10 times more abundant. Finally, Brooks (1999) found that protected areas in the Desert Tortoise Research Natural Area supported a greater abundance and species richness of birds and lizards than nearby portions of the desert subjected to intense OHV use and past sheep grazing. In one study, however, road mortality did not appear to have detrimental effects on densities of small mammals inhabiting highway right-of-ways, although the authors admit that they could not rule out confounding effects of immigration (Adams and Geis, 1983). In a study of 36 radio-marked flat-tailed horned lizards (*Phrynosoma mcallii*) subjected to high (60 percent OHV track coverage in 60 minutes of riding time), low (30 percent in 20 minutes of riding time), and no (0 percent) impact by OHV traffic in 100 × 100 m (109.4 × 109.4 yd) plots, all survived. At the time of OHV treatment, however, 32 of the lizards were in their hibernation burrows 2–17 cm (0.8–6.7 in) underground (Grant, 2005), and it remains unclear whether soil substrates and vegetation growing above the burrows helped protect the animals from being crushed (21 of the 32 were under shrubs, and 8 burrows were known to have been run over directly by OHVs).

A major indirect effect of OHV activity on vertebrate survivorship is loss of vegetation cover. For all terrestrial vertebrates sampled, including species of conservation concern (desert

kangaroo rat [*Dipodomys deserti*] and fringe-toed lizard [*Uma notata*]), Bury and others (1977) found a positive correlation between the percent canopy cover of creosote bush and species richness, abundance, and biomass. In a study of OHV effects on biota (including herbaceous and perennial plants, arthropods, lizards, and mammals) of the Algodones Dunes area in California, Luckenbach and Bury (1983) detected 9.4 times more cover, and 40 times more overall volume in control plots than in OHV-impacted plots, largely because shrubby perennial cover was greater in control plots. Another indirect effect of OHV activity on wildlife mortality is the proliferation of routes that provide greater access to remote places by hunters, poachers, and people seeking several forms of nonconsumptive recreation (Boyle and Samson, 1985; Andrews, 1990). Boyle and Samson (1985) also report a variety of nonconsumptive recreation impacts on wildlife, including flushing animals off nests; unnecessary energy expenditures; and displacement of animals from food, shelter, and other vital resources. Of particular concern was the increasing access that roads provide for tortoise collectors, which may explain declining trends in tortoise numbers along highways (Boarman and others, 1997).

#### 2.4.6 Annotated Bibliography for OHV Effects on Wildlife and Habitats: Native, Threatened, and Endangered Species

**Berry, K.H., 1980**, A review of the effects of off-road vehicles on birds and other vertebrates, in DeGraaf, R.M., and Tilghman, N.G., eds., *Management of western forests and grasslands for nongame birds—Workshop proceedings*, Salt Lake City, Utah, February 11–14, 1980: Ogden Utah, U.S. Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report INT–86, p. 451–467.

A review of the literature on the effects of off-road vehicles revealed that OHV use has significant effects and can reduce numbers, diversity, and biomass of birds and other vertebrates. The degree of impact depends upon amount and intensity of OHV use, habitat type, and sensitivity of the species.

**Boarman, W.I., and Sasaki, M., 2006**, A highway's road-effect zone for desert tortoises (*Gopherus agassizii*): *Journal of Arid Environments*, v. 65, no. 1, p. 94–101.

Roads can affect populations of animals directly (vehicle-animal collisions) and indirectly (due to habitat fragmentation and dispersal/proliferation of non-native or predatory species). This study investigated the effect of a 2- to 4-lane highway (with a posted speed limit of 65 mi/hr [105 km/hr] and an average daily traffic intensity of 8500 vehicles) on threatened desert tortoise (*Gopherus agassizii*) populations in the Mojave Desert, California, and attempted to determine the width of the road-effect zone by counting signs of tortoises (shells, tracks, scats, burrows, and pallets) along transects at 0, 400, 800, and 1600 m from and parallel to the edge of a highway. Mean sign count was 0.2/km (0.32/mi) at 0 m (0 yd), 4.2/km (6.72/mi) at 400 m (437.4 yd), 5.7/km (9.12/mi) at 800 m (874.9 yd), and 5.4/km (8.64/mi) at 1600 m (1749.8 yd) from the highway edge. The differences between all distances except 800 and 1600 m (874.9 and 1749.8 yd) were statistically significant, suggesting that tortoise populations in the study area were depressed within a zone extending at least 400 m (437.4 yd) from the highway.

**Brattstrom, B.H., and Bondello, M.C., 1983**, Effects of off-road vehicle noise on desert vertebrates, in Webb, R.H., and Wilshire, H.G., eds., *Environmental effects of off-road vehicles—Impacts and management in arid regions*: New York, Springer-Verlag, p. 167–206.

This study determined that sand lizards (*Uma scoparia*) and kangaroo rats (*Dipodomys deserti*) suffered hearing loss lasting for weeks after being exposed to less than 10 minutes of playback recordings of dune buggy sounds played intermittently at intensities lower than the average intensity levels actually emitted by OHVs. Such impacts led to the inability of both of these species to respond to recordings of predator sounds. A spadefoot toad (*Scaphiopus couchii*) emerged prematurely from its burrow when exposed to 30 minutes of taped motorcycle sounds.

**Brooks, M.L., 1999**, Effects of protective fencing on birds, lizards, and black-tailed hares in the western Mojave Desert: Environmental Management, v. 23, no. 3, p. 387–400.

Effects of a protective (fenced) area on birds, lizards, black-tailed hares (*Lepus californicus*), perennial plant cover, and structural diversity of perennial plants were evaluated from spring 1994 through winter 1995 at the Desert Tortoise Research Natural Area (DTNA), in the Mojave Desert, California. Abundance and species richness of birds were greater inside than outside the DTNA; these effects, however, were more pronounced during breeding season and a year of high rainfall than during winter and a year of low rainfall. Nesting activity was also more frequent inside the enclosure. Total abundance and species richness of lizards and individual abundances of western whiptail lizards (*Cnemidophorus tigris*) and desert spiny lizards (*Sceloporus magister*) were greater inside than outside the enclosure. Black-tailed hares generally prefer areas of low perennial plant cover, which may explain why they were more abundant outside than inside the DTNA. Habitat structure may not affect bird and lizard communities as much as availability of food at this desert site, and the greater abundance and species richness of vertebrates inside than outside the DTNA may correlate with abundances of seeds and invertebrate prey.

**Bury, R.B., Luckenbach, R.A., and Busack, S.D., 1977**, Effects of off-road vehicles on vertebrates in the California desert USA: Wildlife Research Report no. 8, U.S. Fish and Wildlife Service, Washington, D.C., p. 1–23.

This study compared differences in avian diversity, abundance, and biomass in unused and OHV-disturbed sites. Compared to OHV sites, reptile species richness was 1.63 times greater and there were 270 more individuals at control sites. Similarly, mammal species richness was 1.25 times greater and there were 115 more individuals at control sites than at OHV sites. The potential for ground nests of birds to be crushed and incubating birds to abandon nests was greater in areas of high OHV activity. Indirect effects of OHV activity on vertebrates were primarily caused by the loss of vegetation cover. There was a positive correlation between the cover of creosote bush and the total number of species, abundance, and biomass of all terrestrial vertebrates sampled.

**Bury, R.B., and Luckenbach, R.A., 2002**, Comparison of desert tortoise (*Gopherus agassizii*) populations in an unused and off-road vehicle area in the Mojave Desert: Chelonian Conservation and Biology, v. 4, no. 2, p. 457–463.

This study examined habitat, abundance, and life history features of desert tortoises (*Gopherus agassizii*) on two 25-ha plots in the western Mojave Desert: one unused and one used by OHVs. The unused plot had 1.7 times more live plants, 3.9 times more plant cover, 3.9 times more desert tortoises, and 4.0 times more active tortoise burrows than a nearby area used heavily by OHVs; these between-plot differences were all statistically significant. Furthermore, the few large-sized tortoises in the OHV plot had less body mass than those in the unused area. Although

the scope of this study was limited to one paired-plot comparison, current data suggest that operation of OHVs in the western Mojave Desert results in major reductions in habitat and tortoise numbers, and possibly the body mass of surviving tortoises.

**Lovich, J.E., and Bainbridge, D., 1999**, Anthropogenic degradation of the southern California desert ecosystem and prospects for natural recovery and restoration: *Environmental Management*, v. 24, no. 3, p. 309–326.

Large areas of the southern California desert ecosystem have been affected by off-highway vehicle use, overgrazing by domestic livestock, agriculture, urbanization, construction of roads and utility corridors, air pollution, military training exercises, and other activities. Secondary contributions to degradation include the dispersal and proliferation of exotic plant species and a higher frequency of anthropogenic fire. Effects of these impacts include alteration or destruction of macro- and micro-vegetation elements, establishment of annual plant communities dominated by exotic species, destruction of soil stabilizers, soil compaction, and increased erosion. This paper provides a broad view of impacts on biota and cites several pertinent studies relative to OHV impacts on wildlife. The authors suggest that given the sensitivity of desert habitats to disturbance and the slow rate of natural recovery, the best management option is to limit the extent and intensity of impacts as much as possible.

**Luckenbach, R.A., and Bury, R.B., 1983**, Effects of off-road vehicles on the biota of the Algodones Dunes, Imperial County, California, USA: *Journal of Applied Ecology*, v. 20, no. 1, p. 265–286.

Algodones Dunes, the largest dune complex in California, contains many unique species; however, it also receives the greatest use by off-road vehicles in California. Studies of paired plots (unused versus OHV-impacted) and animal tracks along sand sweeps clearly demonstrated that OHV activities in the Algodones Dunes significantly reduced the biota. There were marked declines in herbaceous and perennial plants, arthropods, lizards, and mammals in OHV-used areas compared with nearby controls. All sand-adapted species, including several rare or threatened plants, were greatly reduced in habitats where OHVs operate; the biota was affected even by relatively low levels of OHV activity. Areas heavily used by OHVs had virtually no native plants or wildlife.

**Rosen, P.C., and Lowe, C.H., 1994**, Highway mortality of snakes in the Sonoran Desert of southern Arizona: *Biological Conservation*, v. 68, no. 22, p. 143–148.

A total of 368 snakes (104 live, 264 dead) were recorded over four years on a paved highway during 15,525 km (9,647.2 mi; mostly within Organ Pipe Cactus National Monument, Arizona) of driving along the road to detect amphibians and reptiles during rainfall events or while basking on the warm road surface. During 4 years, an estimated 2,383 snakes were killed on this stretch of pavement, although the actual number killed was probably closer to 4,000.

**Webb, R.H., and Wilshire, H.G., 1983**, Environmental effects of off-road vehicles—Impacts and management in arid regions: New York, Springer-Verlag, 534 p.

This book discusses the physical and biological effects of OHVs (recreational, mining, and military vehicles) on arid-land ecosystems, including effects on soils, vegetation, and wildlife. It also points out the loss of choices that OHV effects impose on future land users. Actual case studies are presented, complete with practical solutions, detailed planning measures



that can be taken to reduce the adverse effects of OHVs, methods that can be used to rehabilitate the physical systems and vegetation communities of disturbed areas, and management concepts and practices that can be employed in protecting susceptible areas, including regulations and education.

## **2.5 OHV Effects on Water Quality**

### **2.5.1 Section Summary**

The direct effects of OHV activity on aquatic systems have received surprisingly little attention, due, in part, to the fact that OHV-impact research has focused on arid environments, where aquatic systems are seasonal or rare. Nonetheless, there is great potential for OHV activities to affect water quality in arid environs as well as well-watered regions. As described in Sections 2.2 and 2.3, soil properties and vegetation cover may be altered by OHV use; in turn, surface patterns of precipitation runoff (amount, velocity) may be altered, resulting in accelerated rates of erosion and sedimentation and elevated levels of turbidity in affected watersheds. Where slope is a factor, the extensive networks of OHV routes proliferating across landscapes can serve as conduits that direct or alter the direction of surface flows. These conduits may be eroded to form gullies that channel dislodged sediments and contaminants into aquatic ecosystems. Water quality also is adversely affected by OHV-raised dust that settles into aquatic systems.

OHV-dispersed chemicals also may be transported into aquatic systems. The operation of OHV engines, especially 2-stroke engines, can impact water quality through spills and emissions. These contaminants may enter aquatic systems via direct flushing, or they may be adsorbed to sediments and/or absorbed by plant materials, both of which are easily transported to aquatic systems by precipitation runoff or wind. Spill or emission contaminants may include 1,3-butadiene, benzene and ethylbenzene, xylenes, and toluene. Prior to the ban on leaded gasoline, lead levels were high in plants and animals near roads, and although the 1996 ban on leaded gasoline has resulted in dramatic declines in lead levels, it persists in the soil and may be mobilized when soils are eroded into wetlands.

### **2.5.2 Sedimentation and Turbidity**

Areas naturally most susceptible to water-quality problems are those where infiltration rates are low, slopes are steep, the ratio of surface sand and gravel to finer particles is low, and where rainfall events are typically prolonged and intense (Iverson and others, 1981). Altering soil texture, disrupting soil crusts or desert pavement, and reducing vegetation cover can increase the soil's susceptibility to erosion; in turn, rates of sedimentation and turbidity levels can increase and alter the water quality of a given watershed, including streams and rivers, lakes, and small, isolated wetlands, including vernal pools (Forman and others, 2003). Sediments can displace the water-holding volume of a wetland, thus diminishing or eliminating the wetland's hydrological function (Luo and others, 1977). For example, where OHVs had traveled over the soil, Iverson and others (1981) found that surface runoff was 5 times greater and yielded 10-20 times more sediment than where soils were undisturbed.

Where OHV activity occurs, networks of OHV routes proliferate. Wheel cuts and tracks within these networks may serve as water conduits that channel and direct water flow containing sediments and contaminants into aquatic ecosystems (Wemple and others, 1996; Forman and others, 2003, p. 185–197). The generally impervious nature of soils compacted by OHV traffic enhances gully formation in these conduits, thus promoting additional flows of sediments and suspended solids into aquatic systems, effectively extending the drainage network of a given

watershed, and potentially changing the timing of peak runoff flows (Wemple and others, 1996). The presence of OHV-route networks is an important factor in determining the severity of potential sedimentation in nearby aquatic systems. In particular, Wemple and others (1996) found that the drainage ditches along logging roads and the gullies that form below culvert outlets (where drainage flows pass under a road, or cross-drains) on steep slopes served as primary conduits linking surface flows to streams. The extent to which sediments might be carried along these conduits and into aquatic systems depends primarily on the presence of obstructions below cross drains and the spatial intervals between them (Haupt, 1959). In situations where cross drains were positioned at sufficient distances from streams, the drainage discharge infiltrated the soil and did not contribute to sedimentation in streams (Haupt, 1959). In areas characterized by soils with relatively low infiltration rates, such as those compacted by OHV use, transport of sediments over greater distances and into aquatic systems may be substantial.

Furniss and others (2000) describe similar effects of road and/or trail networks across a landscape. In particular, they discuss the continuous “hydrological connections” that facilitate sediment transport between surface flows and waterways. Furniss and others (2000) go on to list ways in which water and associated sediments enter stream systems from roads, including (1) inboard ditches (ditches perpendicular to the road footprint and that bisect the road) delivering runoff to a stream at a road-stream crossing, (2) inboard ditches delivering water to a cross-drain (culvert, dip, waterbar), (3) where sufficient discharge is available to create a gully or sediment plume that extends to the stream channel, (4) roads sufficiently close to streams so that the fillslope (road fill between the outside edge of the road and the base of the fill where it meets the natural ground surface) encroaches on the stream, and (5) landslide scars on the road fill. These connections provide direct routes for accelerated runoff transporting sediments and road-associated contaminants to natural drainage channels.

### 2.5.3 Dust and Contaminants

Water quality also is adversely affected when fugitive dust and contaminants enter aquatic systems. Emissions from OHVs, particularly those with 2-stroke engines, can include a variety of contaminants, which may settle directly in wetlands or they may be deposited in snow or directly on soils during rain events, from which they may be mobilized into wetlands. Arnold and Koel (2006), who tested snowmelt runoff exposed to significant snowmobile emissions in Yellowstone National Park, detected benzene, ethylbenzene, m- and p-xylene, o-xylene, and toluene, and although all compounds were within the limits set by the U.S. Environmental Protection Agency, it is not clear what the cumulative impacts of these chemicals may be in watersheds. Adams (1975) found that the stamina of brook trout experimentally exposed to elements commonly found in snowmobile emissions, as measured by their ability to swim against the water current, was significantly diminished compared to that of control fish.

Airborne dust—and contaminants adsorbed to dust particles—raised by OHV traffic may eventually settle directly into wetlands (Forman and others, 2003, p. 231–234). The potential for adsorbed contaminants to be carried along with precipitation runoff and into wetlands is also a concern, as are plant materials containing adsorbed contaminants. Finally, contaminants may enter aquatic habitats by direct flushing of exposed contaminants (for example, petroleum puddles). Prior to the ban on leaded gasoline, lead levels were high in plants and animals near roads (Daines and others, 1970; Motto and others, 1970; Quarles and others, 1974; Wheeler and Rolfe, 1979). Although the 1996 ban on leaded gasoline has since resulted in dramatic declines

in lead levels along roadsides and in organisms, it persists in the soil and may be mobilized when soils are eroded into wetlands.

#### 2.5.4 Annotated Bibliography for OHV Effects on Water Quality

**Adams, E.S., 1975**, Effects of lead and hydrocarbons from snowmobile exhaust on brook trout (*Salvelinus fontinalis*): Transactions of the American Fisheries Society, v. 104, no. 2, p. 363–373.

Prior to snowmobiling season, hydrocarbon levels in the water of a pond in Maine were undetectable; by the time of ice-out in spring, hydrocarbon levels had reached 10 parts per million (ppm) in the water and 1 ppm in exposed fish. In addition, exposed brook trout fingerlings contained 9 to 16 times more lead than control trout. Brook trout (*Salvelinus fontinalis*) held in aquaria for 3 weeks in melted snow containing three different concentrations of snowmobile exhaust also showed hydrocarbon and lead uptake. Stamina, as measured by the ability to swim against current, was significantly less in trout exposed to snowmobile exhaust than in control fish.

**Brabec, E., Schulte, S., and Richards, P.L., 2002**, Impervious surfaces and water quality—A review of current literature and its implications for watershed planning: Journal of Planning Literature, v. 16, no. 4, p. 499–514.

This paper focuses on the effect of impervious surfaces on the health of nearby aquatic habitats. Although considerable research has been done to define watershed thresholds of impervious surfaces (beyond which water quality declines), there are numerous flaws in the assumptions and methodologies used. Given refinement of the methodologies, accurate and usable parameters for preventive watershed planning can be developed, including thresholds of impervious surfaces and balances between pervious/impervious surfaces within a watershed.

**Brown, K.J., 1994**, River-bed sedimentation caused by off-road vehicles at river fords in the Victorian Highlands, Australia: Water Resources Bulletin, v. 30, no. 2, p. 239–250.

This study investigated some of the effects occurring at OHV crossings on two rivers in eastern Australia, where many road crossings occur at low-level fords. It provides a method whereby the amount of sediment redeposited downstream of a ford can be measured. Attention is drawn to the fact that sediment is contributed to rivers by five major processes: the exposure of surfaces, the concentration of surface runoff in wheel ruts, soil compaction and subsequent reduction of water infiltration leading to increased surface runoff, backwash from the vehicle, and undercutting of banks by bow-wave action. The last two of these processes have not been reported previously. Sediment collection experiments in two upland rivers indicated a mean deposition rate at the stream bed of approximately 1,000 g/m<sup>2</sup> over a period of 30 days.

**Furniss, M.J., Flanagan, S.A., and McFadin, B.A., 2000**, Hydrologically connected roads—An indicator of the influence of roads on chronic sedimentation, surface water hydrology, and exposure to toxic chemicals: U.S. Forest Service, Stream Systems Technology Center, Rocky Mountain Research Station, Technical Report, 4 p., [http://www.stream.fs.fed.us/streamnt/jul100/jul100\\_2.htm](http://www.stream.fs.fed.us/streamnt/jul100/jul100_2.htm).

This study defines the concept of forest-road drainage as a transport system for sediment into streams and proposes design changes to road drainage that would prevent or minimize this movement. The proportion of road that is hydrologically connected to a stream network may be a useful indicator of the potential for several adverse effects, including (1) the delivery of road-

derived sediments to streams; (2) hydrologic changes associated with subsurface flow interception, concentration, and diversion; (3) increased drainage density; (4) extension of the stream network; and (5) the potential for road-associated spills and chemicals to enter streams.

**Hamilton, L.J., 2002**, A study of the effects of ORV stream crossings on water quality of two streams located in the Angelina National Forest, Texas—A physicochemical and benthic macroinvertebrate analysis: *Masters Abstracts International*, v. 40, no. 3, p. 668.

A study was conducted for the U.S. Forest Service to determine whether OHV-based stream crossings affected water quality of two streams located in Texas. The sites differed most in turbidity, total solids, Shannon's diversity index, dissolved oxygen, nitrate, and ratios of Chironomidae:EPT (Ephemeroptera + Plecoptera + Trichoptera, a common indicator of taxonomic richness detected during stream surveys to assess water quality), although there were no significant differences in the physicochemical properties. At one site, however, the upstream and downstream plots differed significantly in terms of two benthic indices—Hilsenhoff's *Biotic Index* and *Ratio of Scrapers to Filtering Collectors*.

**Katz, M., Legore, R.S., Weitkamp, D., Cummins, J.M., and Anderson, D., 1972**, Effects on freshwater fish: *Journal of the Water Pollution Control Federation*, v. 44, no. 6, p. 1226–1250.

This is a literature review of the effects of water pollutants on freshwater fish. Topics include (1) tests to determine the lethality of estuarine and some polluted river waters to trout and cyprinids; (2) estimated degrees of river pollution based on bacterial and chemical analysis of water samples; (3) documentation of some effects of municipal wastewater effluents on the water quality, fish populations, and bottom-fauna characteristics of a receiving stream; and (4) observations of the environmental effects of pollutants such as synthetic detergents, industrial wastes, and pesticides.

**Roy, A.H., Rosemond, A.D., Leigh, D.S., Paul, M.J., and Wallace, J.B., 2003**, Habitat-specific responses of stream insects to land cover disturbance—Biological consequences and monitoring implications: *Journal of the North American Benthological Society*, v. 22, no. 2, p. 292–307.

This study analyzed the impact of a range of physical and chemical stressors on aquatic insects and tested whether the effects of these stressors differed in three habitat types: riffles, pools, and banks. Riffle assemblages were affected by both physical (for example, streambed mobility) and chemical (specific conductance, nutrient concentration) variables. The density of aquatic insects in pools also was correlated to physical and chemical variables, but there were few relationships with pool or bank richness or bank density. Because relative impacts of disturbance in riffles were greater than in banks, the authors found greater differences between riffle and bank richness in streams with greater sedimentation. The proportion of bank richness (bank richness/bank + riffle richness) increased with finer bed sediment and increased bed mobility. The study also compared richness of facultative taxa (found in multiple habitats) between sites characterized as minimally impacted and sediment-impacted. In riffles, richness of facultative taxa was lower in sediment-impacted than in minimally impacted sites, but was similar for both disturbance groups in banks.

**Wheeler, A.P., Angermeier, P.L., and Rosenberger, A.E., 2005**, Impacts of new highways and subsequent landscape urbanization on stream habitat and biota: *Reviews in Fisheries Science*, v. 13, no. 3, p. 141–164.

This paper emphasizes a more thorough consideration of highway impacts and, ultimately, better land-use decisions by conceptualizing road development in three stages: initial construction, road presence, and eventual landscape urbanization. Road construction is characterized by localized physical disturbances, which generally subside through time. In contrast, road presence and landscape urbanization are characterized by persistent physical and chemical impacts. Though not specific to OHV activity, this paper does focus on the fact that landscape urbanization is clearly the greatest threat to stream habitat and biota, as stream ecosystems are sensitive to even low levels (less than 10 percent of a given watershed) of urban development. Researchers know little about the occurrence, loading rates, and biotic responses to specific contaminants in runoff from roads. Also needed is a detailed understanding of how drainage crossings, especially culverts, affect fish populations via constraints on movement and how road networks alter natural regimes (streamflow, temperature).

## **2.6 OHV Effects on Air Quality**

### **2.6.1 Section Summary**

Fugitive dust raised by OHV traffic on unpaved roads/trails can contribute significantly to air-quality problems. Also problematic are OHV emissions, particularly from 2-stroke engines. Currently, many OHVs in use, including off-highway motorbikes and ATVs, run on 2-stroke engines, which do not burn fuel completely and produce significant amounts of airborne contaminants, including nitrogen oxides, carbon monoxide, ozone, aldehydes, and extremely persistent polycyclic aromatic hydrocarbons (PAH), including the suspected human carcinogen, methyl tert-butyl ether (MTBE). Some airborne contaminants settle onto plants or into soils and function as fertilizers, thus causing changes in plant community composition and altering growth rates. The accumulation of emissions contaminants is evident in the tissues of plants and animals exposed to them. Prior to the ban on leaded gasoline, lead also was prevalent in plants and animals near paved roads and other travel routes, and because it persists in the environment, it can still have impacts when contaminated soils are mobilized.

### **2.6.2 Fugitive Dust Raised by OHV Traffic**

Fugitive dust (largely composed of lightweight soil particles, including silt and clay) suspended in the air may impact more total area than any other impact of roads (paved or unpaved; Forman and others, 2003), and it can have significant effects on ecosystems (Westec, 1979). Dust is created and raised into the air as OHVs disturb soil crusts, abrade and pulverize soils, and generate wind currents. Once soil surfaces are disturbed, wind erosion may increase the amount of debris flow (Lovich and Bainbridge, 1999). In 1973, satellite photos detected six dust plumes in the Mojave Desert covering more than 1,700 km<sup>2</sup> (656.2 mi<sup>2</sup>); the plumes were attributed to destabilization of soil surfaces resulting from OHV activities (Nakata and others, 1976; Gill, 1996). Along roads in Alaska heavily traveled by various types of vehicles, Walker and Everett (1987) found that dust had buried mosses and very low-statured vegetation in the 10-m-wide area adjacent to each side of the road; dust blankets measured up to 10 cm (3.9 in) deep. Accumulations of dust on vegetation can disrupt photosynthetic and respiration processes, leading to reduced plant growth, reproduction, and survivorship.

### **2.6.3 Contaminants Associated with OHV Use**

Before emissions controls on automobiles became significantly more effective, there was little concern about emissions from small engines; today, however, their relative contribution to

air-quality problems is significant (see <http://www.egr.msu.edu/erl/Small%20Engine%20Emissions.html>). This is because small engines, especially 2-stroke models (many of which are being phased out), do not burn fuels completely; thus, their emissions contain the resulting by-products of incomplete combustion, including nitrogen oxides NO<sub>x</sub>, sulfur dioxide (SO<sub>2</sub>), carbon monoxide (CO), ozone (O<sub>3</sub>), aldehydes, and extremely persistent polycyclic aromatic hydrocarbons (PAH). In fact, a very small, 2-stroke engine running for 2 hours emits the same amount of hydrocarbons as driving 10 cars (of the fuel-burning efficiency produced in 1995) for 250 miles each ([http://www.arb.ca.gov/msprog/offroad/sm\\_en\\_fs.pdf](http://www.arb.ca.gov/msprog/offroad/sm_en_fs.pdf)).

Pollutants emitted from exhaust can cause a variety of impacts on vegetation. Carbon dioxide may function as a fertilizer and cause changes in plant species composition (Bazzaz and Garbutt, 1988; Hunt and others, 1991; Ferris and Taylor, 1995); nitrogen oxides also may function as fertilizers, producing similar effects along roadsides (Falkengren-Grerup, 1986; Holzappel and Schmidt, 1990; Angold, 1997). Spencer and Port (1988) found that the soluble nitrogen content of perennial ryegrass (*Lolium perenne*) plants growing within 0-6 m (0-6.6 yd) of a paved road than in plants growing more than 6 m (6.6 yd) from the road, which contributed to greater growth rates and fecundity of aphids (*Rhopalosiphum padi*) inhabiting the plants closest to the road. Sulfur dioxide, which can be taken up by vegetation, may result in altered photosynthetic processes (Winner and Atkison, 1986; Mooney and others, 1988).

Several species of Mojave Desert perennials and annuals were fumigated in experimental chambers to determine their sensitivities to SO<sub>2</sub>, nitrogen dioxide (NO<sub>2</sub>), and O<sub>3</sub>; Thompson and others, 1980; Thompson and others, 1984). Creosote bush (*Larrea* sp.), the only perennial species found to be sensitive to SO<sub>2</sub> and NO<sub>2</sub>, exhibited leaf injury and reduced growth when exposed to SO<sub>2</sub> and NO<sub>2</sub>; however, numerous annuals, including redstem stork's bill (*Erodium cicutarium*) and desert Indianwheat (*Plantago insularis*; extremely sensitive), cleftleaf wildheliotrope (*Phacelia crenulata*; very sensitive), and wooley desert marigold (*Baileya pleniradiata*), exhibited more dramatic effects, including extensive injury and death (Thompson and others, 1980). Another study by Thompson and others (1984) revealed several annual species that are extremely sensitive to SO<sub>2</sub> and O<sub>3</sub>, including brown-eyed primrose (*Camissonia claviformes*), Santa Cruz Island suncup (*C. hirtella*), and Nevada cryptantha (*Cryptantha nevadensis*).

OHV emissions also contain a variety of heavy metals, including zinc, copper, nickel, chromium, and lead (National Research Council, 1986). In terms of overall quantity, lead was one of the most significant heavy metals emitted prior to the ban on leaded gasoline in 1996 (Daines and others, 1970; Motto and others, 1970; Quarles and others, 1974; Wheeler and Rolfe, 1979). At least in desert regions, concentrations of lead particulates along roads were positively correlated with traffic volume (Motto and others, 1970). Within 80 m (87.5 yd) of roadsides, Quarles and others (1974) found that lead concentrations diminished notably from road edges (543 and 190 ppm) to 10 m (47 and 5 ppm, respectively) away from the edge; beyond 80 m, accumulations of lead diminished at lower rates. The declining gradient in lead concentrations away from roadsides may have been due, in part, to the direction of surface water flow (Byrd and others, 1983) as soil and other debris to which lead adheres were flushed away by the volume of water that runs off road surfaces. Although lead emissions from gasoline have declined dramatically since control policies were implemented in the 1970s (Forman and others, 2003), it persists in soils and can continue to move through the environment when contaminated soils are dislodged.

#### 2.6.4 Annotated Bibliography for OHV Effects on Air Quality

**Agrawal, Y.K., Patel, M.P., and Merh, S.S., 1981**, Lead in soils and plants—Its relationship to traffic volume and proximity to highway (Lalbag, Baroda City): *International Journal of Environmental Studies*, v. 16, no. 3–4, p. 222–224.

Accumulations of lead from motor-vehicle exhausts on soils and trees growing along a busy thoroughfare in the Lalbag area of Baroda City were studied. Analysis of soils and tree samples showed that the distribution of emitted lead was influenced by the direction of the prevailing wind. Lead concentrations in plants and soils near the roadside were greater than they were in soils and plants 4–6 m away from the roadside.

**Bazzaz, F.A., and Garbutt, K., 1988**, The response of annuals in competitive neighborhoods—Effects of elevated CO<sub>2</sub>: *Ecology*, v. 69, no. 4, p. 937–946.

Four members of an annual plant community were used to investigate the effects of changing neighborhood complexity and increased carbon dioxide (CO<sub>2</sub>) concentration on competitive outcome. Plants were grown in monoculture and in all possible combinations of two, three, and four species in CO<sub>2</sub>-controlled growth chambers at CO<sub>2</sub> concentrations of 350, 500, and 700 microliters/liter (μL/L) (1 ppm), with ample moisture and light. Species responded differently to enhanced CO<sub>2</sub> level. The biomass of some species (*Abutilon theophrasti*, for example) increased with increasing CO<sub>2</sub>, while that of others (*Amaranthus retroflexus*) decreased with increasing CO<sub>2</sub> concentration. The potential effects of CO<sub>2</sub> on community structure could be profound, particularly at the intermediate levels of CO<sub>2</sub> that are predicted for the first half of the 21st century.

**Gish, C.D., and Christensen, R.E., 1973**, Cadmium, nickel, lead, and zinc in earthworms from roadside soil: *Environmental Science and Technology*, v. 7, p. 1060–1062.

Cadmium (Cd), nickel (Ni), lead (Pb), and zinc (Zn) in soils and earthworms along two Maryland highways decreased with increasing distance (10, 20, 40, 80, and 160 ft) from the road. Along each highway, metal residues were greater where traffic volume was greater. Correlations between residues in earthworms and soil decreased with decreasing atomic weights (Pb, Cd, Zn, Ni). Metal residues in soils were positively correlated with quantities of soil organic matter. Earthworms accumulated up to 331.4 ppm of Pb and 670.0 ppm of Zn, concentrations that may be lethal to earthworm-eating animals.

**Motto, H.L., Daines, R.H., Chilko, D.M., and Motto, C.K., 1970**, Lead in soils and plants—Its relationship to traffic volume and proximity to highways: *Environmental Science and Technology*, v. 4, p. 231–237.

Lead concentrations increased with traffic volume and decreased with distance from highways. Much of the lead was present as removable surface contamination on plants, and major effects were limited to the soil surface within 100 ft (30.48 m) of the highway.

**Nakata, J.K., Wilshire, H.G., and Barnes, G.C., 1976**, Origin of Mojave Desert dust plumes photographed from space: *Geology*, v. 4, p. 644–648.

OHV-raised dust has been an enormous problem in the Mojave Desert, as illustrated by satellite photos that revealed six dust plumes covering more than 1,700 km<sup>2</sup> (656.4 mi<sup>2</sup>) of the western Mojave region in January 1973; the dust plumes were attributed to destabilization of ground surfaces, primarily from OHV activity.

**Quarles, H.D., Hanawalt, R.B., and Odum, W.E., 1974**, Lead in small mammals, plants, and soil at varying distances from a highway: *Journal of Applied Ecology*, v. 11, no. 3, p. 937–949.

Lead particulates were measured at varying distances from three highways. Lead concentrations were greatest within 10 m (10.9 yd) of the highways. Lead concentrations in the soil along two transects dropped from 543 ppm and 190 ppm at the road edge to 47 ppm and 5 ppm 10 m from the road edge. Both plants and animals were susceptible to lead uptake.

**Spencer, H.J., and Port, G.R., 1988**, Effects of roadside conditions on plants and insects. II. Soil conditions: *Journal of Applied Ecology*, v. 25, no. 22, p. 709–715.

An experiment was done to investigate the performance of plants (*Lolium perenne*) grown in roadside soil. Significantly fewer plants germinated in soil taken 0 to 6 m from the road compared with soil taken 6 m from the road. For a given population size, however, plants grown in soil taken from beside the road attained significantly greater dry weight and significantly greater soluble nitrogen content. Nitrogen oxide emissions, identified as the probable cause of these effects, were absorbed by the roadside soil and subsequently assimilated by the plants.

**Thompson, C.R., Olszyk, D.M., Kats, G., Bytnerowicz, A., Dawson, P.J., and Wolf, J.W., 1984**, Effects of ozone or sulfur dioxide on annual plants of the Mojave Desert: *Journal of the Air Pollution Control Association*, v. 34, no. 10, p. 1017–1022.

Forty-seven species of annual plants from the Mojave Desert were grown in pots and exposed in open-top field chambers located at Riverside, California, to test their relative sensitivity to SO<sub>2</sub> and O<sub>3</sub>. Species differed widely in their response to the pollutants. Three species, *Camissonia claviformis*, *Camissonia hirtella*, and *Cryptantha nevadensis*, were quite sensitive to both pollutants, exhibiting leaf injury when exposed to 0.1 ppm O<sub>3</sub> or 0.2 ppm SO<sub>2</sub>. The other species were intermediate in sensitivity, and O<sub>3</sub> sensitivity did not always correspond to SO<sub>2</sub> sensitivity. For 8 of 11 species tested, total sulfur concentration was greater in plants exposed to 0.2 ppm SO<sub>2</sub> than in unexposed plants. *Baileya pleniradiata* and *Perityle emoryi* exhibited the greatest increases in sulfur concentration for exposed versus control plants.

**Walker, D.A., and Everett, K.R., 1987**, Road dust and its environmental impact on Alaskan taiga and tundra: *Arctic and Alpine Research*, v. 19, no. 4, p. 479–489.

The physical and chemical characteristics and ecological consequences of road dust in arctic regions were reviewed with emphasis on recent information gathered along the Dalton Highway and the Prudhoe Bay Spine in northern Alaska. Enhanced dust-control measures were considered, particularly where the road passes through scenic lichen woodlands, acidophilic tundra, and in calm valleys where dust commonly was a traffic-safety hazard.

**Westec Services Inc., 1979**, Fugitive dust impacts during off-road vehicle (ORV) events in the California desert: Tustin, California, WESTEC Services, Inc., Technical Report, 40 p.

Results and analysis of dust monitoring for five desert races demonstrated that factors such as distance from the point of generation, soil moisture, soil characteristics, wind, and relative humidity, as well as the type and number of vehicles in the race, had the largest effect on the amount and type of dust, particulate size, how quickly it settled, and the extent of the human health hazard present during the race. Long period (daily) dust-exposure levels were 10 times



greater than the standard, whereas short period (hourly) dust levels were 100 times greater than the standard under adverse conditions near the race activity.

## **2.7 Socioeconomic Implications of OHV Use**

### **2.7.1 Section Summary**

The socioeconomics of OHV use include OHV user demands, concerns, and attitudes; the economic effects of OHV use on communities near OHV-use areas; the economics of managing OHV activities; the effects of OHV use on non-motorized recreators; and the economics of losing ecosystem services. Although not currently addressed through BLM's indicators of rangeland health, natural resource attributes are heavily influenced by socioeconomic factors. Since the mid 1980s, the incidence of OHV use on public lands has increased substantially, and this trend is expected to continue. Moreover, the economic benefits from travel expenditures and the sales of supplies and equipment in communities bordering OHV-use areas generates significant pressure to maintain or increase current levels of OHV activity. As OHV activity increases, however, increasing stress is placed on natural resources, land managers who must monitor and regulate OHV activities, and visitors seeking non-motorized forms of recreation.

### **2.7.2 Trends in OHV Use and Technology**

In a survey of Utah OHV users commissioned by the Utah Department of Natural Resources, Fisher and others (2001) found that public lands are primary destinations among most users; only one quarter of survey respondents took trips to private land. More specifically, BLM land was the primary destination for ATV, motorcycle, and 4 x 4 vehicle users; U.S. Forest Service land was the secondary destination among ATV and 4 x 4 users; and State land was the secondary destination among motorcycle users (Fisher and others, 2001). Increasing OHV use is likely to be accompanied by greater demand for places where OHVs can be used, particularly near urban areas and corridors; as urban populations increase, so do the numbers of recreators on nearby public lands, thereby putting more stress on the landscape (Brooks and Champ, 2006). The increasing demands also pose problems for land managers already balancing the needs of a dynamic land base, often with limited budgets and/or staffing (Brooks and Champ, 2006; Rocky Mountain Research Institute, 2002). These limitations constrain land managers but not OHV use; thus, OHV recreation is largely "unmanaged." In addition, technology advancements in outdoor recreation equipment have led to production of OHVs that easily access lands previously unimpacted by mechanized recreation (Meine, 1998; Ewert and Shultis, 1999). As a result, new problems have arisen for both previously unimpacted areas and backcountry users who now encounter OHVs. Problems potentially arising from a constrained ability to manage lands include resource degradation, displacement of wildlife, and conflict among users, both within and across user types.

### **2.7.3 Types, Sources, and Effects of OHV User Conflict**

Much of the OHV literature addresses conflicts between OHV users and other land users, even those who are not directly affected by OHV users. Researchers have addressed conflict issues by using a variety of tools or models designed to help managers understand and reduce conflicts between or among user groups. Bury and others (1983, p. 401) describe conflict as existing "whenever incompatible activities occur" and offer three elements that contribute to the incompatibility of activities: spatial and temporal proximity, dominance over the environment, and dependence on technology. When the proximity of activities does not result in direct or

indirect (seeing the effects of other uses) encounters among user types, then environmental dominance and technological dependence are more likely to come into play. Dominance over the environment refers to how much an individual feels the need to exert some kind of control over the environment. Dependence on technology can cause conflict when people who retreat to backcountry to seek solace from modern technology clash with those who use technology to enhance their outdoor experiences. Conflict also occurs between land users and land managers. Inconsistent management policies across different land management agencies can cause such conflict, particularly as OHV recreation is ushered from being “unmanaged” to “managed.” On many public lands, trails are currently considered open unless posted as closed, and once a trail has been established by users, it is often considered open for use (Brooks and Champ, 2006).

Graefe and Thapa (2004) outline some of the traditional approaches to examining user conflicts through research, including studies of goal interference (first introduced by Jacob and Shreyer, 1980). Goal interference occurs when a user comes into direct (seeing the conflicting recreation type) or indirect (seeing the *effects* of a recreation type) contact with another user type and is impeded from accomplishing the desired purpose of his or her recreation (Badaracco, 1976). The factors that contribute to goal interference are activity style, resource specificity, mode of experience (whether individuals are focused or unfocused), and tolerance for lifestyle diversity. Another model classifies conflict as either interpersonal conflict or a conflict of social values (Vaske and others, 1995). Interpersonal conflict is similar to goal interference in that a user has a problem with another use type and encounters an individual participating in, or evidence of, that type (hearing OHV noise, for example). Social values conflict occurs regardless of whether or not differing user types encounter one another—just knowing that the other recreation type is permitted may be unacceptable.

In the literature on user conflict, conflict is more often characterized as one-sided than two-sided (Badaracco, 1976; Bury and others, 1983; Watson and others, 1997; Graefe and Thapa, 2004). For example, while backpackers may perceive OHV users as disruptive to their experience, it is less likely that OHV users will find backpackers disruptive to their experience (Jackson and Wong, 1982). Displacement is the most common personal coping mechanism by which conflict is abated (Watson et al, 1997; Graefe and Thapa, 2004). That is, if an individual feels negatively enough about certain recreational activities occurring in the area he/she wishes to use, there is a possibility that the individual will simply forgo recreating in the area altogether, thereby increasing the probability that area managers will gradually lose support from that user base (Watson and others, 1997; Graefe and Thapa, 2004).

## 2.7.4 OHV Users and Their Preferences

Overall, understanding the social effects of OHV use requires understanding the full array of recreational activities sought and the preferences of both OHV and non-OHV users alike. For example, people engaged in camping may include both OHV and non-OHV users, which can result in dissatisfaction among campers. In a survey of campers that included both OHV and non-OHV users, 66 percent indicated that having a regulated OHV riding area nearby would make their stay more enjoyable because it would reduce the number of riders in other areas and maintain a safer environment for both riders and campers (Bury and Fillmore, 1974). When given a choice between having (1) no motorcycle riding area but permission to ride on campground roads, (2) prohibition of all motorcycle riding, or (3) a nearby motorcycle area and no permission to ride on campground roads, 75 percent of riders and campers surveyed preferred the third alternative (Bury and Fillmore, 1974; riders and campers were socioeconomically similar).

Fisher and others (2001) reported that although 63.2 percent of motorcycle users surveyed did not stop to engage in any other type of recreational activity, almost 60 percent of ATV owners and 75 percent of 4 X 4 vehicle owners did engage in other recreational activities during their trips. Of those OHV users who did stop to engage in additional recreational activities, hiking was the most popular (>75 percent of motorcycle/4 X 4 vehicle users and 20 percent of ATV users). Hunting was the other most common recreational activity among ATV users and the second most common activity among 4 X 4 vehicle users; other recreational activities included fishing, camping, and sightseeing (Fisher and others, 2001).

Overall, the results of the user preference surveys discussed previously reveal a potentially conflicted OHV user base in that the quality of their associated recreational activities could be affected by OHV activities. For example, campers who wish to ride OHVs for additional recreation, but who feel strongly that OHV use should be restricted to designated areas, are likely to feel dissatisfied if other OHV users ride through the campground and/or on hiking trails. Similarly, if OHV use in preferred hunting or fishing areas—or other areas crucial to healthy populations of game and fish species—degrades habitat quality that results in diminished game and fish populations, then OHV riders who also hunt and fish may experience dissatisfaction.

Understanding the social effects of OHV activities (and potential outcomes of OHV activities) also requires determining where OHV users like to go and what their preferences are while riding. For example, in Colorado (where user attitudes are likely relatively moderate), Crimmins (1999) reported that

- 38.5 percent of OHV riders use U.S. National Forest Service land,
- 22.4 percent use private land,
- 18.6 percent use BLM land,
- 6.0 percent use State land,
- 3.4 percent use City or county land, and
- 2.3 percent use National Recreation Areas.

These data indicate that the use of public lands for OHV riding far outweighs that of private lands. Crimmins (1999) further reported OHV user preferences in terms of riding area attributes, which included

- no fee for use (if on public land),
- signs indicating all activities allowed on the trail, and
- locations removed from other human activity.

The least important attributes included

- patrolling by staff of land management agencies or local OHV clubs,
- restrooms, and
- loading ramps (Crimmins, 1999).

When presented with a list of priorities for uses of public funds, OHV users selected

- purchasing right-of-ways for OHV access,
- new OHV trail construction,
- erosion control, and
- OHV trail system planning and maintenance.

The low ranking of management patrols probably indicates that users desire more flexibility regarding where they may ride (Crimmins, 1999). Crimmins (1999) also pointed out that although the availability of facilities ranked low in terms of user preferences, management

agencies nonetheless generally focus on providing facilities and generally report high user demand.

In terms of OHV user preferences for trail types and features, Bury and Fillmore (1974) reported that variation in terrain was the most important factor. The authors' recommendations for an effective OHV area included

- riding areas established near some, but not all, campgrounds;
- trails kept  $\geq 600$  feet (183 m) from the nearest campground;
- trails  $\leq 6$  feet (1.83 m) wide; and
- trails that traverse hillsides and include a variety of technical (obstacles, rugged terrain) and non-technical (no obstacles, smooth riding surface) features.

Fisher and others (2001) reported that motorcycle and ATV riders in Utah preferred

- riding off established trails (38.1 and 49.4 percent, respectively),
- double-track trails (12.7 and 17.1 percent),
- single-track trails (12.7 and 4.3 percent),
- moto-cross or ATV courses (9.5 and 15.1 percent), and
- roads (11.1 and 4.3 percent).

The issue of traveling off established trails is a serious concern with respect to natural resource management (Forman and others, 2003; Petersen, 2006); however, areas closed to OHVs and a shortage of designated OHV areas are common complaints among users (Achana, 2005; Fisher and others, 2001; Nelson and others, 2000). For example, in a survey commissioned by the Utah Department of Natural Resources to identify the most important issues affecting OHV use in Utah, 42.3 percent of respondents indicated that "Having enough places to ride" was most important; 8.4 percent indicated "Too many areas closed to OHV use;" and 5.6 percent indicated that "Resource management conservation" was the most important issue (Fisher and others, 2001). In a survey conducted by Nelson and others (2000), 44.6 percent of respondents selected "Do not reduce current trail/route system and OHV access" to indicate the most important thing that should not be changed, and 30.1 percent selected "Develop more trails/routes/area and connections to services" to indicate the most important thing that should be changed. When provided with several OHV-management statements with which to agree or disagree, Crimmins (1999) found that "Most trail closures have been done for good reason" received the highest level of disagreement.

Similar patterns in attitudes and beliefs were revealed through a survey of 336 ATV and motorbike users conducted by the Idaho Department of Parks and Recreation (Achana, 2005). On a scale of 0-7 (from least to most serious), respondents were asked to rank 23 issues of concern to them. Results indicated that the most serious issues of concern (in descending order of seriousness; scores greater than 4) were

- permanent closure of an area the recreator uses most,
- temporary closure of an area the recreator uses most,
- inattentive/careless recreators engaged in motorized recreation,
- litter,
- too many rules and regulations, and
- poor communication of rules and regulations.

Conversely, respondents felt that issues they were not concerned with (in ascending order of seriousness; scores less than 3) were

- too few rules and regulations,

- inadequate facilities at campsites,
- ATV impacts on water,
- motorcycle impacts on water,
- problems with parking availability for OHV-support vehicles,
- lack of suitable campsites,
- ATV impacts on wildlife, and
- some other (unlisted) issue of concern in OHV use areas.

Issues of concern that fell in the middle (in descending order of seriousness) were

- inattentive/careless non-motorized recreators,
- OHVs traveling too fast,
- motorcycle impacts on soil,
- motorcycle impacts on vegetation,
- ATV impacts on vegetation,
- hunters on OHVs off designated roadways and trails,
- ATV impacts on soil,
- motorcycle impacts on wildlife, and
- noise from OHVs.

When asked which of 16 possible factors contributed to creation of unauthorized trails in recreational regions of Idaho, survey respondents selected (from most to least frequently)

- belief that OHV users should be free to go anywhere,
- lack of enough designated places to ride,
- avoidance of crowded designated areas,
- lack of operator experience,
- riding motorcycles for fun,
- treeless terrain,
- riding ATVs for fun,
- using ATVs for hunting access,
- lack of enforcement regulations,
- using motorcycles for hunting access,
- using ATVs for camping,
- inadequate regulation,
- using motorcycles for camping,
- using motorcycles for fishing access,
- using ATVs for fishing access, and
- some other (unlisted) regional resource impact.

Combined, the top three possible factors contributing to creation of unauthorized trails indicate that closures of OHV areas could result in at least local increases in dispersed use. Finally, when presented with a list of four alternatives for creating uniform OHV access requirements to all recreation areas, trails, and roads on Idaho public lands, 53 percent of the respondents selected the alternative “Open to OHVs unless posted as closed by signing,” and 33 percent selected the alternative “Open to OHVs unless posted as closed by signing, designation, or description.” Only 6.1 and 1.0 percent felt that areas should be “Closed to OHVs unless open by signing, designation, or description” or “Closed to OHVs unless open by signing,” respectively (6.7 percent did not respond to this question). These results are consistent with the top possible

factors contributing to creation of unauthorized trails: the belief that OHV users should be free to go anywhere unless posted as closed by signing, designation, or description.

### 2.7.5 Economic Benefits and Costs of OHV Use

The economic benefits resulting from OHV sales, operation and maintenance, and associated sales and activities have been well documented (American Motorcyclist Association, 1978; Dave Miller Associates, 1981; Reed and Hass, 1989; Dean Runyon Associates, 2000; Nelson and others, 2000). OHV recreation and camping, in particular, can generate significant revenues for local economies through campground fees, grocery sales, eating and drinking in restaurants, and sales associated with operating and maintaining OHVs and support vehicles. In 1999, camping at public campgrounds on local, State, BLM, and U.S. Forest Service lands in California generated \$500 million; an additional \$130 million was spent solely on going to and from the campground and/or home (Dean Runyon Associates, 2000). A study conducted in 1988 by Reed and Hass (1989) indicated that, during a 12-month period in 1987-1988, Colorado OHV users spent \$488.7 million on OHV purchases, operation and maintenance, support equipment (tow trailers, storage sheds, and so on), and travel expenses associated with OHV trips. Nelson and others (2000) reported that, between July 1998 and June 1999, the average Michigan OHV licensee spent \$1,944 on non-trip related purchases, 80 percent of which was for equipment. When extrapolated to the estimated number of licensees in Michigan, Nelson and others (2000) found that this amounted to \$134 million in spending on equipment; a similar extrapolation indicated that \$40 million was spent on local trips.

The literature search conducted for this report, as well as personal communications with experts working in the field of outdoor recreation socioeconomics, revealed no published studies on the socioeconomic costs generated by OHV use. These costs could include the degradation or loss of ecosystem services, the costs of restoring OHV sites, and the loss of revenues from non-motorized recreators who seek alternate areas for recreation where motorized recreation does not occur. Examples of degraded or lost ecosystem services would be the diminished capacity for a given watershed to provide high-quality water, diminished water infiltration into aquifers, and flooding resulting from increased runoff where soils become compacted. Lost constituencies (and associated revenues) could include not only non-motorized recreators, but also hunters and anglers whose primary recreational foci (wildlife and fish) may have undergone population declines due to the effects of OHV use. At this time, however, the true benefit:cost ratio of OHV use remains unknown.

### 2.7.6 Annotated Bibliography for Socioeconomic Implications of OHV Use

**Badaracco, R.J., 1976**, ORVs—Often rough on visitors: *Parks and Recreation*, v. 11, no. 9, p. 32-35, 68-75.

This paper first reviews relevant literature on user conflict and discusses the one-sidedness of conflicts between OHV and non-OHV users, as well as the spatial nature of conflicts that occur when non-OHV users seek solitude and quiet and OHV users seek places for challenge and adventure. The paper then describes the ISD (impairment, suppression, displacement) syndrome: impairment is the diminished enjoyment among non-OHV users when they come into direct or indirect contact with OHV impacts; suppression is reduced participation of the non-OHV group; and displacement is the abandonment of a site impacted by OHV activity. Land planners and managers often misinterpret displacement as disinterest in the abandoned activity and, in so doing, may focus management efforts and other resources on OHV user demands.

**Bury, R.L., and Fillmore, E.R., 1974**, Design of motorcycle areas near campgrounds—Effects on riders and non riders: College Station, Texas, Department of Recreation and Parks, Texas A & M University, Technical Report, 72 p.

This document analyzes some of the psychological and sociological effects of constructing motorcycle riding areas adjacent to fixed-site campgrounds. It describes rider and camper profiles, rider and camper perceptions of riders, and camper and rider preferences and satisfactions with respect to the proximity and design of riding areas.

**Cordell, H.K., Betz, C.J., Green, G., and Owens, M., 2005**, Off-highway vehicle recreation in the United States, regions, and states—A national report from the National Survey on Recreation and the Environment (NSRE): U.S. Forest Service, Southern Research Station, Technical Report, 90 p.

This report was prepared for the U.S. Forest Service's National OHV Policy and Implementation Teams. The data from the NSRE were collected between the fall of 1999 and late 2004. The focus of this report is off-highway driving of motor vehicles. The 15 July 2004, U.S. Forest Service draft rule regarding management of motorized vehicle use has increased attention on where and how OHV recreation occurs and is offered. As public land managers are tasked with the responsibility of examining and implementing clear and consistent agency policy, understanding who the OHV recreators are has become ever more important. The growing use of motor vehicles is prompting the Forest Service to revise its management of this use so that the agency can continue to provide opportunities desired by the public, while sustaining National Forest System lands.

**Crimmins, T., 1999**, Colorado off-highway vehicle user survey—Summary of results: Denver, Colorado, Colorado State Parks, Technical Report.

This report summarizes a State Parks user survey designed to elucidate OHV rider-use patterns, what riders want in a recreation area, enthusiast values and beliefs, use of OHVs in hunting, how the state OHV fund should use the funds collected, and rider perceptions of how OHV funds are used, lands are allocated, and routes are managed.

**Dave Miller Associates, 1981**, An economic/social assessment of snowmobiling in Maine: Windham, Maine, Dave Miller Associates, Technical Report, 52 p.

This summarizes a user survey covering economics (number of trips, distance traveled, duration, fuel, lodging, equipment) and analyzing the statewide impacts and trends indicated by the responses. (No information on demographics or user perception was gathered.)

**Dean Runyan Associates, 2000**, Campers in California—Travel patterns and economic impacts: Portland, Oregon, Dean Runyan Associates, Technical Report, 76 p.

This document charts the distribution of camping opportunity according to type of environment and land ownership, tallies the results of a questionnaire distributed to people using public campgrounds, and develops a comprehensive profile of camping travel patterns, demographics, and expenditures. The report provides significant detail on a wide range of camping patterns, such as how many trips, how long and where, a breakdown of the activities pursued by campers once on site, and the ethnic and income classifications of campers. Although not OHV-specific, it shows where OHV recreation fits into the big picture.

**Decker, D.J., Krueger, R.A., Bauer, Jr., R.A., Knuth, B.A., and Richmond, M.E., 1996,** From clients to stakeholders—A philosophical shift for fish and wildlife management: *Human Dimensions of Wildlife*, v. 1, no. 1, p. 70-82.

This paper begins with a call for wildlife professionals to “adopt and use the term stakeholder,” the development of which they review and the definition of which they indicate as being any citizen potentially affected by or having a vested interest in an issue, program, action, or decision leading to an action. The authors maintain that successful natural resource management in today’s society requires recognizing the array of stakeholders that demand a voice or involvement in decision-making about natural resource management. The authors describe taking a stakeholder approach to planning and decision-making in natural resource management by including all those who might be impacted by natural resource management decisions (the authors focus on fish and wildlife management, but the principle is applied throughout natural resource management). The process entails developing communication strategies for understanding and representing stakeholder concerns, attitudes, and conflicts. The authors maintain that today’s successful professional resource managers need to “...seek a widely recognized image of giving unprejudiced consideration to all significant stakeholder interests in management decisions.”

**Fisher, A.L., Blahna, D.J., and Bahr, R., 2001,** Off-highway vehicle uses and owner preferences in Utah: Logan, Utah, Institute for Outdoor Recreation and Tourism, Department of Forest Resources, Utah State University, Report no. IORT PR2001–02, 80 p.

This study entailed an OHV user survey to examine owner characteristics, attitudes, and preferences. Respondents were selected at random from Utah OHV registrations and interviewed by telephone. This was a very extensive questionnaire, including the verbatim responses to interviewers’ open-ended questions. Other questions included demographics, vehicle type used, where ridden, distance traveled, types of riding preferred, attitudes toward OHV program fund use, attitudes toward training and safety, and much more.

**Jim, C., 1989,** Visitor management in recreation areas: *Environmental Conservation*, v. 16, no. 1, p. 19–32.

This paper discusses various visitor-management measures for diminishing or precluding the effects of visitor impacts on natural resources in recreation areas by employing existing recreation-management research on visitor decisions—such as trip duration, difficulty, and desired environment—to suggest ways of dispersing use into patterns that do not result in damage to natural resources. It also examines various management scenarios: signs and maps to direct users into a managed pattern, restricting admission, lotteries, and various rationing/pricing concepts.

**Kockelman, W.J., 1983,** Management Concepts, in Webb, R.H., and Wilshire, H.G., eds., *Environmental effects of off-road vehicles—Impacts and management in arid regions*: New York, Springer-Verlag, p. 399–446.

Noise and motorized intrusion were the major impacts of ORVs on non-OHV users. Permitting OHV activity on public land is described as “inefficient” in the goal to provide for multiple uses because the noise, dust, and speed of just one OHV can exclude all other recreators from an area. The author categorizes OHV users as work-related users, recreational users, or



“bad apples.” Work-related users are natural resource managers and utility workers, among others. Recreators are further categorized as casual (value aesthetics more than the challenges of riding) or endurance riders. “Bad apples” are characterized by a complete lack of concern about their impacts and are likely to be noncompliant with regulations.

*Nelson, C.M., and Lynch, J.A., 2001*, A usable pilot off-road vehicle project evaluation: East Lansing, Michigan, Department of Park, Recreation and Tourism Resources, Michigan State University, Technical Report, 50 p.

This report details the results of an interagency effort to increase compliance with OHV rules in a Michigan State forest. An OHV-rider survey asked for respondents’ perceptions of signs, maps, and trail systems in the pilot area, as well as rider perceptions of any law enforcement contact riders may have had during the study period. The survey also queried each respondent’s understanding of pilot area regulations and offered the opportunity to give open-ended comments. There is also a detailed discussion of the participating law enforcement agencies’ response to the pilot project, including officer concerns, jurisdiction conflicts, workload distribution vs. agency priorities, and an analysis of sign survival in the pilot project areas. Finally, interviews with park manager/grant recipients and discussion of the results in terms of park administration, funding, staffing, and resource protection are provided.

*Nelson, C.M., Lynch, J.A., and Stynes, D.J., 2000*, Michigan licensed off-road vehicle use and users 1998–99: East Lansing, Michigan, Department of Park, Recreation and Tourism Resources, Michigan State University, Technical Report, 49 p.

This details a survey of randomly selected OHV owners in 1999. In addition to questions about demographics, expenditures, type of OHVs owned, and preferred activities, respondents were queried about their perceptions of specific aspects of the State OHV program. One section is dedicated to comparing this survey with a similar survey from 1988.

*Propst, D.B., Shomaker, J.H., and Mitcheckm, J.E., 1977*, Attitudes of Idaho off-road vehicle users and managers: Moscow, Idaho, College of Forestry, Wildlife and Range Sciences, University of Idaho, Technical Report, 30 p.

This report provides background information on, and an introduction to OHV use in, the era when it was new and poorly understood, and includes one of the earliest OHV/OSV (over-snow vehicle) user surveys. It compares user and land manager responses in the same survey; both groups were queried about their perceptions of environmental impacts, causes of conflicts, uses of public money for facilities, regulation enforcement, impacts on wildlife, and reasons for pursuing OHV/OSV activities.

## **3.0 Potential Indicators for Evaluating and Monitoring OHV Effects**

### **3.1 Summary**

There are numerous parameters that have the potential for serving as indicators of OHV effects in monitoring or research programs. Every attempt was made to provide an inclusive list of potential indicators of OHV effects described in the OHV effects literature (listed below). Of those listed, some correspond with BLM’s 17 indicators of rangeland health; others are quite different but could provide supplemental data for evaluating or monitoring OHV effects (for

example, erosion and/or sedimentation rates would complement assessments of rill formation and other surface changes) or fill indicator voids (such as those pertaining to wildlife ecology).

**(1) Soil health and watershed condition**

- Soil strength
- Soil bulk density
- Water infiltration rate
- Permeability
- Erosion and sedimentation rate
- Sedimentation or turbidity in wetlands
- Surface changes (for example, formation of rills, gullies, and terracettes)
- Presence/condition of soil crusts (in some cases: depending on crust type)

**(2) Vegetation health**

- Plant community composition (including species diversity, ratio of native to non-native or invasive species, structural diversity)
- Abundance of individuals and/or stem density
- Percent vegetation cover
- Plant size
- Growth rate
- Biomass

**(3) Habitat condition and health of wildlife populations** (direct and indirect)

- Habitat patch size and connectivity
- Wildlife community composition (including species diversity, ratio of native to non-native or invasive species)
- Abundance, density, and distribution
- Population sizes and trends
- Survivorship, productivity, body mass, and roadkill rates
- Age-class and gender structure
- Frequency of OHVs passing through a given area
- Road or trail type and width
- Level (decibels), duration, and timing of traffic noise

**(4) Water quality**

- Sedimentation rate
- Levels of turbidity and suspended solids
- Contaminants levels, including levels of petroleum-derived compounds from spills (aromatic hydrocarbons in particular)

**(5) Air quality**

- Dust levels
- Levels of by-products of OHV emissions (including polycyclic aromatic hydrocarbons, carbon monoxide, nitrogen oxides, ozone, and sulfur dioxide)

**(6) Socioeconomics** (direct and indirect)

- Recreator satisfaction with their recreation (or other) experiences
- Compliance with OHV (or other) regulations
- Knowledge regarding effects of user activities on various aspects of land health

- Mapping the distribution and intensity of OHV versus non-motorized recreation and other land uses,
- Patterns of regulation compliance (as evidenced by creation of unauthorized trails, damage to vegetation, and so on)
- Trends in local economic indicators associated with OHV and non-motorized recreation and other land uses (for example, sales in camping equipment, gasoline, restaurants, lodging facilities)

Specific research questions and management goals—as well as sensitivity to OHV effects and the availability of funding and personnel—will determine the potential efficacy of using any one indicator to evaluate or monitor OHV effects on BLM lands. Qualitative indicators may be most useful for rapid assessments, whereas quantitative indicators may be needed for long-term monitoring. Ultimately, however, implementing an OHV effects monitoring program will require consultation with topical experts and additional research to identify or develop appropriate and efficient indicators and field methods for evaluating and monitoring OHV effects (personal communication from D.A. Pyke to Z.H. Bowen, U.S. Geological Survey, Fort Collins, Colorado, August 2007). Work on developing such indicators is currently underway by rangeland ecologist, D.A. Pyke, U.S. Geological Survey in Corvallis, Oregon.

### **3.2 BLM's Indicators of Land Health Compared to Indicators of OHV Effects Described in the Literature**

In terms of the specific land health attributes assessed, there is some limited correspondence between several indicators of OHV effects described in the literature and some of BLM's 17 qualitative assessment indicators (see Pellant and others, 2005). The area of greatest overlap is that of soil health and watershed condition; there is somewhat less overlap in the area of vegetation health (table 3.1). Attributes addressed in the literature but not by BLM's 17 indicators include wildlife population and habitat health, water and air quality, and socioeconomics. Even indicators that measure the same or similar attributes, however, may differ notably with respect to the scale and scope to which they are or can be applied, or the precision and accuracy they can provide.

The differences between BLM's indicators and those described in the literature do not imply that BLM's indicators are inappropriate for assessing some attributes under some conditions. Rather, they underscore the need for a variety of indicators to meet equally variable needs. For example, qualitative indicators (such as those employed by the BLM) often entail making visual estimates, which may be suitable for rapid assessments by time-limited personnel operating with small budgets; qualitative measurements, however, are subject to observer bias. Research and monitoring studies, on the other hand, generally require quantitative indicators (or strict decision rules to guide data collection for qualitative parameters) that minimize observer bias and maximize statistical precision and accuracy to ensure defensible results and the detection of trends; quantitative measurements, however, can drive up the cost and time requirements of research and monitoring efforts. Therefore, the choice of indicators employed will depend on the specific goals, budgets, sites, and other factors. In some cases, BLM's indicators may be suitable; other cases may require more quantitative indicators. Co-opting indicators from other disciplines also may be extremely useful for revealing OHV effects on land health.

**Table 3.1.** Indicators emphasized in the literature reviewed for effects of off-highway vehicles (OHV) on land health compared to indicators of land health employed by the U.S. Bureau of Land Management (BLM) (Pellant and others, 2005).

<b>Land health category</b>	<b>Indicators of OHV effects described in reviewed literature</b>	<b>BLM indicators<sup>a</sup></b>
Soils and watersheds	Soil strength	9,11*
	Soil bulk density	11
	Soil permeability	8,9*,11*
	Water infiltration rate	1,2,3,4,5,8*,9*,10*,11*
	Erosion rate	1,2,3,4,5,6,7,8*,10*
	Sedimentation rate	
	Presence/condition of biotic and abiotic soil crusts	2,4,6,7,8*
Vegetation	Plant species diversity	12*,13,16*
	Ratio of native plants to non-native and/or invasive plants	12,16
	Percent plant cover	4,13,14
	Plant size	11,13,14,15*,17
	Plant growth rate	11*,13,14,15*,17
Wildlife and habitats	Habitat patch size and connectivity (can be expressed as ratio of road edge:habitat area or as native:non-native habitat)	4,12*,16*
	Shape/scope of animal movements relative to roads	
	Wildlife diversity and/or species abundance	
	Ratio of native, endemic wildlife to non-native and/or invasive species	
	Population size and trend	
	Gender/age ratio trend	
	Productivity trend	
	Average body mass for a given age/gender	
	Average survivorship	
Vehicle-caused mortality rate		
Water quality	Sedimentation rate or depth	
	Amount of suspended solids	
	Turbidity level	
	Level of atmospheric deposition associated with OHV emissions	
	Level of petroleum or its by-products (benzene, ethylbenzene, toluene, xylenes, 1,3-butadiene, lead)	
Air quality	Levels of OHV emission by-products (nitrogen oxides, carbon monoxide, sulfur dioxide, ozone, aldehyde, PAHs <sup>b</sup> )	
	Level of suspended particulates	
	Plant-absorbed level of emissions by-products	

<sup>a</sup> 1 = Number and extent of rills.  
2 = Presence of water flow patterns.  
3 = Number and height of erosional pedestals or terracettes.

- 4 = Bare ground (excluding rock, litter, lichen, moss, plant canopy).
  - 5 = Number of gullies and erosion associated with gullies.
  - 6 = Extent of wind scoured blowouts and/or depositional areas.
  - 7 = Amount of litter movement (description of size and distance expected to travel).
  - 8 = Average soil surface (top few mm) resistance to erosion.
  - 9 = Soil surface structure and content of soil organic matter (to include type of structure and A-horizon color and thickness).
  - 10 = Effect of plant community composition (relative proportion of different functional groups) and spatial distribution on infiltration and runoff.
  - 11 = Presence and thickness of compaction layer (usually none).
  - 12 = Functional/structural groups (in descending order of dominance by above-ground production or live foliar cover).
  - 13 = Amount of plant mortality and decadence (include which functional groups are expected to show mortality or decadence).
  - 14 = Average percent and depth of litter cover.
  - 15 = Expected annual production (this is total above-ground production, not just forage production).
  - 16 = Potential invasive (including noxious) species (native and non-native).
  - 17 = Perennial plant reproductive capability.
- <sup>b</sup> Polycyclic aromatic hydrocarbons.

Ultimately, **any indicator used to evaluate or monitor OHV effects will need a standard value (or range of values) that represents the baseline condition or a threshold value above (or below) which management is triggered.** Ecosystem properties, however, can vary widely across (and within) **spatial scales**. Therefore, selecting an appropriate standard or threshold for any one indicator necessitates an evaluation of the spatial scale(s) at which the associated effect occurs or is likely to affect ecosystem function. For example, OHV-caused sedimentation in a first-order stream might have significant by very localized effects on that stream, but no significant effects downstream; in contrast, OHV-caused sedimentation in a first-order stream might not have significant effects on that stream, but sedimentation in multiple first-order streams may result in significant cumulative downstream effects in second- and third-order streams. Similarly, the **temporal scale** at which ecosystems respond to land uses can vary from short-term (hours) to long-term (decades or longer); thus, it is important to consider temporal scale(s) as indicator standards or thresholds are established. For example, wildlife behaviors may exhibit immediate responses to OHV traffic by moving away from OHV routes; population trends, however, may take several generations to show effects of OHV disturbance, in which case the time required to detect trends will depend on how long it takes for generations turn over. Where OHV effects are not an immediate concern, one could incorporate long-term, annual, qualitative assessments of OHV-use areas, but where effects are of immediate concern, short-term, quantitative assessments may be implemented.

Standards for a given land health indicator can be developed by ascertaining baseline values at control sites under a given set of conditions. Once the baseline values are established, it becomes important to standardize the conditions under which subsequent measurements of that indicator are made. For example, the freezing and thawing of soils tend to decompact soils, and precipitation tends to alter other soil properties; thus, it would be important to monitor soils at similar times of year and under similar soil-moisture conditions.

### 3.3 Some Potential Indicators for Evaluating and Monitoring OHV Effects

#### 3.3.1 Potential Indicators of OHV Effects on Soils and Watersheds

A major effect of OHV traffic on soil health is compaction—the reduction of a soil's porosity. Potentially useful indicators for monitoring soil compaction include soil strength, soil bulk density, and infiltration rate (or permeability). **Soil strength** is typically measured in terms of the soil surface's resistance to a vertical force exerted by a penetrometer and is expressed as  $\text{kg}/\text{cm}^2$  (see <http://cropsoil.psu.edu/extension/facts/agfacts63.cfm> for explanations and diagrams of this method). **Soil bulk density** is measured as the ratio of dry solid mass (after soil is oven-dried) to bulk volume of soil and is expressed as  $\text{g}/\text{cm}^3$  (or  $\text{Mg}/\text{m}^3$ ). **Infiltration or permeability** is the rate at which the water infiltrates the soil and is expressed as  $\text{cm}/\text{hr}$ . Infiltration tests can be conducted in the field with relatively simple equipment (for a demonstration, see <http://www.grow.arizona.edu/Grow--GrowResources.php?ResourceId=181>); however, many replicates are needed to obtain adequate comparisons, and it takes time for infiltration to occur. Additional resources on the utility of devices and techniques for monitoring soil health include Leung and Meyer (2003) for soil compaction; O'Sullivan and Ball (1982), Hooks and Jansen (1986), Komatsu and others (1988), and Keener and others (1991) for soil strength; and Flint and Childs (1984), Isensee and Luth (1992), Miller and others (2001), and Lowery and Morrison (2002) for soil bulk density. McBrayer and others (1997) and Amezketa Lizarraga and others (2002) describe techniques used to measure infiltration rates. Overall, soil strength and bulk density are the most commonly used indicators of soil compaction in visitor impact studies (Liddle, 1997).

Soil strength, which increases with increasing soil compaction, depends on a number of inherent variables, such as particle size, type of clay mineral, the size/distribution of pores, and aggregate stability. For example, Adams and others (1982) found that soil strength in undisturbed areas of the Mojave Desert ranged between  $5.1 \text{ kg}/\text{cm}^2$  at 6 percent water content and  $21.1 \text{ kg}/\text{cm}^2$  at 1.8 percent water content, indicating that soil strength decreases with increasing moisture content. In general, a soil strength of less than  $20 \text{ kg}/\text{cm}^2$  ( $284.4 \text{ lb}/\text{in}^2$ ) was indicative of undisturbed terrain, whereas trails intensely used by motorcycles had soil strengths (during wet conditions) that typically ranged from  $20$  to  $60 \text{ kg}/\text{cm}^2$  ( $284.4$  to  $853.2 \text{ lb}/\text{in}^2$ ) (Adams and others, 1982). When soil strengths exceeded  $20 \text{ kg}/\text{cm}^2$  ( $284.4 \text{ lb}/\text{in}^2$ ; measured at about field capacity) due to compaction, Grimes and others (1975, 1978) found that root extension of certain plants, including alfalfa (*Medicago sativa*), corn (*Zea mays*), and cotton (*Gossypium hirsutum*), was limited.

Soil bulk density also increases with increasing soil compaction. For example, in the Mojave Desert, Webb (2002) and Caldwell and others (2006) found that bulk densities of undisturbed surface soils ranged from  $1.40$  to  $1.68 \text{ g}/\text{cm}^3$ ; however, bulk density increased significantly to  $1.80 \text{ g}/\text{cm}^3$  at high-disturbance sites (Caldwell and others, 2006). Measuring soil bulk density, however, is time-consuming and difficult in gravelly soils (Webb, 2002), which are typical of many desert sites. Thus, its practicality may vary not only from region to region, but from soil to soil within a region. Infiltration, on the other hand, decreases with increasing soil compaction. In undisturbed desert habitats, Eckert and others (1979) found soil infiltration rates to be  $3.2 \text{ cm}/\text{hr}$ . In the same study, infiltration rates were 15 percent lower where motorcycle ( $2.7 \text{ cm}/\text{hr}$ ) and 33 percent where truck ( $2.1 \text{ cm}/\text{hr}$ ) traffic had occurred.

For each of the indicators identified above, it will be crucial to consider soil type and water content when setting standards, as these factors clearly influence overall inherent values of

each parameter. It also is clear that variability in soil type may preclude using a single indicator—much less one standard—for monitoring soil health across all sites. Overall, monitoring soil health would entail measuring soil properties in tracked versus untracked areas of similar soil type and under similar conditions of soil water content. For areas previously unaffected by OHV activities but proposed to become OHV areas, managers may wish to collect predisturbance data on soil properties to serve as a baseline from which trends in soil properties may be assessed over time. An acceptable percent change in soil properties could be selected, and if soil properties were to exceed these threshold values then management actions could be implemented to bring the soil properties back to acceptable values.

A possible method of monitoring surface changes in watersheds might be to establish permanent monitoring sites for repeat photography studies. By standing in the same spot, orienting the camera in the same direction, and using the same focal length for each site visit, sequential photographs would provide a qualitative, relatively easy means of monitoring surface changes due to erosion and OHV tire cuts. Helpful websites that discuss repeat photography (both terrestrial and aerial) include <http://biology.usgs.gov/luhna/chap9.html>, [http://www.paztcn.wr.usgs.gov/wyoming/rpt\\_ground.html](http://www.paztcn.wr.usgs.gov/wyoming/rpt_ground.html), and <http://www.cpluhna.nau.edu/Tools/repeatphotog.htm>. Scientists with the National Science and Technology Center are using close-range (terrestrial or ground-based) photogrammetry techniques and associated tools for producing and interpreting close-range images (less than 300 m, as opposed to aerial photogrammetry distances of more than 300 m) that may be used to document soil crusts, soil erosion, vegetation, and other resources (see <http://www.blm.gov/nstc/prodserv/ST134/pdf/Handout3CloseRange.pdf>).

### 3.3.2 Potential Indicators of OHV Effects on Vegetation

Some plant responses to OHV activities are preceded by, and result from, OHV effects on soil properties. In other words, soil characteristics, particularly soil compaction, play important roles in the distribution, abundance, growth rate, reproduction, and size of plants. Furthermore, some plant responses are likely to lag behind changes in soil properties, and, by the time effects are detected in plants, site recovery could be more difficult and/or lengthy. As such, it would be important to implement management strategies for maintaining or improving soil condition before plants are affected and no longer provide enough cover to hold soils in place during restoration efforts. Several vegetation parameters, however, have potential value as direct indicators of OHV effects on plant communities.

As mentioned in section 3.3.1, soil compaction results in reduced water infiltration. As a result, overall plant productivity, as measured by **percent plant cover, abundance or stem density, growth rate, biomass, plant height and width, ratio of large:small species, and/or reproductive output** may be diminished (Johnson and others, 1975; Vasek and others, 1975; Adams and others, 1982; Webb, 1983; Prose and others, 1987; Holzapfel and Schmidt, 1990; Lightfoot and Whitford, 1991; Brooks, 1995; Bolling and Walker, 2000). It is important to consider, however, the differential growth habits and responses of plant species to conditions generated by OHV activities; they may be favored or inhibited by OHV effects (Holzapfel and Schmidt, 1990; Angold, 1997). For example, the productivity of some species may increase due to abnormal conditions of moisture availability from runoff near compacted areas and/or where water roadbed materials allow increased infiltration rates (Johnson and others, 1975; Vasek and others, 1975; Holzapfel and Schmidt, 1990; Lightfoot and Whitford, 1991).

To evaluate and monitor plant productivity, researchers often use transect-intercept methods for measuring larger- or site-scale indicators, such as percent cover, and quadrat-based

sub-sampling at random locations along transects for measuring smaller-scale (individual plants) indicators, such as plant size or growth rate. Repeat photography is also potentially useful for monitoring vegetation cover when personnel budgets are limiting, although ground-based repeat photography methods may be more realistic than satellite imaging in terms of staff expertise and funding required (see methods and URLs provided in Section 3.3.1). Satellite imagery, however, can be very effective for ascertaining landscape-scale changes in vegetation cover during long-term studies at selected study sites (Johansen and others, 2007).

**Plant community composition or diversity**—a parameter that factors relative proportions of each species into species richness—is a commonly used indicator health of a vegetation community (Davidson and Fox, 1974; Adams and others, 1982; Prose and others, 1987; Wilcox, 1989; Tyser and Worley, 1992; Lovich and Bainbridge, 1999; Parendes and Jones, 2000). For example, a plant community comprising 5 individuals each of 10 species and 150 individuals of another (200 total individuals) would be considered depauperate compared to a community comprising 20 individuals each of 10 species (200 total). Native species diversity is further compromised when non-native and/or invasive plants dominate the plant community (Holzapfel and Schmidt, 1990). OHVs caked with mud acquired elsewhere potentially introduce or disperse seeds of non-native and invasive species; thus, OHV-route margins often become populated with exotics and invasives that eventually may spread and outcompete native species at the landscape level. Therefore, an important consideration when evaluating plant species diversity is the presence of non-native and/or invasive species. In other words, although species diversity can be useful for evaluating and monitoring the impacts of OHV activities on vegetation, the ratio of native to non-native and invasive plant species must be taken into account. Monitoring transects oriented perpendicular to OHV travel routes would help identify range expansions beyond the linear routes.

Similar to the precautions issued above for selecting standards of soil health, vegetation characteristics also vary widely according to soil type, slope, aspect, microclimate, and other factors. Ultimately, having baseline data before a site is disturbed, and/or having nearby reference sites not subjected to OHV activity would help differentiate between site-based variations and OHV impacts on vegetation.

### 3.3.3 Potential Indicators of OHV Effects on Wildlife and Habitats: Native, Threatened, and Endangered Species

The physical imprint of a road or OHV route creates barrier effects that may effectively alter **habitat patch size and connectivity**, which potentially alters or inhibits **animal movements** (Oxley and others, 1974; Mader, 1984; Swihart and Slade, 1984; Samways, 1989; Andrews, 1990; Baur and Baur, 1990; Forman and Alexander, 1998; Jackson and Griffen, 1998). Roads and trails also create edges that can alter wildlife habitat use and movements (Nicholson, 1987; Yahner, 1988; Reed and others, 1996; von Seckendorff Hoff and Marlow, 1997; Gibbs, 1998; Vos and Chardon, 1998), and in many instances these **edge effects** extend well beyond the road's actual footprint into habitat interiors. Unfortunately, both direct and indirect indicators of animal movements and habitat or home-range use can be difficult to measure, simply because populations are mobile and easily affected by many factors besides OHV activity if care is not taken to avoid, or control for, these additional effects. Furthermore, adequate sample sizes and accurate measurements of animal movements generally require capture-mark-release or capture-mark-resight studies, which can be costly in terms of funding for equipment and personnel time. Therefore, evaluating and monitoring movement responses of suitable indicator species or



functional groups to OHV activities and routes might be more efficient than trying to monitor many species. For example, species least likely to cross OHV routes or networks of routes (beetles or small mammals, for example) would be more suitable for studying barrier effects of OHV routes than species inhibited from crossing only multi-lane, paved highways (large ungulates). Ultimately, animal movement studies might be most appropriate in comprehensive, long-term research projects at selected study sites representative of locations and habitats being impacted most by OHV activities. An appropriate measure of edge effects on wildlife may entail studies of spatial distribution relative to distance from OHV routes, as well as density and other population dynamics among target indicator species that require habitat interiors.

Traffic intensity and noise level of OHVs may be useful indirect measures of OHV effects on wildlife behavior and survivorship. If measured, temporal variation in animal activity or presence would need to be considered, as diurnal animals may be more affected by OHV traffic and noise than nocturnal animals if most OHV activity occurs during daylight hours (Ouren and Watts, 2005). Vehicle speed also may be an important parameter to measure, as it can affect mortality rates of animals as they attempt to navigate landscapes where OHV travel is significant. There are technologies available for field monitoring of noise levels and traffic volume and speed (see examples on the Internet at <http://www.jhuapl.edu/ott/technologies/technology/articles/P01254.asp> and <http://www.noisemeters.com/accessories/outdoorkits.asp>), although again it would be more cost-effective to use them in selected study sites for targeted research questions as opposed to broad-scale monitoring programs.

Ideally, any program for monitoring OHV effects on wildlife would include assessments of whether/how wildlife responds to OHV-related factors. If population dynamics were understood *before* the onset of OHV activities, then monitoring any changes that occur afterward could be straightforward if other conditions are held relatively constant. Climate, however, typically makes long-term monitoring of animal population dynamics very complex, and wide-ranging animals may be more difficult to monitor than those with smaller or more restricted movements. Similar to the dynamic ways in which wildlife populations use a given area, OHV use in a given area is also dynamic; if the area affected and the intensity of disturbance enlarges considerably, wildlife may respond as well. These and other factors typically drive up the funding and staffing needs associated with collecting population dynamics data. Thus, to determine thresholds of OHV activity potentially tolerated by wildlife, it may be more realistic to measure long-term changes relative to gradients and changes in OHV activity. Again, careful selection of suitable indicator species, or functional groups, may help increase the effectiveness of monitoring wildlife populations (Lindenmayer, 2000; Noon, 2003, p. 51-55).

To date, there have been few simultaneous studies of OHV use and wildlife responses to OHV activities, but such studies could provide more precise assessments of the relationship between patterns of OHV activity and wildlife responses, particularly behavioral responses to varying traffic patterns, intensity, and total area affected. GPS and satellite technologies could be employed to build Geographic Information System (GIS) data layers of OHV-associated variables, both static (for example, road width) and dynamic (vehicle speed and traffic volume). When overlaid with GPS-based telemetry data layers that map animal movements, one could relate changes in static and dynamic OHV variables to wildlife responses, making these particularly powerful tools for long-term studies aimed at evaluating OHV impacts on wildlife.

### 3.3.4 Potential Indicators of OHV Effects on Water Quality

The literature on OHV impacts offered little information specific to evaluating or monitoring OHV effects on water or air quality. Based on studies of water quality in other disciplines, however, potentially useful indicators highly relevant to OHV effects would be **sedimentation** and **turbidity**. Sedimentation can be measured in terms of deposition rate or total amount of solids deposited where surface and directed flows enter aquatic systems downslope of OHV-use areas. A useful reference on different methods for measuring sedimentation may be found in Lisle and Eads (1991). Turbidity, which indicates the level of **suspended solids** in water, can be measured easily in the field with a Secchi disk (see <http://www.noble.org/Ag/Wildlife/SecchiDisk/Index.htm>). With respect to monitoring levels of contaminants in water from OHV emissions and fuel or other chemical spills, water samples can be collected and analyzed in laboratory settings; however, this can be costly, and would probably be more suitable for selected, long-term research sites than in broad-scale monitoring programs. Potentially important contaminants to test for in OHV-impacted watersheds could include **benzene; ethylbenzene; m-, p-, and o-xylene; toluene; 1,3-butadiene; and lead** (Forman and others, 2003: p. 205-213; Arnold and Koel, 2006). In addition, nitrogen deposition from nitrogen oxides can affect water quality if nitrogen loading alters the chemical balance of nutrients in aquatic organisms.

Although it has already been stated that, in general, it is important to compare OHV-impacted sites with similar reference (unaffected) sites when evaluating OHV effects, an additional consideration with respect to water quality is to make comparisons within the same drainage. This is because water quality variables can change depending on the geology, adjacent habitat, and hydrology of the area. Thus, an appropriate technique for assessing OHV effects on aquatic systems might be to compare water quality at replicate sites both upstream and downstream of where OHV activities are occurring.

### 3.3.5 Potential Indicators of OHV Effects on Air Quality

There are several measures of air quality that can be used to assess effects of OHVs, including levels of fugitive dust (**suspended particulates**) and/or **OHV emissions** (including **carbon monoxide, ozone, sulfur dioxide, aldehyde, and polycyclic aromatic hydrocarbons**). Due to the effects of humidity, precipitation, fallout rates of different particle sizes, and wind speed and direction, however, measuring dust levels specific to any one site or set of OHV activities can be difficult. A useful technique for assessing the amount of dust associated with OHV use is to collect PM<sub>10</sub> (particulate matter less than 10 microns in diameter, which can pass through the nose and throat and get deep into the lungs) data, as dust is a common component of PM<sub>10</sub>. Technological advancements continue to provide additional devices useful for monitoring dust and other suspended particulates (Sanders and Addo, 2000)—including satellite imagery (Nakata and others, 1976; Gill, 1996; Stefanov and others, 2001)—although cost becomes a greater factor with increasing sophistication of instruments used. Fox (1986) provides a list of appropriate procedures for measuring and evaluating various air-quality parameters, and the Environmental Protection Agency's National Ambient Air Quality Standards include primary standards (those designed to protect overall public health and the health of "sensitive populations") for carbon monoxide, lead, nitrogen dioxide, particulate matter, ozone, and sulfur oxide levels (see <http://www.epa.gov/air/criteria.html>).

### 3.3.6 Potential Indicators for OHV Effects on Socioeconomics

Resource planning has been known to take recreation and economic values of OHV use into greater consideration than biological considerations (Adams and Dove, 1989). **Human behaviors, attitudes, and economics**, however, are the ultimate drivers of OHV impacts on natural resources (Decker and others, 1996; Vaske and others, 2001); thus, understanding the socioeconomics of OHV use is crucial to the success of any program designed to address OHV effects, whether they impact natural resources or land users. This includes understanding the economic effects—**both benefits and costs**—of OHV management and use on OHV users, other land users, local businesses, land-management agencies, and ecosystem services.

Bight and others (2003) provide a framework and guidelines for conducting social assessments and identifying/organizing social science data, including measurable indicators (see Chapter 3, p. 21) for use in natural resource planning. Indicators suitable for monitoring the socioeconomic implications of OHV use (human behaviors, attitudes, and economics) may be identified through stakeholder interviews, focus groups, and surveys (mail or telephone); economic assessments; and developing maps depicting areas used for different forms and intensities of recreation (Massachusetts Department of Environmental Management, 1995; Decker and others, 1996; Stokowski and LaPointe, 2000; Nelson and Lynch, 2001; Dillman, 2007). For example, interviews can be designed to elucidate not only OHV impacts on all types of user experiences, but also ways in which those impacts might be mitigated. Trail openings or closures may affect levels of OHV user demand and satisfaction, which could be identified through well-designed survey questions that target OHV users (see Dillman 2007).

Likewise, understanding the effects of OHV site development and regulation compliance first requires monitoring where OHV users like to go and what their preferences are when riding. For example, Nelson and Lynch (2001) conducted a study to determine the effectiveness of OHV areas, the approaches for which included a survey of licensed OHV riders, interviews with key stakeholders about project management, and an assessment of the signs established to identify designated OHV trails. Monitored over time, these indicators could be used as guidelines for adaptive management. Finally, identifying the economic impacts associated with OHV activities and regulations potentially affecting nearby communities may entail economic analyses of businesses and services that cater to outdoor recreators (including OHV users and non-motorized recreators; English and others, 2001). Economic assessments also may be used to determine the financial effects associated with losing ecosystem services, regulation enforcement, resource restoration, and other potential costs of OHV use.

A potentially powerful tool for identifying socioeconomic effects of OHV use would be GIS applications (Massachusetts Department of Environmental Management, 1995; Stokowski and LaPointe, 2000; Kopperoinen and others, 2004). For example, areas considered by recreators as being most important for excluding motorized forms of recreation could be identified by users on a map and then used to develop time-series GIS data layers that illustrate long-term changes in preferences pertaining to land-management actions or other factors. Overlaid with maps that identify areas ecologically most suitable for OHV use, managers also could determine which areas are most likely to be resilient to OHV use and provide OHV user satisfaction.

## **4.0 Mitigation and Site-Restoration Techniques**

### **4.1 Summary**

Mitigation of OHV effects and restoration of OHV-impacted sites requires a range of approaches and techniques. Social science in particular has strong applicability for ameliorating the effects of OHV activities, not only in terms of their impacts on non-motorized recreators and other OHV users, but also in terms of their effects on natural resources, as ultimately human behavior is what drives OHV use and related behaviors. Important tools for managing OHV use, therefore, include not only interviews, surveys, and focus groups, but also strong educational campaigns. Once impacted by OHV use, however, ecosystems may need to be closed and rested, if not restored. Sites with severely compacted soils and/or bedrock exposures due to erosion may need restoration through importation of native soils, scarification, decompaction, stabilization, inoculation with microbes and mycorrhizae, and/or mulching before reseeded and/or planting can be done.

### **4.2 Mitigation and Site-Restoration Techniques**

The OHV literature has addressed many effects of both motorized and non-motorized recreation on components of ecosystem health (Cole, 2004; Stokowski and LaPointe, 2000; Cline and others, 2007), including soils, vegetation and habitat, wildlife behavior and population dynamics, and the quality of water and air. Resource degradation and wildlife disturbance are not uniform, however. Factors influencing the extent and degree of impact include user types and behaviors, the environment's resistance and resilience, and the timing, intensity, and distribution of use (Cole, 2004). Therefore, management and mitigation planning and implementation must take these factors into consideration.

#### **4.2.1 Understanding Land User Preferences and Conflicts**

Although addressing ecosystem degradation and user conflicts stemming from OHV use generally requires policy and management considerations (Vancini, 1989), there is the likelihood that one group or another will be dissatisfied with the outcome of any one management decision. Therefore, it is important to promote acceptance of, if not support for, management decisions prior to implementation, because those not accepted are likely to fail in the long run, regardless of how sound the reasoning is behind them (Shindler and others, 2004). One way to potentially improve policy acceptability is to identify, assess, and include all users who may be affected by management decisions and include them in the decision-making process; useful tools for accomplishing this goal include stakeholder and demographic analyses, and arranging stakeholder focus groups (Decker and others, 1996; National Oceanic and Atmospheric Administration, 2005). Basic discussions, such as defining different interpretations of OHV use or seeking consensus on the meaning of OHV use to disparate users, can potentially preclude feelings of marginalization by any given group that could lead to conflict between users and/or between users and managers (Stokowski and LaPointe, 2000).

A baseline understanding of OHV users (including recreators, livestock operators, and energy-development operators) can further help to alleviate conflicts among different users. If users can be classified, even broadly, managers can maximize their efforts by using that information to form relevant management plans and/or communication and education campaigns. For example, understanding the problems that users have with each other, as well as their motivations for recreating, can yield more effective management that placates most, if not

all stakeholder groups, and does not lead to marginalization or displacement of any one group. Often, outdoor recreators of all types have fairly similar goals and reasons for participating in outdoor recreation (Schuett and Ostergren, 2003), including a need to “get away” from the pressures and commotion of everyday life, rejuvenation, and enjoyment of the natural environment. Even when the mechanisms by which those needs are met are not homogeneous among user groups, knowledge of stakeholder preferences can help to improve the management of OHV recreation on public lands.

Managing the social effects of OHV activities and promoting compliance with regulations also require determining where OHV users like to go and what their preferences are when riding (Nelson and Lynch, 2001). Likewise, management must consider the levels of environmental dominance and technology associated with different forms of land use. Once again, GIS data layers could be developed to identify spatial management needs and predict where conflicts may occur. For instance, nature study, an activity characterized by “low dependence on technology and low dominance over the environment,” and OHV touring, which is characterized by “high dependence on technology and high levels of environmental dominance,” need to be segregated spatially to help prevent user conflicts. If it is found on a map grid that two such activities are taking place in adjacent quadrats, there is a high likelihood that recreators who participate in these activities will come into conflict (Bury and others, 1983). Maps of sites suitable for a given activity could be overlaid with user preferences for certain locations or landscape features to further fine-tune planning and mitigation of user conflicts.

Finally, if recreators are made aware of their impacts and understand the implications of those impacts, they may be more willing to take steps that lessen those effects, thereby diminishing the necessary level of managerial monitoring (Vancini, 1989; Anderson and others, 1998). Communication and education campaigns can be difficult, however, due in part to (1) modern-day information overload, increasing the likelihood that recreators will disregard information pertaining to natural resources and recreation, and (2) the fact that managers and designers of education campaigns rarely have a formal knowledge and understanding of persuasion techniques (Absher and Bright, 2004). Assuming that these factors can be surmounted by well-designed educational resources and manager training, education is a crucial first step in alleviating negative perceptions of trail closures and other regulations or management actions. For example, management agencies need to explain the reasons and rationale for closures so that they do not appear arbitrary (Crimmins, 1999). Such educational campaigns may be more successful if they target the many OHV users participating in some other form of outdoor recreation that depends on a healthy ecosystem. Hunting and fishing are two such forms of recreation, and if an OHV area is closed seasonally to protect elk during calving season or fish during spawning season, communicating this to OHV users is likely to elicit more compliance with the closures. When OHV users understand that their hunting and fishing activities may be at stake, they are more likely to respect closures. In closed areas already subjected to high levels of illegal riding, education would be crucial for communicating to users the reasons for the closures and related management actions.

#### 4.2.2 Mitigating OHV Use Effects

Lands managed by BLM are placed into one of three broad types pertaining to OHV-use designation: “open,” “limited,” or “closed.” Within the “limited” category there can be several types of limitations: OHVs can be “limited to existing routes,” “limited to designated routes,” or “limited seasonally” (see [http://www.blm.gov/nhp/news/releases/pages/2000/pr000110\\_ohv\\_qa.html](http://www.blm.gov/nhp/news/releases/pages/2000/pr000110_ohv_qa.html)). Indeed, trail/area

closures are among the management options available for allowing soils and vegetation to recover from OHV effects or to help preclude localized impacts on air and water quality. However, in areas where OHV effects would be notable with the first few uses and/or generate significant, long-lasting impacts, it would be prudent to consider whether such places are appropriate for OHV use in the first place (Cole and Landres, 1995; Cole, 2004). A well-placed, concentrated system of trails could alleviate the difficulties of enforcement that extend across a large territory (Major, 1987). Spatial models, including GIS data layers, developed for identifying areas most suitable for resisting or recovering rapidly from OHV impacts, or those most suited for concentrated and/or self-monitored OHV use, would be effective tools for establishing OHV sites in appropriate areas and avoiding the need for frequent, long-term closures, expensive restoration actions, and/or the high cost of enforcement monitoring. For example, erosion, sedimentation, and rill or gully formation are much more likely to occur in, and downslope of, OHV-use areas located on or at the top of a slope than in/from a flat site or depressional area lacking watershed outlets. The GIS data layers could, therefore, identify areas to exclude from development for OHV use.

Although trail/area closures may be among the easiest management actions to implement, they may prove difficult to enforce, particularly under a policy of “closed unless posted open.” The enforcement difficulty will depend on the number of trails involved, their locations relative to one another, and the number of enforcement personnel available. In the absence of funding for adequately monitoring regulation compliance, educating the public about the effects of their recreational pursuits may prove more economical and yield self-monitored trail users. In areas affected heavily by recreational activities, however, visitor management may be required (Jim, 1989). “Rationing” is a visitor management strategy that can be used to control the number of visitors over a given area where the available recreational resources are finite and/or unique. If the number of visitors is restricted, their quality of experience may be greater; a drawback of this approach is that the benefit is realized by fewer users (see Dimara and Skuras, 1998). Other strategies may include reserving a permit in advance, a permit lottery system, or implementing user fees that reflect the quality of experience (for example, it may cost more to use a high-use area that offers a high-quality experience than a low-use area that offers a low-quality experience). In many cases, these strategies could help alleviate pressures on law enforcement.

Wildlife is affected by OHV recreation in numerous ways, including displacement caused by human disturbance or direct mortality caused by vehicle-animal collisions (Cole and Landres, 1995; Knight and Cole, 1995; Miller, 1998; Stokowski and LaPointe, 2000; Cline and others, 2007). As OHV-related landscape fragmentation increases, habitat area and required juxtapositions of habitat types that meet the different needs of a given species, as well as adequate cover from disturbance, are diminished. Because the resulting effects may be detrimental to individuals and/or local populations (Knight and Cole, 1995), mitigation and management may be required to protect wildlife. One approach for mitigating the effects of wildlife displacement and disturbance may be to control the spatial and/or temporal proximity of OHV activities to wildlife, especially during critical nesting and breeding times (Gutzwiller, 1995). Again, GIS data layers could be very useful for identifying crucial wildlife areas and ensuring that they are not overlapped, fragmented, or otherwise disturbed by OHV-use areas.

#### **4.2.3 Restoration of OHV-Impacted Areas**

Revegetation of natural communities in arid environments is particularly difficult (Wallace and others, 1980) and studies evaluating revegetation have shown varying degrees of success (Graves and others, 1975, 1978; Kay and Graves, 1983; Grantz and others, 1998); thus,

restoration of sites significantly degraded by OHV activity may be needed before sufficient levels of revegetation can take place, particularly if underlying bedrock has become exposed. Webb and others (1978) recommend that soil be imported and stabilized to replace the displaced soil where bedrock has become exposed. Generally, restoring soil horizons for re-establishing microbial communities can be achieved by inoculating soils with native microbes and mycorrhizae (Belnap, 1993; Bolling and Walker, 2000). Bolling and Walker (2000) suggest that decompacting OHV tracks and flattening out the lateral and center berms associated with them may increase the probability of community redevelopment with a more natural surface shape. Recovery of cryptobiotic soils, however, is more complex and may require long periods of time (Wilshire, 1983b; Lovich and Bainbridge, 1999); ultimately, their recovery rate will depend on the degree of soil compaction and the nature and intensity of the initial disturbance (Bolling and Walker, 2000).

To reduce the potential for erosion at restoration sites, it is important to use mulch, stabilization techniques, and/or establish vegetation. Rasor (1976, cited *in* Webb and others, 1978) suggests that ground cover (such as wire netting) be applied across the restoration site to stabilize soils. Kay and Graves (1983) recommend that seeding with local seed stock begin as the disturbance desists. Revegetation techniques also may include container planting (Grantz and others, 1998), hand seeding (Lovich and Bainbridge, 1999), drill seeding (Kay, 1988), and establishment of visually dominant species, such as creosote bush (*Larrea tridentata*; Kay and Graves, 1983).

## 5.0 Monitoring and Research Needs

### 5.1 Summary

More information is needed to help support policy making and land management as they pertain to the natural resources and people affected by OHV policies and management. Research needed to help support policy makers and land managers includes (but is not limited to)

- well-designed studies that incorporate planned comparisons of treatment (OHV-impacted) and control (unimpacted/reference) sites, as well as “before and after OHV-impact” studies;
- studies at various spatial and temporal scales across all impacted habitat types;
- studies on habitat fragmentation and road-edge effects caused by OHV activities;
- studies on effects of various gradients in OHV disturbance and at varying distances from OHV routes;
- studies of OHV effects on plant and animal population dynamics;
- simultaneous evaluations of wildlife responses and OHV route-specific variables;
- studies to improve knowledge about the physical and chemical dynamics of soil compaction;
- studies evaluating the effects of erosion, sedimentation, and turbidity downslope of OHV-affected sites;
- improvements in techniques for successful site restoration;
- improvements in techniques and technologies for assessing OHV impacts over large areas and long time periods;

- studies that evaluate the effectiveness of various techniques to manage OHV use and its ecological and socioeconomic effects while simultaneously providing the greatest satisfaction among all land users; and
- studies that determine the economic and sociological costs of OHV use.

The experimental design of past studies on the ecological effects of OHVs often proved inadequate for providing reliable, defensible results. In particular, use of comparable treatment and control sites with adequate replication has been minimal. To better elucidate OHV effects on wildlife, habitats, and vegetation, there is a need for well-replicated research based on treatments and controls ranging across various spatial and temporal scales within the full range of habitat types represented on BLM lands. In desert ecosystems, for example, the impacts of OHV activities can occur at several spatial and temporal scales (Forman and others, 2003: p. 129-134; Matchett and others, 2004; Brooks and Lair, 2005; see discussion in section 2.1); thus, research conducted across the scale(s) at which OHV activities and ecosystem responses are likely to occur will produce the most reliable information about OHV effects on land health and users of the land (Brooks and Lair, 2005). There also is a need for long-term monitoring of OHV effects at both designated OHV sites and undesignated (rogue use) sites, as well as revegetation sites.

Monitoring and research approaches that take advantage, and push the advancement, of existing and emerging technologies are needed to fully represent the scale and diversity of OHV impacts likely affecting plant and animal populations and communities, and to ascertain indicator thresholds as they pertain to BLM's land health standards. Current technologies, including satellite imagery, GPS, and GIS, among others, would be extremely useful in broadening the scope of OHV-impact research from site-based effects to ecosystems and landscapes. Technology also provides opportunities for better assessing OHV effects on wildlife, vegetation, and other natural resources. Finally, multiple assessments and the simultaneous recording of independent and dependent variables would improve overall results and better inform management decisions.

## **5.2 Monitoring and Research Needs**

Remaining questions about effects of OHVs on ecosystems and people are numerous and varied. Information regarding management approaches for sustaining or restoring resources—from the level of single OHV routes to entire landscapes—to pre-disturbance conditions while still providing for quality OHV experiences is especially sparse. Therefore, the need for solid, well-designed research for supporting management decisions cannot be understated. Based on major unresolved issues and questions raised in the OHV impacts literature, current research needs include (but are not limited to)

- well-designed research capable of producing scientifically sound results by incorporating planned comparisons of treatment (OHV-impacted) and control (unimpacted/reference) sites, as well as studies that take advantage of opportunities to compare “before and after OHV-impacts” at sites that may be slated for—but are not yet impacted by—OHV use;
- studies to evaluate OHV effects on natural resource attributes at various spatial and temporal scales, particularly those appropriate for evaluating and understanding effects occurring at watershed, landscape, and plant and animal population levels;
- studies to improve the overall understanding of habitat fragmentation and road-edge effects caused by OHV activities in OHV-impacted habitat types;



- studies that evaluate effects of OHV activities at various gradients in OHV disturbance levels and at varying distances from OHV routes;
- studies to evaluate how OHV activities and habitat fragmentation affect plant and animal population dynamics;
- simultaneous evaluations of wildlife responses (from individual- to population-level scales) and route-specific variables, including route type and width, and the intensity, noise levels, and speed of traffic;
- studies to improve the understanding of the physical and chemical dynamics, as well as the consequences, of soil compaction, sedimentation, and turbidity downslope of OHV-affected sites;
- improvements in techniques and technologies for assessing OHV impacts over large areas and long periods of time;
- improvements in techniques for successful site restoration;
- studies to determine the economic value of ecosystem goods and services provided by natural resources on or in BLM (and affected) lands and waters; and
- studies to determine the costs of OHV use, including degradation or loss of ecosystem goods and services, loss of supportive constituencies, managing/enforcing regulations of OHV use, and restoring OHV-impacted sites.

### 5.2.1 Scientifically Rigorous Research Projects

Several studies discussed in this document compared areas impacted (treatment) to areas unimpacted (control) by OHVs. Many studies, however, did not compare treatment and control sites, or the control and treatment sites differed with regard to some major factor (for example, other recreation activities, livestock grazing, logging, or energy-development activities) that could have masked true differences pertaining to OHV effects. In other words, controls in research and monitoring programs provide the necessary frame of reference for identifying true effects of the variable(s) of interest; in turn, identifying true effects will better inform management actions. Therefore, among the greatest research needs pertaining to OHV effects on natural resources are scientifically defensible studies based on planned comparisons of OHV-impacted and unimpacted sites that are otherwise similar in terms of soils, topographies, climatic patterns, plant and animal communities, non-motorized activities, and other potentially confounding factors. This is particularly important for developing appropriate threshold indicator values for sustaining current resource conditions or triggering management actions.

An additional approach to research that can provide informative results is to conduct before-and-after comparisons of sites previously unimpacted by OHV use but slated for future OHV use. Although year-to-year variations in climate and plant or animal population cycles can introduce too much variation in ecological before-and-after data to provide statistically meaningful results, this research approach can provide valuable information when conditions are reasonably similar during each phase of the project. Thus, it would be prudent to take advantage of such opportunities as they come up.

Technologies and tools that could prove very useful in study design and site selection pertaining to OHV effects include satellite imaging and GIS. Although they are still advancing rapidly in terms of their capabilities and utilities, they are nonetheless already very helpful in studies ranging from the site to the landscape scale. Satellite imagery can help locate sites with differing extents of OHV activity, and, when rendered into GIS database layers, they can provide opportunities for repeating imagery over time and evaluating landscape-scale changes. U.S.

Geological Survey scientists, for example, are currently using these tools and technologies to study the effects of energy-development activities in sage-steppe systems on BLM lands in Wyoming (C. Aldridge, pers. comm.).

### 5.2.2 OHV Effects at Various Spatial and Temporal Scales, Across Habitat Types

Past studies regarding OHV impacts on natural resources have focused primarily on effects at the single route or site level; thus, the overall understanding of landscape-, watershed-, and population-scale effects, including habitat/population fragmentation, is inadequate for managing OHV effects at larger spatial and longer temporal (Boyle and Samson, 1985) scales. Most of what is known pertains to very localized and short-term effects on sub-populations. Even then, past studies evaluating changes in animal densities of sub-populations may have violated basic assumptions of closed-population status. That is, studies that “failed to detect OHV effects on animal densities” may have been confounded by the immigration of new individuals after original individuals experienced poor survivorship due to direct or indirect effects of OHV activities. Mark-recapture studies that take advantage of radio-marking technologies, both in and away from the affected site, can help evaluate the extent to which assumptions of closed versus open populations are upheld or violated.

Research is also needed to better understand the edge effects of roads on different habitats and populations of different species or taxonomic groups. Here again, scale is important. Many past studies have evaluated the effects of traffic in immediately adjacent habitats (road rights-of-way, for example), whereas the effects may be realized well into the habitat interior quite far from travel routes. Thus, study designs that incorporate gradients of distance away from OHV routes or route networks would be crucial.

### 5.2.3 Research Regarding Effects of OHVs on Animal Populations

Many prior studies of OHV impacts on wildlife have focused on indirect indicators of animal population health, such as distribution and behavior, at the expense of more direct indicators, such as population trend/size, gender and age ratios, and productivity. In part, this is because such data can be significantly more difficult and expensive to collect than behavioral and distribution data. Studies that address possible changes in plant and animal genetics in ecosystems fragmented by OHV roads and trails also are needed. For species that naturally occur at low densities, such as the desert tortoise, bighorn sheep (*Ovis canadensis*), and mountain lion, this is particularly important, as isolation of their populations could more easily lead to localized extinctions.

Understanding direct effects of OHV activities on wildlife populations would be further enhanced by research that evaluates wildlife population dynamics in different habitat types (Bury and others, 1977), at different spatial and temporal scales, and under different conditions (levels) of OHV use. Likewise, research programs that incorporate representative and disparate taxonomic groups would help identify ecosystem-level effects. For example, a given habitat-fragmentation factor (a network of OHV routes) might not have any significant impact on large ungulates, but it might lead to complete loss of genetic diversity among flightless invertebrates. In conjunction with this type of research, it would be important to identify which specific environmental and anthropogenic factors promote or limit the exchange of individuals across OHV-impacted habitat types or landscapes.

Few past studies have employed multiple-assessment or simultaneous survey methods to detect rare or sensitive species that may not be detected through standard monitoring techniques, resulting in biases towards more common and easily detected species and an incomplete

understanding of the community at risk. For example, multiple survey techniques can be used to determine whether changes in species composition are due to changes in detectability across habitat types, times of day or season, geographical area, and abundance. For detecting reptiles and amphibians, researchers could combine noosing, pitfall sampling, night surveys, and road driving surveys. For mammal studies, track, scat, and camera surveys might enhance species detections. Many avian-ecology researchers now use combinations of road driving, point sampling, and mist netting, in addition to double-observer methods, for improving overall survey results.

Studies of OHV effects on wildlife also could be improved through simultaneous recording of independent and dependent variables. For example, many studies relating effects of OHVs on animal populations also lack any measurements of static and dynamic road- and OHV-related variables—such as width and traffic intensity/noise levels (Andrews, 1990)—that may strongly influence species behavior, distribution, abundance, survivorship, and productivity. Given the importance of relationships between these independent and dependent variables, employing long-term monitoring that incorporates their simultaneous measurement would be very helpful (see Andrews, 1990). This type of information would be particularly useful for identifying indicator thresholds that might trigger area closures, re-routing of OHV routes, and/or implementing a restoration project. A variety of technologies and tools now available would be useful in these endeavors, including satellite telemetry, Global Positioning Systems (GPS), infrared photography, pneumatic vehicle counters, and so on.

Finally, there are a number of specific questions that researchers could ask with respect to OHV effects on animal populations. For example, the discussion in section 2.3.3 regarding edge effects of OHV routes raises the question of whether high densities of animals in roadside habitats represent favorable conditions for native fauna or dominance by invasive or non-native organisms and, if the former, whether these habitats are population sources or sinks (see Van Horne, 1983).

#### **5.2.4 Research to Determine Socioeconomic Costs Associated with OHV Use**

The literature search conducted for this report yielded no published studies of the economic costs associated with OHV use. Costs could include the degradation or loss of crucial ecosystem goods and services (such as a decline in water quality due to accelerated sedimentation and increased turbidity in wetlands caused by OHV traffic, or the loss of livestock and wildlife forage due to soil compaction caused by OHV traffic), the loss of economic and political support from both OHV users and non-motorized constituencies whose recreation experiences (or other land uses) are degraded by OHV effects, and the costs of managing OHV recreation and restoring sites impacted by OHV traffic. Although the costs of OHV effects may be challenging to assess, there are efforts underway to first identify the economic values of ecosystem goods and services and factor them into economic analyses of human activities. For example, Ducks Unlimited Canada and The Nature Conservancy have co-published a report that calls for the immediate acceleration of “efforts to measure, protect, and enhance the natural capital of Canada,” including the need to “invest in science to measure, value, and monitor ecological goods and services, and develop economic instruments that recognize and protect natural capital, rather than continue to reward its destruction” (Olewiler, 2004). A companion report details the values of goods and services provided by wetlands (Gabor and others, 2004). Similar efforts to place a value on the goods and services provided by lands affected by OHV activities would provide the necessary basis for balancing economic equations of OHV use.

### 5.2.5 Research to Improve Site Restoration

The success of site restoration ultimately depends on the ability to return soils, including abiotic crusts and desert pavement, vegetation, and biotic crusts to their original condition. Therefore, research is needed to study the mechanisms behind, and mitigation that could diminish, changes in soils. Adams and others (1982) called for research on the disproportionate hardening of only slightly compacted desert soil and whether soil hardening is caused by chemical cementation or by a greater number of interstitial water bonds remaining between soil particles after drying. Webb and others (1978) called for studies that explore the amount of time required for soils to respond to revegetation of OHV sites and develop ways of mitigating changes in soil properties during OHV use. More recently, Bolling and Walker (2000) expressed the need for long-term monitoring and analysis of soil microbial populations. Answers to these and other important questions that elucidate the ways in which systems recover from the effects of OHVs are crucial to the possibility of long-term OHV use without incurring irreparable damage to ecosystems.

## 6.0 Conclusion

It is apparent from the literature identified and discussed herein that the effects of OHV activities on ecosystems are diverse and potentially profound, if poorly understood. Studies have revealed a variety of effects on soil properties, watersheds, and vegetation resulting from one to multiple passes by OHV vehicles. Likewise, research has shown a variety of OHV effects on both OHV users and non-motorized recreators. Considerably less is known about impacts to wildlife or air and water quality. Whereas the results of past OHV-effects research have been reasonably consistent in demonstrating the nature of OHV effects in the immediate vicinity of single trails and OHV sites, there is a need for stronger emphasis on the cumulative effects—both spatial and temporal—of OHV use. For example, the effects of a single OHV route on a watershed may be greater when it is part of a route network than when it is the only route within the watershed. Furthermore, a network of OHV routes is likely to accommodate more users than a single route. Therefore, route density is an important consideration when evaluating and monitoring OHV effects across a given landscape.

The Council on Environmental Quality's (CEQ) regulations for implementing the National Environmental Policy Act define a cumulative impact as "...the impact on the environment that results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions" (Council on Environmental Quality, 1997). In other words, cumulative impacts can result from what may appear on small spatial or temporal scales to be minor, but which become collectively significant when such actions take place over large areas and long periods of time. Moreover, one effect may interact with other effects to generate additional effects that are not apparent when evaluating effects individually.

The concept of cumulative impacts as they relate to OHV activity, therefore, must be applied in a landscape context, as these impacts are not site-specific and may affect adjacent or even more remote habitats and landscapes. For example, dust created from OHV activities can be dispersed to areas far away from habitats directly impacted by OHV activities. Likewise, erosion of soils during heavy rain events may increase sedimentation far downstream of areas directly subjected to OHV activities, and edge or corridor effects of OHV routes may promote widespread dispersal of non-native and invasive species. Thus, there is a need for greater

monitoring and research emphasis on the effects of OHV activities not only in the areas directly subjected to those activities, but across impacted habitat types, watersheds, and landscapes. Overall, monitoring of cumulative impacts is needed at a scale larger than the physical imprint of the OHV-use area. By the same token, economic analyses of OHV use are needed to account for not only the immediate and apparent economic benefits, but also the long-term, large-scale, and ongoing costs associated with OHV use. Without factoring these variables into models of economic impacts, true cost:benefit ratios of OHV use will remain unknown.

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## Appendix 2. Search Methods and Results of Off-Highway Vehicle Effects Literature and Internet Resources

### 2.1 Methods

#### 2.1.1 Literature Search

From May 10–26, 2006, a comprehensive literature search was conducted to encapsulate the current knowledge on effects of off-highway vehicle (OHV) activities as it pertains to natural resource attributes addressed by the Bureau of Land Management’s (BLM) land health standards (U.S. Bureau of Land Management, 2001; Pellant and others, 2005). The search was conducted through 33 electronic literature databases available at Colorado State University’s (CSU) library (table 2.1) and search engines available on the Internet. The databases searched encompassed all major, and some minor, sources of relevant literature, including professional, peer-reviewed journal papers and technical reports/articles published in magazines representing the industrial sector and non-governmental conservation organizations.

Search terms used included “OHV,” “off-highway vehicle,” “ORV,” or “off-road vehicle” combined with terms representing the BLM’s land health standards, including soil health and watershed condition, nutrient cycling, wildlife health and habitat quality for native plants and animals (especially for species of special status), water quality, and air quality (table 2.1). In addition, searches were conducted on the socioeconomics of OHV use. Within each database searched, all search terms were applied to the 26 topic areas (see footnote 1 associated with table 2.1) listed in CSU’s library database subject list. Relevant citations also were gleaned from highly relevant reports and journal articles. All relevant citations identified were grouped by land-health categories to build extensive bibliographies for each land-health category. If a given citation was relevant to more than one land-health category, it was listed in each of the related bibliographies.

#### 2.1.2 Internet Search

Specific goals of the Internet search were to (1) identify websites and other Internet resources provided by the BLM and U.S. Forest Service (FS) regions 2 (time constraints limited this search to Colorado), 3, and 4; (2) classify OHV-related Internet websites by focus/intent and resource type; and (3) report on highly relevant websites. Two primary products were subsequently developed: (1) a thesaurus (table 2.2) of search topics and terms related to OHV effects, and (2) a list of significant BLM and FS resources and corresponding Internet websites. The thesaurus was developed to identify Internet-based resources regarding OHVs and the types of OHV effects. All possible combinations of search terms were used, but any one search string depended on the search engine used. Although *FirstGov* is a good search engine for finding government publications and reports, it limits search results to 100. In contrast, *Google* returns up to 1000 results, and its filter may be used to constrain searches to a specific type of website (for example, “.gov”); however, *Google* is unable to employ multiple exclusion criteria to exclude irrelevant websites (for example, it cannot specify “NOT FS” and NOT BLM”) whereas *FirstGov* does handle multiple exclusion criteria. In other words, *Google* was searched with an OHV term combined with an impact term while limiting any one search to “BLM,” “EPA” (U.S. Environmental Protection Agency), “FS” (U.S. Forest Service), “NPS” (U.S. National Park Service), or “USGS” (U.S. Geological Survey) sites. Then *FirstGov* was searched with the same

**Table 2.1.** Search terms used and publication years included when using search engines and 33 electronic literature databases at Colorado State University’s library to assemble an extensive bibliography of literature on effects of off-highway vehicles.

Database searched (for publications years) <sup>1</sup>	Search term										
	Air quality	Benefits	Domestic livestock grazing	Erosion	Noise	Soil impacts	Travel and transportation management	Visual impacts	Vegetation impacts	Water quality	Wildlife impacts
AGRICOLA EBSCO (1970-2006)	X		X	X		X			X	X	X
AGRICOLA National Agricultural Library (1970-2006)	X		X	X		X			X	X	X
Agricultural and Environmental Biotechnology Abstracts (1993-2006)	X			X	X	X	X		X	X	X
Agricultural Sciences (in Cambridge Scientific Abstracts) (compilation of multiple databases <sup>2</sup> )	X		X	X		X			X	X	X
Animal Behavior Abstracts (1982-2006)		X	X		X						X
Applied Science and Technology Abstracts (1983-2006)	X			X	X	X	X	X		X	
ASFA 1: Biological Sciences and Living Resources (1971-2006)					X				X		X

Database searched (for publications years) <sup>1</sup>	Search term										
	Air quality	Benefits	Domestic livestock grazing	Erosion	Noise	Soil impacts	Travel and transportation management	Visual impacts	Vegetation impacts	Water quality	Wildlife impacts
ASFA 2: Ocean Technology, Policy & Non-Living Resources (1971-2006)	X			X		X	X	X			
ASFA 3: Aquatic Pollution and Environmental Quality (1990-2006)	X			X	X	X	X	X		X	
BioEngineering Abstracts (1993-2006)				X		X	X				
Biological Abstracts (1969-2006)			X						X		X
Biological Sciences (1982-2006)			X						X		X
Biological Sciences (in Cambridge Scientific Abstracts) (compilation of multiple databases <sup>2</sup> )			X						X		X
Biology Digest (1989- 2006)									X		X
Biotechnology and Bioengineering Abstracts (1982-2006)				X		X	X				
CAB Abstracts Archive (1900-1973)											X
Ecology Abstracts (1969-2006)		X	X						X	X	X

Database searched (for publications years) <sup>1</sup>	Search term										
	Air quality	Benefits	Domestic livestock grazing	Erosion	Noise	Soil impacts	Travel and transportation management	Visual impacts	Vegetation impacts	Water quality	Wildlife impacts
EIS: Digests of environmental impact statements (1985- 2006)							X				
Engineering Index (1884-2006)				X		X	X				
Environmental Engineering Abstracts (1990-2006)				X		X	X				
Environmental Sciences & Pollution Management (compilation of multiple databases <sup>2</sup> )	X			X	X	X	X				
Forest Service database (dates not indicated)			X	X		X	X		X	X	X
Geobase (1980-2006)				X		X					
Human Population & Natural Resource Management (1995- 2006)			X				X				
Plant Management Network (compilation of multiple databases <sup>2</sup> )									X		
Plant Science (1994- 2006)									X		
Pollution Abstracts (1981-2006)	X				X		X				

Database searched (for publications years) <sup>1</sup>	Search term										
	Air quality	Benefits	Domestic livestock grazing	Erosion	Noise	Soil impacts	Travel and transportation management	Visual impacts	Vegetation impacts	Water quality	Wildlife impacts
Pollution Management & Environmental Sciences (in Cambridge Scientific Abstracts) (compilation of multiple databases <sup>2</sup> )	X				X		X				
Threatened and Endangered Species System (dates not indicated)									X	X	X
Toxicology Abstracts (1981-2006)	X					X					
Water Resources Abstracts (1967-2006)										X	
Wildlife & Ecology Studies Worldwide (1935-2006)											X
Zoological Record (1978-2006)											X

<sup>1</sup>Topic areas searched in databases included biology, botany, civil engineering, construction management, earth resources, ecology, engineering, environment, environmental health, fishery, fisheries, forestry, forest science, geology, hydrology, life sciences, natural resource recreation, tourism, natural sciences, physical sciences, plant science, plant pathology, rangeland ecosystem science, soil and crop sciences, toxicology, water resources, weed science, wildlife, wildlife biology, zoology.

<sup>2</sup>Dates vary by database.

**Table 2.2.** Search topics and their associated search terms used in searching the Internet for publications and documents pertaining to off-highway vehicle effects and policies.

<b>Search topic</b>	<b>Search term(s)</b>
Off-highway vehicle	OHV Off-road vehicle Off-road vehicles
Air quality	Air quality
Benefits	Benefits
Domestic livestock grazing	Domestic livestock grazing
Erosion	Erosion
Human dimension	Human dimension Human dimensions
Noise	Noise
Soil impact	Soil impact Soil impacts
Transportation management	Transportation management
Travel	Travel
Vegetation impact	Vegetation impact Vegetation impacts
Visual impact	Visual impact Visual impacts
Water quality	Water quality
Wildlife impact	Wildlife impact Wildlife impacts

terms while excluding “BLM,” “EPA,” “FS,” “NPS,” “USGS,” and “.com” domains, which captured websites representing individual States, military agencies, and other non-commercial entities.

After the Internet searches were conducted, each website identified were reviewed (limited to 2 minutes per website) and assigned a relevance-class code (relevance to OHV effects and policies; table 2.3). Websites classified as H (highly relevant), R (relevant), or S (slightly relevant) were further categorized by focus area (table 2.4). All BLM and FS regions 2 (Colorado only), 3, and 4 websites were included in the results tallies; websites containing news releases, specific flora assessments, and BLM Resource Advisory Council meetings were omitted. Highly relevant websites were selected for presentation.

## **2.2 Results**

### **2.2.1 Literature Resources**

The literature search, and additional sources uncovered outside of the formal search, yielded approximately 700 citations, a number of which overlap in terms of their relevance to categories of land health (table 2.5).



**Table 2.3.** Relevance class codes and definitions pertaining to Internet websites found to contain information regarding off-highway vehicle effects and policies.

<b>Relevance class</b>	<b>Definition</b>
H	Highly relevant—high-quality resources related directly to OHV impacts; generally included number of OHV trail miles and visitor days, or reasons why OHVs excluded from specific locations; includes OHV strategy/plan documents or public communication sites on OHV recreation areas
R	Relevant—targeted mention of OHV but not as specific or detailed as a highly relevant site
S	Slightly relevant—mention of OHV but with few supporting statements or details
U	Unrelated—no or minimal OHV content
Z	Unable to access, page would not load, URL has changed, page loads but is empty of content
ZDup	Content duplicate of previous entry

**Table 2.4.** Focus areas and definitions of Internet websites found to contain information regarding off-highway vehicle effects and policies.

<b>Focus area</b>	<b>Definition</b>
Administration	Information sourced from the Federal level
Citizen input	Site contains or informs about public comments on OHV use
EIS	Site contains a draft or final environmental impact statement (EIS) or environmental assessment (EA)—attempt was to keep this category to sites related to actions up through completion of a management plan although there is some overlap with the next category due to title ambiguity
Impact	Site focus was measurement of impact
Legal	Response to appeals regarding travel management plans or EIS documents
Manual	Site containing a handbook or manual
Management plan	Sites with completed management plans or actions stemming from implementation of a management plan; includes monitoring, revision of plans, assessment for roadless areas, and road analyses
Monitoring	Usually annual reports of monitoring activity prescribed by a management plan
Press	Site with information in the form of a press release or media announcement
Road guide	Sites intended to provide public information about OHV and recreation site use; includes descriptions, trail maps, event calendars, safety, licensing and regulation, and closure information

**Table 2.5.** Number of relevant publications found, and publication dates included, in a literature search on effects of off-highway vehicle activity as they pertain to the U.S. Bureau of Land Management’s land health standards.

<b>Land health category</b>	<b>No. citations</b>	<b>Years included</b>
Soils	314	1959-2006
Air quality	104	1970-2006
Water quality	218	1959-2005
Vegetation	326	1962-2006
Wildlife	387	1970-2006
Land users	211	1967-2006

### 2.2.2 Internet Resources

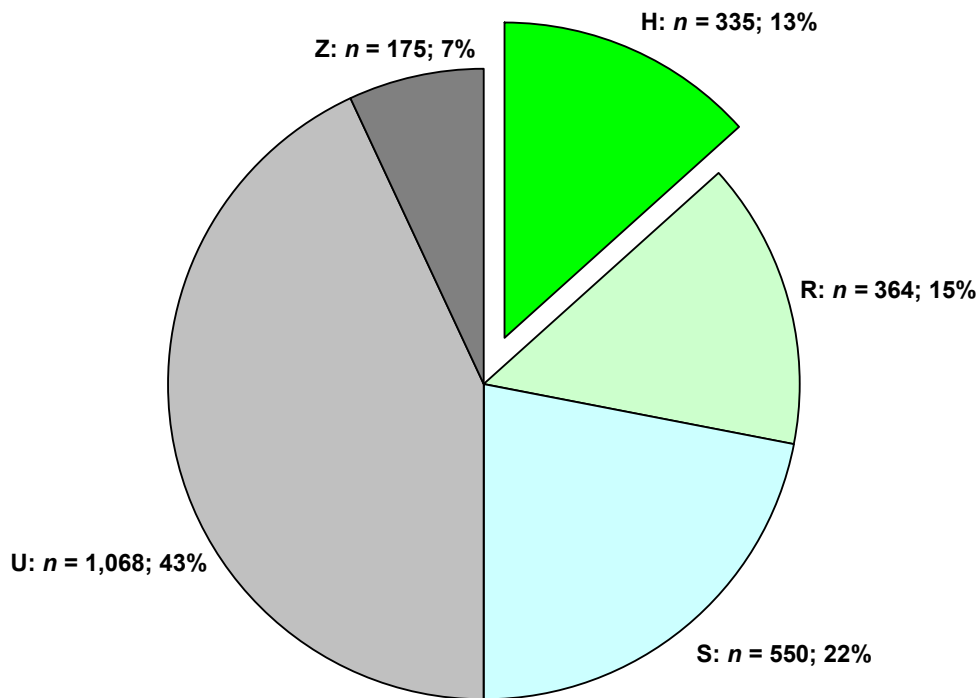
The Internet search yielded nearly 30,000 State and Federal government websites, of which 8,693 were unique (a single HTML page or .pdf file); 23 percent ( $n = 1,998$ ) were BLM websites, 55 percent ( $n = 4,817$ ) were FS websites, and 7 percent ( $n = 568$ ) were NPS websites (table 2.6). FS regions 2 (Colorado only), 3, and 4 together represented 12 percent of the websites. Of the 8,693 unique sites, 2,495 were visited and reviewed (29 percent) using the methods described above. All search term combinations returned at least 100 results, and some returned as many as 3,700 (table 2.6).

Of the unique websites identified, only 13% ( $n = 335$ ) were classified as highly relevant; 15 percent were relevant, 22 percent were slightly relevant, and 50 percent were unrelated/not available (figure 2.1). Forty-seven percent of those classified as highly relevant were BLM sites, and 53 percent were FS sites. The majority of highly relevant sites (68 percent) were dedicated to environmental impact statements (EIS) or management plans (figure 2.2). Only two percent of the highly relevant sites focused on measuring or monitoring the effects of OHV activities. When all sites were considered, a slightly higher percentage of sites (approximately 5 percent) included monitoring or impact assessment (figure 2.3).

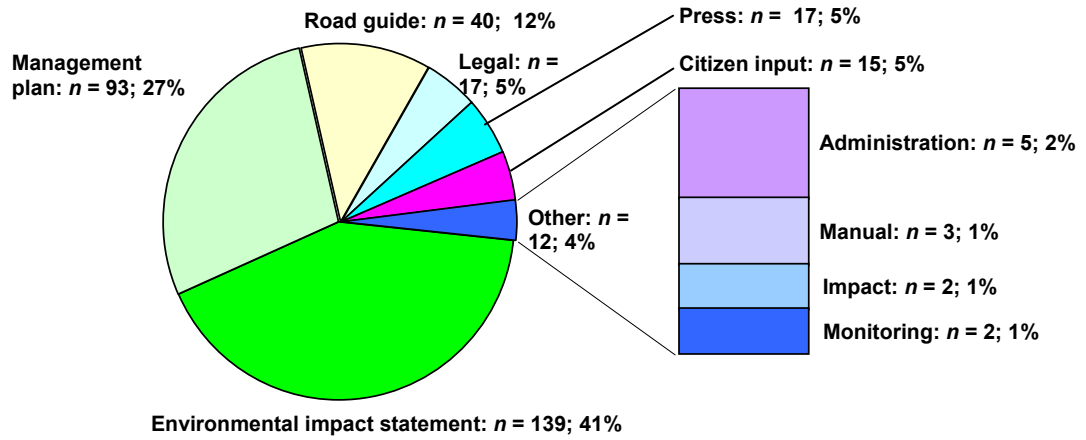
Key similarities between highly relevant BLM and FS websites (figures 2.4 and 2.5) included equal emphasis on road guides (about 12 percent of sites) and little emphasis on monitoring and impacts (0 and 1 percent for BLM, respectively; 1 and 1 percent for FS, respectively). The BLM sites had slightly greater emphasis on EISs and management plans (73 percent) than did FS sites (65 percent). Interestingly, 10 percent of the FS sites concerned legal issues—primarily appeals to decisions—whereas no material of this type was found on BLM websites. This may be due to an agency decision of what type of material is posted to the Internet or it may be a result of a difference in EIS/management plan implementation status between the two agencies. Table 2.8 presents examples of five highly ranked web sites (if available) from BLM and/or FS Region 2 for each of the focus areas.

**Table 2.6.** Search results, by topic, for all Internet websites pertaining to off-highway vehicle effects and policies (n = 22,990).

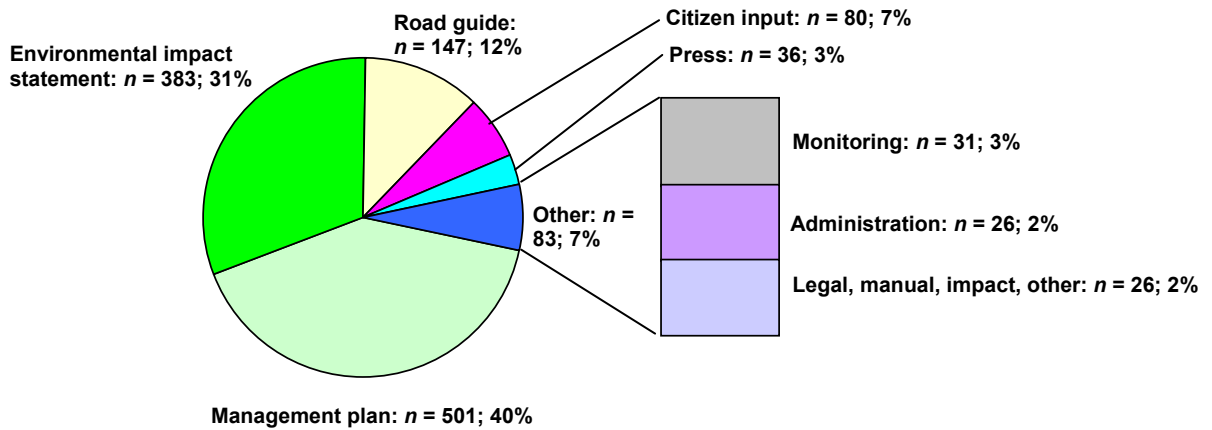
Search topic	Results
Air quality	3,040
Benefits	3,081
Domestic livestock grazing	373
Erosion	3,228
Human dimension(s)	241
Noise	2,650
Soil impact(s)	461
Transportation management	453
Travel	3,726
Vegetation impact(s)	155
Visual impact(s)	1,392



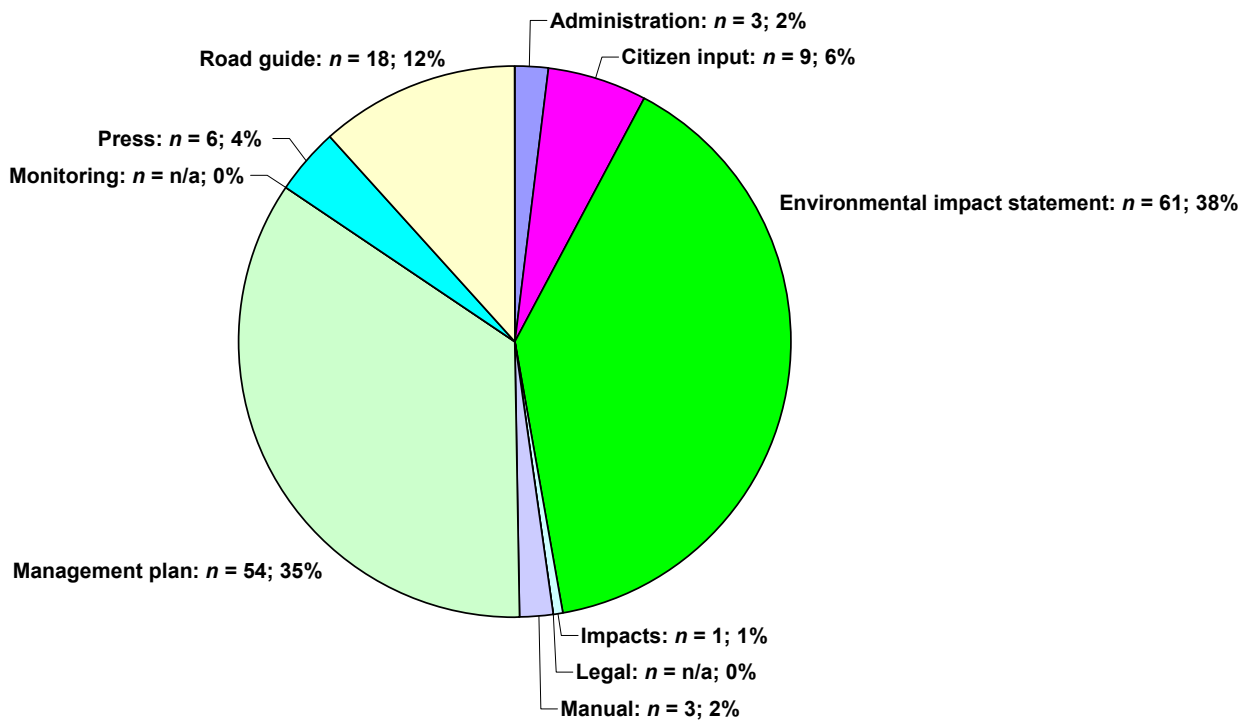
**Figure 2.1.** Breakdown of unique Internet websites (n = 2,495) classified as “highly relevant” (H), “relevant” (R), “slightly relevant” (S), and “unrelated/unavailable” (U, Z) to off-highway vehicle effects and policies.



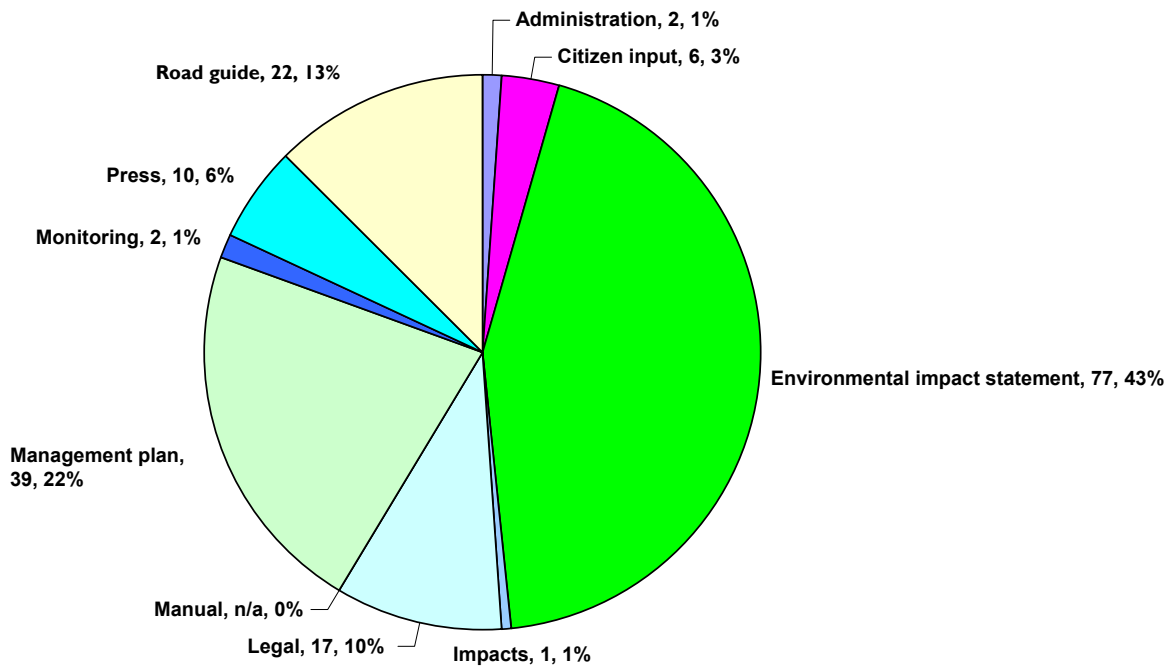
**Figure 2.2.** Focus areas of Internet websites (n = 333) classified as highly relevant to off-highway vehicle effects and policies.



**Figure 2.3.** Focus areas for all Internet websites (n = 1,230) classified as highly relevant, relevant, and somewhat relevant to off-highway vehicle effects and policies.



**Figure 2.4.** Focus areas of U.S. Bureau of Land Management Internet websites (n = 155) classified as highly relevant, relevant to off-highway vehicle effects and policies.



**Figure 2.5.** Focus areas of U.S. Forest Service (regions 2 [Colorado only], 3, and 4 only) Internet websites (n = 176) classified as highly relevant to off-highway vehicle effects and policies.

The large percentage of highly relevant websites assigned to the EIS and management plan categories indicate that OHV impact is an important topic to both the BLM and FS. The relatively small number of agency sites that address assessment or monitoring of OHV effects suggests that assessment or monitoring of OHV effects may be important topics for future website development. EISs and management plans do not focus on providing quantitative measures for determining the suitability of OHV trails (aside from the problem of trail redundancy for a given area); a trail-management plan of “fewer but better” seemed to be the approach in most plans, although a few plans specified that areas with a high degree of slope are unsuitable for trails. Almost no plans addressed OHV-related dust or noise problems, although some addressed areas of significant erosion by moving trails.

Overall, there appear to be more FS than BLM websites dealing with OHV management and related issues, including monitoring and the legal response to approved plans. Although road management plans are being developed for many land units by both the BLM and FS, only a few of these plans include OHV travel as an aspect of road management. The BLM, however, has produced a nation-wide OHV strategy, and Montana, Wyoming, and Idaho also have prepared state OHV management strategies. In general, policy appears to be taking the form of management plan implementation (such as closing areas due to muddy conditions or fire risk rather than making specific policy statements).

**Table 2.7.** Internet websites classified as highly relevant, by focus area and source, pertaining to off-highway vehicle effects and policies.

Focus/ source <sup>1</sup>	Title and URL
<b>Administration</b>	
BLM	BLM National Management Strategy for Motorized Off-Highway Vehicle Use <i><a href="http://www.fs.fed.us/recreation/programs/ohv/blm_strategies.pdf">http://www.fs.fed.us/recreation/programs/ohv/blm_strategies.pdf</a></i>
FS-R2	Recreation, Wilderness, and Related Resource Management WO Amendment 2300-94-3 <i><a href="http://www.fs.fed.us/cdt/admin.htm">http://www.fs.fed.us/cdt/admin.htm</a></i>
<b>Environmental impact statement</b>	
BLM	Environmental Assessment EA No.: AZ-020-04-0115 for the Arizona Association of Four-Wheel Drive Clubs 2004 4x4 Jamboree <i><a href="http://www.blm.gov/ca/publish/etc/medialib/blm/az/pdfs/nepa/library/4wd.Par.7790.File.dat/ASA4WDC-Jamboree-EA.pdf">http://www.blm.gov/ca/publish/etc/medialib/blm/az/pdfs/nepa/library/4wd.Par.7790.File.dat/ASA4WDC-Jamboree-EA.pdf</a></i>
BLM	Environmental Assessment: DARPA Grand Challenge <i><a href="http://www.blm.gov/ca/pdfs/barstow_pdfs/darpa/chapter_3_affected_environment.pdf">http://www.blm.gov/ca/pdfs/barstow_pdfs/darpa/chapter_3_affected_environment.pdf</a></i>
BLM	Final environmental impact statement for the Imperial Sand Dunes Recreation Area Management Plan and Proposed Amendment to the California Desert Conservation Plan 1980 <i><a href="http://www.blm.gov/ca/pdfs/elcentro_pdfs/FinalEISandRAMP/FinalEIS.pdf">http://www.blm.gov/ca/pdfs/elcentro_pdfs/FinalEISandRAMP/FinalEIS.pdf</a></i>
BLM	Red Rock 4-Wheelers Jeep Safari and Fall Campout 5-Year Permit Renewal <i><a href="http://www.blm.gov/ut/st/en/info/newsroom/2006/01/blm_renews_jeep_safari.html">http://www.blm.gov/ut/st/en/info/newsroom/2006/01/blm_renews_jeep_safari.html</a></i>
FS-R2	Decision Notice and Finding of No Significant Impact for the Clear/Crazy Designated Motorized Trail System, Powder River Ranger District, Bighorn National Forest <i><a href="http://www.fs.fed.us/r2/bighorn/projects/projectfiles/clearcrazy/clear_crazy_fonsi_032005.pdf">http://www.fs.fed.us/r2/bighorn/projects/projectfiles/clearcrazy/clear_crazy_fonsi_032005.pdf</a></i>
FS-R2	Scoping Document for the Hunt Mountain Travel Management Plan, Medicine Wheel/Paintrock Ranger District, Bighorn National Forest <i><a href="http://www.fs.fed.us/r2/bighorn/projects/projectfiles/hunt_mtn_carea/scoping_carea.pdf">http://www.fs.fed.us/r2/bighorn/projects/projectfiles/hunt_mtn_carea/scoping_carea.pdf</a></i>
FS-R3	Munds Park Roads and Trails Project: Environmental Assessment <i><a href="http://www.fs.fed.us/r3/coconino/nepa/2004/munds-drft-ea-final-9_24_04.pdf">http://www.fs.fed.us/r3/coconino/nepa/2004/munds-drft-ea-final-9_24_04.pdf</a></i>

<b>Focus/ source<sup>1</sup></b>	<b>Title and URL</b>
<b>Impact</b>	
BLM	Air Quality Baseline and Analysis Report, Price Field Office, Price, Utah <a href="http://www.blm.gov/utah/price/pricermp/documents/Baseline_and_Analysis_Report.pdf">http://www.blm.gov/utah/price/pricermp/documents/Baseline_and_Analysis_Report.pdf</a>
FS-R2	Anthropogenic Influences Used in Conducting Multiple Scale Aquatic, Riparian, and Wetland Ecological Assessments for the USDA Forest Service – Rocky Mountain Region, Report 2 <a href="http://www.fs.fed.us/r2/projects/scp/arw/protocols/anthropogenicinfluencesusedinconductingmultiplescale.pdf">http://www.fs.fed.us/r2/projects/scp/arw/protocols/anthropogenicinfluencesusedinconductingmultiplescale.pdf</a>
Wildlands	Resource website that provides publications on PHV effects, restoration, enforcement, policy, and other related issues and materials <a href="http://www.wildlandscpr.org/resources">http://www.wildlandscpr.org/resources</a>
<b>Legal</b>	
FS-R2	Recommendation Memorandum for Uncompagre Travel Management Plan, July 13, 2000 <a href="http://www.fs.fed.us/r2/projects/nepa/appeal-decisions/2000/gmug/uncompahgre_travel_39.htm">http://www.fs.fed.us/r2/projects/nepa/appeal-decisions/2000/gmug/uncompahgre_travel_39.htm</a>
FS-R2	Recommendation Memorandum for Gunnison Interim Travel Restrictions, July 13, 2001 <a href="http://www.fs.fed.us/r2/projects/nepa/appeal-decisions/2001/gmug/gunntrvl_16.htm">http://www.fs.fed.us/r2/projects/nepa/appeal-decisions/2001/gmug/gunntrvl_16.htm</a>
FS-R2	Recommendation Memorandum for Uncompahgre Travel Management Plan, June 18, 2002 <a href="http://www.fs.fed.us/r2/projects/nepa/appeal-decisions/2002/gmug/tvl_mgmt_23.htm">http://www.fs.fed.us/r2/projects/nepa/appeal-decisions/2002/gmug/tvl_mgmt_23.htm</a>
FS-R2	Recommendation Memorandum for Uncompahgre Travel Management Plan, June 19, 2002 <a href="http://www.fs.fed.us/r2/projects/nepa/appeal-decisions/2002/gmug/tvl_mgmt_24.htm">http://www.fs.fed.us/r2/projects/nepa/appeal-decisions/2002/gmug/tvl_mgmt_24.htm</a>
FS-R2	Recommendation Memorandum for Radial Mountain Travel Management Environmental Assessment, Sept. 13, 2001 <a href="http://www.fs.fed.us/r2/projects/nepa/appeal-decisions/2001/mbr/radial_mtn_25.htm">http://www.fs.fed.us/r2/projects/nepa/appeal-decisions/2001/mbr/radial_mtn_25.htm</a>
<b>Manual</b>	
BLM	Western Oregon Plan Revisions: Proposed Planning Criteria and State Director Guidance <a href="http://www.blm.gov/or/plans/wopr/files/PlanningCriteriaDocument.pdf">http://www.blm.gov/or/plans/wopr/files/PlanningCriteriaDocument.pdf</a>
BLM	Interpreting Indicators of Rangeland Health <a href="http://www.blm.gov/nstc/library/pdf/1734-6rev05.pdf">http://www.blm.gov/nstc/library/pdf/1734-6rev05.pdf</a>
BLM	Biological Soil Crusts: Ecology and Management <a href="http://www.blm.gov/nstc/library/pdf/CrustManual.pdf">http://www.blm.gov/nstc/library/pdf/CrustManual.pdf</a>
<b>Management plan</b>	
FS-R2	U.S. Forest Service, Travel Management: New Rule <a href="http://www.fs.fed.us/r2/recreation/travel_mgmt/">http://www.fs.fed.us/r2/recreation/travel_mgmt/</a>



<b>Focus/ source<sup>1</sup></b>	<b>Title and URL</b>
FS-R2	Decision Notice & Finding of No Significant Impact, Grand Mesa Travel Management, December 1, 2003, Delta And Mesa Counties, Colorado <i><a href="http://www.fs.fed.us/r2/gmug/policy/gm_travel/fonsi_dec2003.pdf">http://www.fs.fed.us/r2/gmug/policy/gm_travel/fonsi_dec2003.pdf</a></i>
FS-R2	Roads Analysis Report: Medicine Bow National Forest <i><a href="http://www.fs.fed.us/r2/mbr/projects/roads/adobepdf/medbow/mbnf_rds_analysis_final.pdf">http://www.fs.fed.us/r2/mbr/projects/roads/adobepdf/medbow/mbnf_rds_analysis_final.pdf</a></i>
FS-R2	Roads Analysis Report: Routt National Forest <i><a href="http://www.fs.fed.us/r2/mbr/projects/roads/adobepdf/routt/routt_rap_final.pdf">http://www.fs.fed.us/r2/mbr/projects/roads/adobepdf/routt/routt_rap_final.pdf</a></i>
FS-R2	Travel Management Rule, Implementation Safety, Rocky Mountain Region <i><a href="http://www.fs.fed.us/r2/recreation/travel_mgmt/references/Final_TravelMgmtStrategy.pdf">http://www.fs.fed.us/r2/recreation/travel_mgmt/references/Final_TravelMgmtStrategy.pdf</a></i>
<b>Monitoring</b>	
FS-R2	Forest Plan Monitoring and Evaluation Reports, Arapaho and Roosevelt National Forests and Pawnee National Grassland <i><a href="http://www.fs.fed.us/r2/arnf/projects/forest-planning/monitoring/">http://www.fs.fed.us/r2/arnf/projects/forest-planning/monitoring/</a></i>
<b>OHV road guide</b>	
BLM	Killpecker Sand Dunes Open Play Area, BLM Wyoming Rock Springs Field Office, Wyoming <i><a href="http://www.wy.blm.gov/rsfo/rec/dunes.htm">http://www.wy.blm.gov/rsfo/rec/dunes.htm</a></i>
BLM	Dunes OHV Area, Farmington Field Office, New Mexico <i><a href="http://www.nm.blm.gov/recreation/farmington/dunes_ohv_area.htm">http://www.nm.blm.gov/recreation/farmington/dunes_ohv_area.htm</a></i>
BLM	Lark Canyon, El Centro Field Office, California <i><a href="http://www.ca.blm.gov/elcentro/larkcany.html">http://www.ca.blm.gov/elcentro/larkcany.html</a></i>
FS-R2	OHV, Pike & San Isabel National Forests, Cimarron & Comanche National Grasslands, South Park Ranger District, Colorado <i><a href="http://www.fs.fed.us/r2/psicc/sopa/roads.shtml">http://www.fs.fed.us/r2/psicc/sopa/roads.shtml</a></i>
FS-R2	Rampart Range Motorized Recreation Area, Pike & San Isabel National Forests, Cimarron & Comanche National Grasslands, South Platte Ranger District, Colorado <i><a href="http://www.fs.fed.us/r2/psicc/spl/spl_ohv.shtml">http://www.fs.fed.us/r2/psicc/spl/spl_ohv.shtml</a></i>
FS-R2	OHV, Arapaho & Roosevelt National Forests, Sulphur Ranger District, Colorado <i><a href="http://www.fs.fed.us/r2/arnf/recreation/ohv/srd/stillwaterpass-grandlake.shtml">http://www.fs.fed.us/r2/arnf/recreation/ohv/srd/stillwaterpass-grandlake.shtml</a></i>

<sup>1</sup> BLM = U.S. Bureau of Land Management; FS = U.S. Forest Service; R = region (Region 2 limited to Colorado)