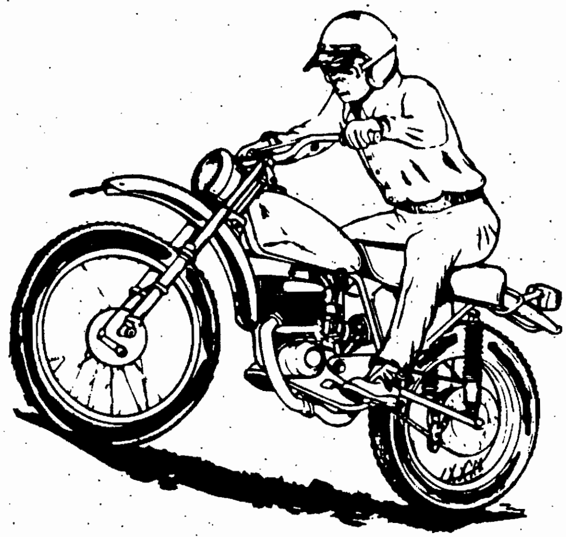
S0-0006

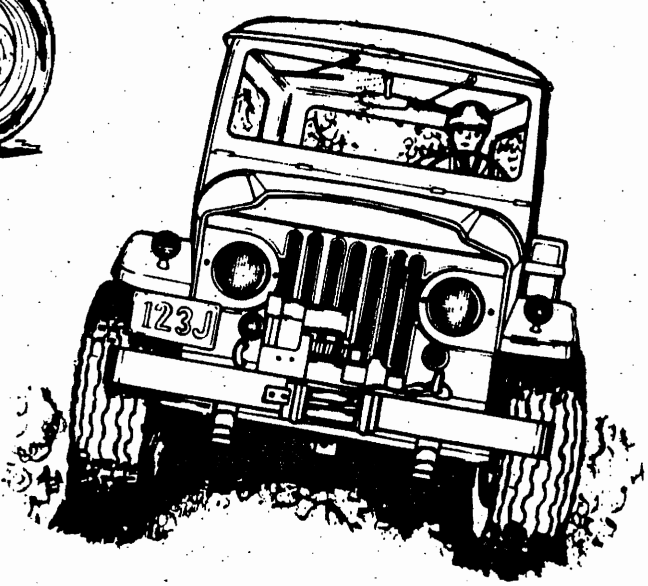
Project Record

APRIL 1980

FOREST SERVICE—U.S. DEPARTMENT OF AGRICULTURE
SAN DIMAS EQUIPMENT DEVELOPMENT CENTER

Predicting IMPACT of Noise on Recreationists





FOREST SERVICE #7

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EPA
U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF NOISE ABATEMENT AND CONTROL—WASHINGTON, D.C.

PREDICTING IMPACT OF NOISE ON RECREATIONISTS

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ED&T PROJECT NO. 2688
–Noise Pollution Prediction Method–

FOREST SERVICE–U.S. Department of Agriculture
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APRIL 1980

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FOREWORD

This *Project Record* consists of two parts. The first part describes the Outdoor Recreation Opportunity Spectrum (OROS) and how the acceptability of impacts of various influences on natural resources varies as a function of outdoor recreation opportunities at any given site. The second part presents a method of predicting the impact of noise on outdoor recreation—called the System for the Prediction of Acoustic [1] Detectability (SPreAD)—and instructions on how to use SPreAD with examples of its use.

Additional *Project Records* are being issued as companion documents to this report so that specific acoustic impacts can be calculated. For instance, "Predicting Snowmobile Acoustic Impact—Simplified Method," which addresses itself to a field-usable method for making preliminary predictions of the acoustic impact of snowmobiles on snow-covered ground when the listener is at least 350 ft away.

PREFACE

Efficient and effective forest management depends upon managers having adequate information about impacts on natural resources. One of the most difficult impacts to assess is sound. The impact of a sound depends upon both the physical properties of the sound and the characteristics of the receiver (in our case, the human "listener"). This *Project Record* addresses the problem of quantifying the impact of sound on the forest recreation experience.

The U.S. Environmental Protection Agency (EPA), Office of Noise Abatement and Control, Washington, D.C., funded the work of the Forest Service engineer and researchers. In Washington, D.C., the Program Manager for the EPA was Gene Wyszpolski and for the Forest Service, Michael Lambert.

Terminology

A glossary of specialized terms is presented in appendix C. Detailed descriptions of three additional terms (sound, noise, and acoustic impact) are presented later in this report. The following brief explanations should be helpful in discerning the difference between these three key terms:

- ***Sound***—A physical phenomenon; a vibration in the air that can be measured.
- ***Noise***—Sound that has characteristics that may irritate or annoy a listener, interfere with the listener's activity, or in some other way be distinguished as unwanted.
- ***Acoustic impact***—Implies that the physical characteristics of a sound have been measured, and its degree of acceptability to a particular group of listeners can be calculated.

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[1] The adjective **acoustic** means "intimately associated with sound waves;" the adjective **acoustical** means "associated in a general way with the science of sound:" Beranek, Leo L., 1954, Acoustics, p.9, McGraw-Hill Book Co., Inc., New York.

Overview—OROS and SPreAD

In a recreation situation, the acoustic impact of a sound depends on the measurable inherent characteristics of the sound, the setting in which the sound is heard, and the individual attributes of the listener. If the acoustic impact upon the listener is negative enough, the sound may be categorized as noise. The SPreAD method of predicting acoustic impact can be used by recreation area decision makers to:

1. Evaluate potential of acoustic impacts when planning the multiple uses of an area.

2. Identify and evaluate sound sources present in existing areas to ascertain whether or not recreation management objectives are indeed being met.

3. Determine which variables in existing sound sources might be changed to reduce their acoustic impact.

4. Ascertain existing levels of acoustic impacts so that recreationists can be forewarned of what to expect in certain locations.

5. Locate the "zones of influence" of sound sources so that recreation areas can be planned to minimize the disruption of the experiences sought by recreationists.

6. Measure planned and unplanned changes in acoustic impacts that take place, over time, in recreation areas.

When used in conjunction with the OROS concepts presented in part I of this report, the information provided by SPreAD (part II) becomes useful to all levels of decision makers. SPreAD can, for example, be used as an aid in planning for recreation opportunities in areas not now used for recreation. Also, SPreAD can be helpful in locating opportunities in areas that are already developed for recreation.

Information obtained through SPreAD is only one of the many variables to be considered in the decisionmaking process. As always, the knowledge, experience, and objectives of planners and managers must be taken into account, along with input on the expectations and preferences of users.

CONTENTS

*Appendix A is a removable booklet.

CONTENTS (Continued)

ILLUSTRATIONS

TABLES

CONTENTS (Continued)

TABLES

PART I

DETERMINING ACCEPTABILITY OF RECREATION IMPACTS— AN APPLICATION OF THE OUTDOOR RECREATION OPPORTUNITY SPECTRUM

by

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and

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INTRODUCTION

Nationwide, increasing numbers of people are seeking outdoor recreation in wildlands. Whether in highly developed, intensively used forest campgrounds or in wilderness, this increase in recreation has caused increasing concern about impacts to the wildlands. Land managers, recreationists, and researchers are all becoming more conscious of potential adverse consequences of recreation use on resources such as vegetation, soil, water, wildlife, etc.

Substantial disagreement clearly exists as to what constitutes unacceptable impacts, since definitions of acceptability depend upon the values and desires of the person making the judgment. A conflict in values seem unavoidable because our wildlands are used for so many diverse recreation purposes.

The OROS concept can be used in making judgments about the acceptability of recreation impacts. Factors that define recreation opportunities are briefly described, followed by a discussion of the role that expectations play in a judgment of acceptability. Finally, applications of the OROS framework to minimizing recreation area noise problems are demonstrated.

RECREATION OPPORTUNITY SETTINGS

When considering outdoor recreation opportunities, people must make choices about what type of setting in which to recreate, plus the kinds of recreation experiences to seek and activities in which to engage. By describing the factors that influence and define the range of possible settings for recreationists, people can make choices that will be in keeping with the experiences desired.

A recreation opportunity setting is defined as ***the combination of physical, biological, management, and social conditions that give value to a place.*** Consequently, the role of values is central to understanding recreation. Different values (producing different tastes, interests, and preferences) lead to diverse demands for recreation opportunities that array themselves along a continuum.

This continuum—the OROS—has been found useful in dealing with a wide range of value-related management issues (such as carrying capacity, depreciative behavior, and recreation impacts). The OROS is distinguished by varying conditions for recreation areas that range from modern and developed to primitive and undeveloped. Six factors (or setting attributes), which influence recreation behavior and have management significance, make up the OROS [2/]:

1. ***Access*** into and within the area, the level of difficulty in attaining the access, and the permitted means of conveyance.

[2/] For a more detailed description of the six factors, how they can be combined, and the OROS framework in general, see: Clark, Roger N., and George H. Stankey, [In press] The outdoor recreation opportunity spectrum: A framework for recreation planning management and research, USDA For. Serv., PNW For. Exp. Stn., Wildland Recr. Res., Seattle, Wash.

2. ***Nonrecreation resource uses*** (such as timber, mining, etc.) and the extent to which these uses are compatible with various outdoor recreation activities.

3. ***On-site management*** and the extent, appearance, and complexity of modification to an area–including the use of exotic vegetation, landscaping, traffic barriers, and facilities (tables, toilets, water supplies, etc.).

4. ***Social interaction*** and the relative intensity of use per unit area–including the level of intergroup contact and space requirements associated with different opportunities.

5. ***Regimentation*** and the nature, extent, and level of control over recreation use that is exercised by management.

6. ***Visitor impacts*** (expanded upon in the section that follows) and the number acceptable for different opportunities.

Each of these factors is characterized by a range of conditions. For example, ***access*** ranges from areas where mechanical access on wide, paved highways is appropriate and in keeping with the opportunity provided, to areas where only foot travel is permitted and no trails exist. Similarly, the level of ***social interaction*** would vary from where high-density use is present–as well as appropriate and expected (such as in some modern campgrounds)– to places where maximum solitude occurs. The point being, the setting attributes are not characterized by any single or absolute standard of appropriateness; rather, the appropriateness varies along the spectrum. Well-developed roads and large numbers of people with frequent contact between parties are not appropriate in wilderness, yet they can be very appropriate in day-use beach areas near an urban site, highly developed campgrounds, etc.

A recreation opportunity setting is the result of a specific combination of the six factors in a particular location. The setting may also include a variety of other natural features and resources (beautiful scenery or landscape, mountains, lakes, wildlife, etc.). Alternative combinations of the factors lead to different types of opportunity settings, giving recreationists many options to choose from that are in keeping with the experiences they desire.

Considerations about the appropriate criteria for any one of the factors are largely judgmental; there are seldom any absolute standards. But, the use of the OROS in opportunity setting decisionmaking forces one to make all conditions explicit. This should maximize the possibility that all recreationists will find the types of opportunities they seek.

ACCEPTABLE VISITOR IMPACTS

Factor 6, ***visitor impacts***, is an aspect of the OROS that is especially critical in recreation management. Recreation activities can disturb soil stability, water, wildlife, and the natural quietness of many outdoor environments. Ofttimes in the past, management response has been to regulate, restrict, or prohibit use (or, at least, certain equipment), harden sites, install protective facilities, etc. But the meaning of these management actions is often unclear to recreationists. Such actions may have consequences for recreationists and recreation opportunities that are as important and disruptive as the impacts they are meant to control.

The assumption implicit in management actions to minimize (or eliminate) impacts from recreation activities is that the impacts are unacceptable. What has not been adequately resolved, however, is what—in fact—defines acceptability, and to whom. While impacts of varying degree often appear to be expected and acceptable in other resource uses (e.g., timber management, mining, grazing, etc.), a "no-impact" standard is usually prescribed for the management of many outdoor recreation opportunities. But the no-impact philosophy may be impossible without drastic use reduction in many areas.

In considering what constitutes appropriate or inappropriate impact, it is helpful to distinguish between the ***magnitude*** of the impact and its ***importance.*** Magnitude refers to the objective measurement of the phenomenon under study; its frequency, extent, and other quantitative dimensions. Magnitude can be reliably measured by independent observers; typically, there will be little disagreement about these measurements.

Importance, on the other hand, reflects the value one assigns to some phenomenon (such as sound, water quality, soil compaction, etc.). It varies among individuals and over time and space. For example, two individuals observing the same impact having a predetermined magnitude can differ greatly in the importance they assign to that impact—a difference reflecting their personal value system and expectations. The role that values and expectations play in defining the importance of recreation (or any other type) impacts is discussed in the paragraphs that follow.

Our view of the world around us is shaped by deeply embedded orientations called values. These provide us with an estimate of the worth of an object in a particular situation. Although values often are not explicitly recognized, they form the base from which we develop our concepts of what is right and wrong, appropriate and inappropriate, acceptable and unacceptable. Many of these notions "go without saying;" that is, we don't really stop and think about them, where they come from, or what they imply. And, because they are general and—in a sense—vague, they are difficult to change. Generally, we tend to seek out and accept those things that we perceive as consistent with our particular values.

In addition, we choose to do things and go to places likely to meet our expectations. These expectations are a function not only of the values we hold, but also of our experience and knowledge. These expectations influence what people define as acceptable or unacceptable actions on the part of others. Expectations are formed by many factors that are either internal or external to the individual. These include the influence of family and/or friends, the media, and religious and educational institutions; personal values formed from available information and from experiences in similar situations, and the norms (informal rules) understood to govern appropriate actions in a particular place.

Thus, people indeed have expectations regarding what they will find at any particular location. Further, in a specific situation, people judge the importance of impacts based on their expectations. This judgment, in this context, has two possible outcomes:

- **The impact is acceptable and does not detract from their satisfaction.**

- **The impact is unacceptable and may lead to a decline in user satisfaction and, perhaps, in a decision never to return to that location.**

In any two situations, the same impact may be judged as either acceptable or unacceptable by the same individual. That is, we generally do not have one standard for acceptability—the judgment depends on the context within which the impact occurs. In addition, a person's expectations may be either realistic or unrealistic for a particular situation. Realistic expectations are based on accurate knowledge of the purpose of an area and the norms operating there. A person with experience in a particular area would have more realistic and strongly held expectations than a novice.

Fortunately, the relative importance that people attach to impacts does not vary randomly along the OROS. That is, people who choose a particular type of recreation opportunity (modern, primitive, etc.) probably hold somewhat similar notions of what is appropriate and in keeping with these kinds of places. Some of these notions become widely and strongly held norms that govern behavior and set standards of appropriateness and acceptability in a specific opportunity setting far more effectively than any agency-promulgated rule ever will. In other cases, specific appropriate, acceptable, or expected criteria are less clear. Here our estimates must be tentative and open to revision.

The challenges are, then, to:

1. Set standards on acceptable impact levels for recreation areas, taking into account user expectations plus other spectrum factors and concerns (such as management's long-term goals and an area's other resources).

2. Provide adequate information about what one will find in an area so that users can make choices about where to go that would be in keeping with their preferences and expectations.

3. Monitor the activities and impacts in an area to ensure that the situation doesn't inadvertently change and then adversely affect the quality of the recreation environment.

ACOUSTIC IMPACTS—AN EXAMPLE

We can illustrate the relative nature of impacts by considering the issue of noise in recreation areas. Some potential sound sources in recreation environments, classified along the lines of the Forest Service's designation of wilderness areas, are as follows:

A. Mechanical

1. Ground vehicles
2. Fixed- and rotary-winged aircraft
3. Devices with motors (e.g., chain saws or generators)

B. Nonmechanical

1. Humans
    a. Voices (e.g., loud talking, singing, or yelling)
    b. Camp tending (e.g., clanging kitchen utensils or wood chopping)

2. Domestic animals (e.g., pets or livestock)

3. Sporting and entertainment devices (e.g., gun shots, musical instruments, radios, or TV's).

Sound is a physical phenomenon; its magnitude can be measured, or at least calculated. (Thus, sound can be assessed using the physical model of part II of this *Project Record.*) But ***noise*** is an interpretation that the magnitude of a sound (such as from one of mechanical or non-mechanical sources just listed) has reached unacceptable levels, durations, or qualities. No absolute standards define these thresholds. Yet, recreationists' complaints about noise are familiar to most managers, and there are clearly some common (albeit not universally shared) notions as to what constitutes unacceptable acoustic impact in certain settings.

The following discussion is an example of how managers can use the OROS to integrate the data supplied by the physical prediction model, so as to keep sound in recreation areas within acceptable levels. The approach we describe is based on state-of-the-art judgments from the best knowledge available from research and management experience. Additional research will be necessary to determine how well these concepts fit reality.

Noise in Recreation Areas

Noise in recreation areas is a concern to both managers and users. When plans are made for any type of recreation area, they include the exclusion of excessive sound. Noise is considered just as inappropriate in a modern campground as in a remote wilderness. The difficulty, however, is that one individual's definition of noise may not be another's. Furthermore, definitions of noise are a function of more than just loudness (level); some types of sounds are perceived as noise regardless of the loudness. For example, even the faint sound of a vehicle might constitute a noise in a wilderness, while in a developed, modern campground the same sound might not be noticed.

Since noise is an interpretation of sound in a particular context or setting, the appropriateness of a sound depends upon a person's expectations for a particular setting. (We recognize that one's expectations may in themself be inappropriate or unrealistic.) Consequently, standards for the loudness, repetitiveness, or duration of sounds in recreation environments should be established only in terms of specified situations.

Applying the OROS

The concepts of magnitude, importance, and the OROS provide a useful framework in determining when sound becomes noise in recreation areas. The methods of part II allow us to determine the physical magnitude (i.e., how loud different sounds are at various distances and across different terrain). SPreAD provides valuable data because it informs managers about the physical consequences of sound sources under a variety of conditions and provides the distances required to buffer one area from another. Determining the importance, and thus the impact, of these sounds, however, is not easy. The following approach suggests a way to use the OROS in this task.

We assume that most people would prefer to have a relatively quiet environment, whether they favor modern or primitive recreation opportunities. But, we must also assume that people expect that opportunities at the modern end of the spectrum will have a greater variety of human-related sounds than opportunities at the primitive end. The OROS framework suggests that a variety of human-related sounds are not only consistent with opportunities towards the modern end of the spectrum, but that are acceptable (and perhaps not even noticeable) to most people who prefer those opportunities. A proposed typology of appropriateness for human-related sounds in recreation areas for four types of recreation opportunities follows.[3/]

Modern Opportunities

The sounds here are "noisy" relative to the full range of recreation opportunities. A variety of both mechanical and nonmechanical sounds is acceptable at levels close to that found in urban residential environments. The sounds may be of long duration, occur frequently, and occasionally be heard during late hours of the night. Sounds that reach well beyond the source are acceptable.

Semimodern Opportunities

The sounds here may have the same sources as in modern opportunity areas. But, the loudness, repetitiveness, and duration of the sounds are noticeably less. Sound impacts are occasionally evident beyond the general area of their source.

Semiprimitive Opportunities

The sounds here are primarily natural. Human-related sounds occur less often than in the semimodern category, last for a shorter period of time, and are infrequent during the night. Sound impacts are generally confined to the general area of their source.

Primitive Opportunities

The sounds here are generally not human-related. They are primarily natural, background sounds (such as wind or water). In those areas that are the most primitive, both mechanical and unnatural, nonmechanical sounds are inappropriate. Sounds do not extend beyond the immediate area of their source.

Sound Characteristics

Even though the presence of a variety of sounds may be acceptable, there are norms (or standards) regarding the duration, repetitiveness, and timing of such sounds. For some modern opportunities, for example, the sound of a chain saw or a motorcycle may be entirely appropriate. On the other hand, the sound from either can be too long or occur too often or be heard at the wrong time.

3/ For illustrative purposes, we have broken the range of opportunities into four types. Depending upon specific needs, more or fewer categories could be used. The opportunity types result as alternative combinations of the OROS spectrum factors. The labels (modern, semimodern, etc.) are arbitrary; other labels (such as urban, rural, natural) could be used, depending on individual preference.

That is, hearing a chain saw or motorcycle may not be bothersome during the day, but if clearly heard inside your tent after 10 pm, they represent unacceptable noise. At the primitive end of the spectrum, however, even the faintest sound at any time from a chain saw or motorcycle would most likely be a disruption of the recreation experience. Sounds, then, only become unacceptable according to the criterion of appropriateness within a specified opportunity, rather than at any absolute level.

In part II, table 16 (appendix A) shows how the acceptability of the physical characteristic detectability, which combines the loudness of the sound ***source*** with that of the sound ***background***—both at the listeners' location, is related to opportunity type. This relationship is based on the assumption that at the high end, the generally accepted appropriate outdoor suburban sound level is also appropriate for highly developed, modern campsites. At the low end, under true primitive conditions, only a very few detectable non-natural events should be allowed. A graphical representation of this relationship is shown in figure 1. The values presented in table 16 and figure 1 are empirical and are ***not*** based on extensive data. Rather, they are based on field experience.

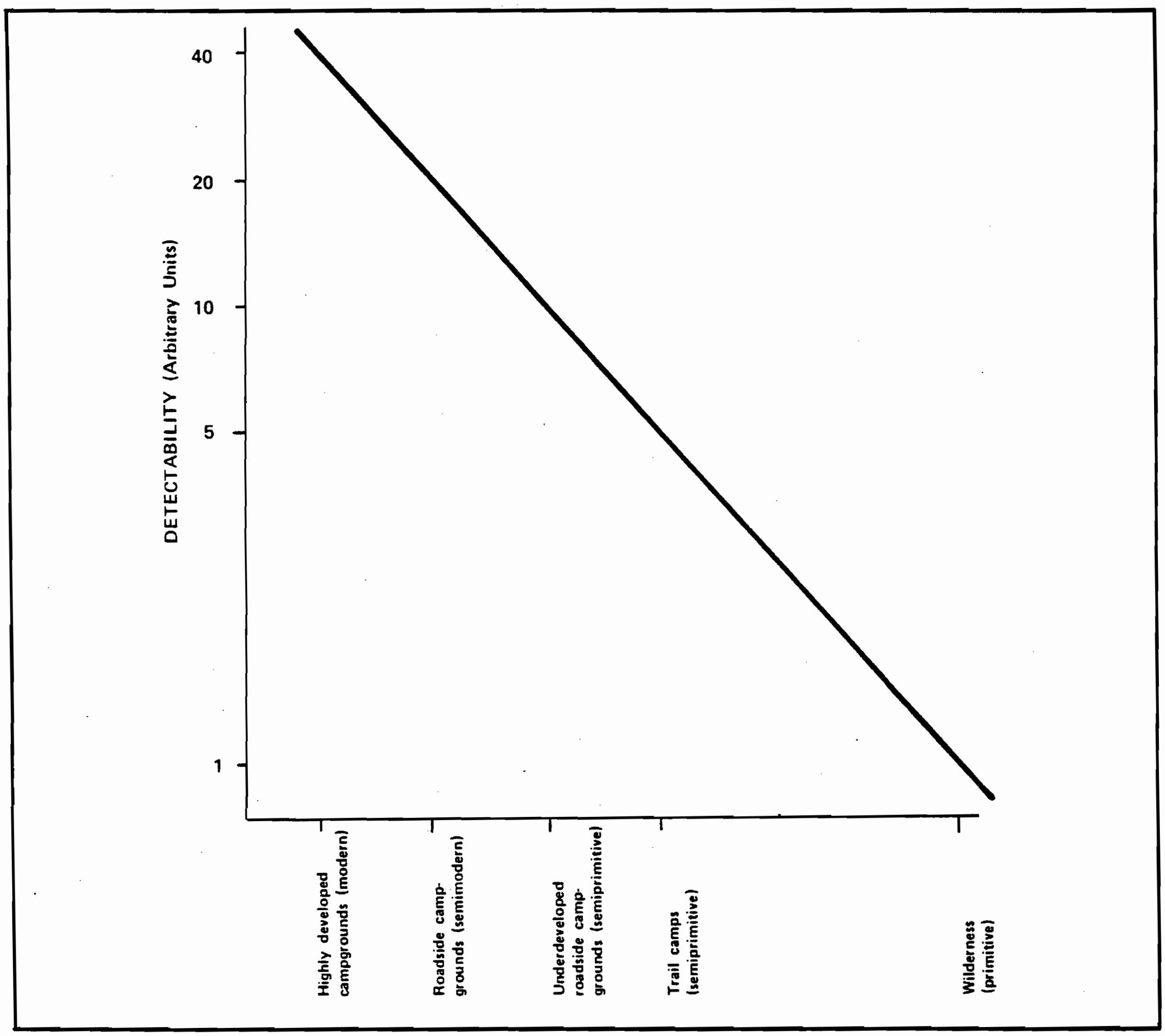


Figure 1. Relationship between detectability and recreation opportunity.

Since the "message" a sound carries is important in determining how acceptable it is in a given recreation opportunity, one must distinguish between those sounds that probably would be perceived as appropriate (because they are the sounds of other, similarly behaving recreationists) and thus likely to be accepted, and those sounds that would probably be considered as annoying (because they connote dissimilar behavior on the part of others). For instance, hikers most likely would not be bothered if they were to hear other hikers chatting. However, if they heard motorcycles–or other hikers who were screaming and yelling–they probably would be bothered to a significant extent.

The methods described in part II and table 16 are based on the assumption that the listener is engaged in activities dissimilar to those that generate the "source" sounds, but that "source" activities are not threatening or connotative of extreme disapproval to the listener. In the discussion that follows, we assume that the manager has determined that, for the area of concern, mechanical sounds are inappropriate. That is, the assumptions used in formulating table 16 are followed, and nonmechanical sounds are more appropriate.

Acoustic Standards

In this example, one might propose that, for modern opportunities, standards for mechanical and nonmechanical sounds should be the same. However, for semiprimitive opportunities, the standard for nonmechanical sounds would be that they are acceptable at a detectability of twice that appropriate for mechanical sounds, which are largely inappropriate in such a setting. Ideally, mechanical sounds would not exist in primitive settings (i.e., sounds would have a detectability of no more than 2), and nonmechanical sounds would, perhaps, be no more than twice that (i.e., have a detectability of approximately 4).

To determine whether a sound from a specific existing or potential source would affect a listener in a particular recreation opportunity setting, follow these steps:

1. Define the recreation management objectives for the area in terms of the OROS–that is, determine the opportunity type (modern, semimodern, semiprimitive, or primitive) and then develop standards specifying acceptable sound levels.

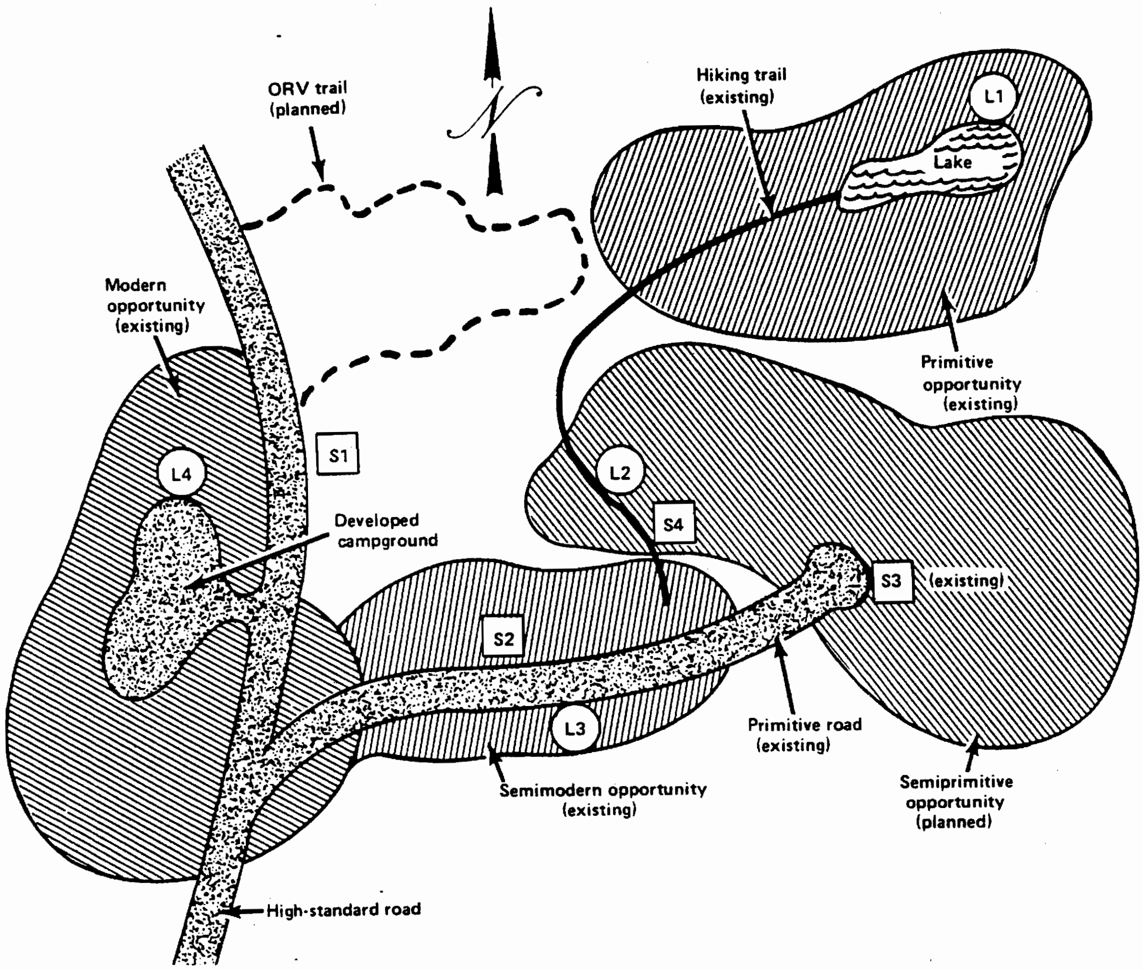
2. Identify existing or potential locations of sound sources and listener locations. (Figure 2 is a schematic that relates examples of sound sources and listener locations to opportunity settings.)

3. Using part II, determine the detectabilities at various listener locations in the area–that is, determine the detectabilities of sounds from source locations S1-S4 at listener locations L1-L4 (fig. 2). Take care to identify critical problem spots, so that you will minimize the number of calculations needed to characterize the area.

4. Determine whether the detectabilities of the sources exceed the standard for the opportunity setting in the area's management objectives plan (see table 16, appendix A).

    a. If no, then only acceptable impacts should occur.

    b. If yes, then unacceptable impacts may occur. The nature of the impact should then be further characterized to determine how severe the impacts may be. One should ascertain:



Sound sources

- S1 = Highway traffic
- S2 = Motorcycles and logging trucks
- S3 = Rock crusher
- S4 = Party of hikers

Listeners

- L1 = Recreationist expecting primitive opportunity (at mountain lake)
- L2 = Recreationist expecting semiprimitive opportunity (camped along trail)
- L3 = Recreationist expecting semimodern opportunity (camped along road)
- L4 = Recreationist expecting modern opportunity (camped in campground)

Figure 2. Existing and planned recreation opportunities, sound sources, and listener locations.

(1) The duration of the sound.

(2) The repetitiveness of the sound.

(3) When (day, night, season, etc.) the sound is heard. (Analyses here might indicate that the detectability standard will only be exceeded during periods of very low recreationist use.)

After these steps have been carried out, and the nature of the impacts has been described in terms of their variability in time and space, then one or more of the following options can be considered:

- Eliminate or move the source of the sound.
- Mitigate the source by performing an engineering modification, putting a buffer in place, or issuing regulations.
- Redefine the area's management objectives, thereby changing the opportunity type to make it consistent with the source.
- Do nothing, thereby accepting the consequences of the impact. This might change the nature of the opportunity, at least in terms of sound impacts.

The final decision requires "sound" judgment as to the consequences and feasibility of each option.

CONCLUSIONS

The OROS does not represent a quality (good-to-bad) continuum. Quality recreation experiences can be derived at any point along the spectrum. They are not restricted to those that conform to values traditionally embraced by professionals in resource management or by any one interest group, for that matter. Quality is a value judgment; what represents a quality experience for one person does not necessarily provide the same experience for another.

The basic rationale underlying the OROS is that, through provision of a diverse set of opportunities, one's ability to find quality in outdoor recreation is best assured. A wide range of tastes and preferences for recreation opportunities exists among the public. For those preferring solitude and a minimum of contact with others, primitive opportunities are appropriate. For those who seek a chance to meet and visit with friends in convenient and comfortable surroundings, modern vehicle-oriented campgrounds are preferable. Providing a wide range of settings that varies in use density, level of development, access, etc., ensures the broadest segment of the public will find the quality recreation experiences that they seek—both now and in the future.

Impacts from and on recreation activities are only one of many factors that define opportunity settings. In some instances for certain places, such impacts may be the limiting factor in determining what recreation activities are possible and in what amount. In other cases, other factors may take precedence. Planners and managers must make these judgments on a case-by-case basis.

When evaluating the meaning of impacts, both their magnitude and their importance must be determined. Although an objective method can be used in determining the magnitude of impacts (e.g., the detectability of sound, the coliform count for water quality, etc.), estimating the importance of the impact is not as easy. Here, value judgments enter into the picture, and considerable differences of opinion can occur between managers and recreationists as to what constitutes unacceptable impacts.

When making these judgments the OROS is useful because it recognizes that impacts are relative, rather than absolute, and what constitutes unacceptable damage in one opportunity setting may be acceptable and appropriate elsewhere along the spectrum.

PART II

BASICS OF SOUND AND A SYSTEM FOR PREDICTION OF ACOUSTIC DETECTABILITY

by

Robin T. Harrison, *P.E.*

INTRODUCTION

The physical properties of sound and the factors that affect how sound is carried through the atmosphere are described. Each of the factors that influence how loud a sound is to a distant listener is then discussed, as are personal characteristics of the listener and how the recreation opportunity presented, in any given area, affects the acoustic impact.

Next, a step-by-step guide for the computation of acoustic impact of a particular sound source on a particular listener location is presented. One complete example and two derivative examples of the use of SPreAD are given. There are three appendixes; appendix A, designed so that it can be removed from the body of the *Project Record*, has worksheets with directions for the various computations and tables of data for the calculations. Appendix B presents a method for predicting how far a sound source must be removed from a listener (or vice-versa) to obtain an acceptable quiet recreation opportunity–in other words, how to predict zones of influence for sound sources. Finally, appendix C contains a glossary of terms.

Why not just ***measure*** acoustic impact? Why go through all the calculations presented here? Well, there is no device that directly measures acoustic impact. We consider acoustic impact to be based on the concept of ***detectability*** (**d'**–pronounced "dee-prime") which, for present purposes, is proportional to the signal-to-background amplitude ratio in the loudest one-third octave band. (See appendix C for definitions of specialized terms.) There are no instruments that can do this job in the field.

Simple sound measuring instruments (e.g., sound level meters) are helpful in applying SPreAD, but cannot–alone–measure the impact of noise. A manager, to use this method properly, ***must*** make field measurements, and **listen.** The most sophisticated measurer of acoustic impact ever developed is the human ear. SPreAD can be helpful, but it must be used with good judgment and common sense.

The mathematics involved in making an acoustic impact prediction with SPreAD are not difficult, but can be tedious if several variables are under consideration. Therefore, a calculator (with square root capabilities) should be available for use.

SOUND BASICS

What is Sound?

Sound is a physical disturbance in the air created by vibration. The disturbance propagates away from what is vibrating–much as rings of ripples propagate away from a pebble that is dropped into a still pond. Most sounds are produced by the vibration of solid material in air. For example, when a motorcycle passes by, one hears a combination of sounds from the exhaust, muffler shell, engine cooling fins, and air intake. Operation of the motorcycle sets each of its parts into mechanical vibration, which, in turn, forces the air around each part into motion. This creates sound waves that propagate out to the listener.

Since sound is a physical quantity, it can be measured; its three primary parameters are:

- **Amplitude**—Measured in decibels (dB); determines loudness.
- **Frequency**—Measured in Hertz (Hz, cycles per second); determines pitch.
- **Duration**—Measured in seconds (sec), minutes (min), hours (hr), or days; is elapsed time.

Amplitude only determines loudness; it is not loudness. Likewise, frequency is not pitch. Amplitude, frequency, and elapsed time are physical measurements; loudness and pitch are subjective impressions that depend on the amplitude and frequency of the sound, ***plus*** the characteristics of the listener.

Sound Propagation

Several factors affect how loud a particular sound seems to a listener. As sound waves travel through the air, they loose energy (i.e., the amplitude decreases) via several mechanisms that are discussed in the paragraphs that follow.

Spherical Spreading Loss

Spherical spreading is the loss of energy that occurs when sound waves spread over a larger and larger area. The loudness of a sound decreases as the distance between the sound source and the listener increases. Doubling the distance causes a reduction (or loss) in loudness of approximately 6 dB. (This value is not exact due to rounding-off of calculations.)

For instance, if at 50 ft the sound level from a snowmobile is 72 dB; at 100 ft, the level will be 66 dB; at 200 ft, 60 dB; at 400 ft, 54 dB. At distances of less than 1,500 ft, spherical spreading loss has an impact greater than any other factor on how loud the listener perceives the sound from the source.

Atmospheric Absorption Loss

Atmospheric absorption is the loss caused by the sound waves imparting energy to the molecules of the atmosphere as the sound travels through the air. This energy loss varies with temperature, elevation (air pressure), relative humidity, and the frequency content of the particular sound. The prediction of atmospheric absorption is very complex, as each of the variables mentioned affects the energy loss in a different way. Atmospheric absorption causes the greatest reduction in a perceived loudness of a sound at distances that are over ¼ mi.

Foliage and Ground Cover

In the great outdoors, trees and shrubs that are between a sound source and a listener absorb some acoustic energy, as does the porous surface of the forest floor. Experiments show that the amount of sound absorbed by various types of trees and shrubs varies only slightly. At distances of less than 75 ft, even if foliage restricts visibility, the acoustic energy loss is negligible. Beyond distances of approximately 350 ft, the foliage loss does not increase.

While these effects are somewhat frequency dependent, this dependence is small and difficult to calculate. For our purposes, the foliage and ground cover loss can be considered independent of the frequency of the sound source.

Long-Distance Loss

If there are more than approximately 350 ft between a sound source and a listener, two related phenomena (refraction and diffraction) affect sound transmission. Refraction occurs whenever sound waves encounter atmospheric conditions that change the speed of sound. Diffraction is the scattering of sound waves around a barrier.

Temperature Effects: As sound waves encounter an atmospheric condition that changes the speed of sound, the waves "bend" towards the direction of lower speed. Suppose, at some location, the air near the ground is warmer than the air above it. Since the speed of sound decreases with a decrease of temperature, the sound waves will bend up toward the cooler air. At some distance from the bending sound waves, a shadow zone is created (fig. 3).

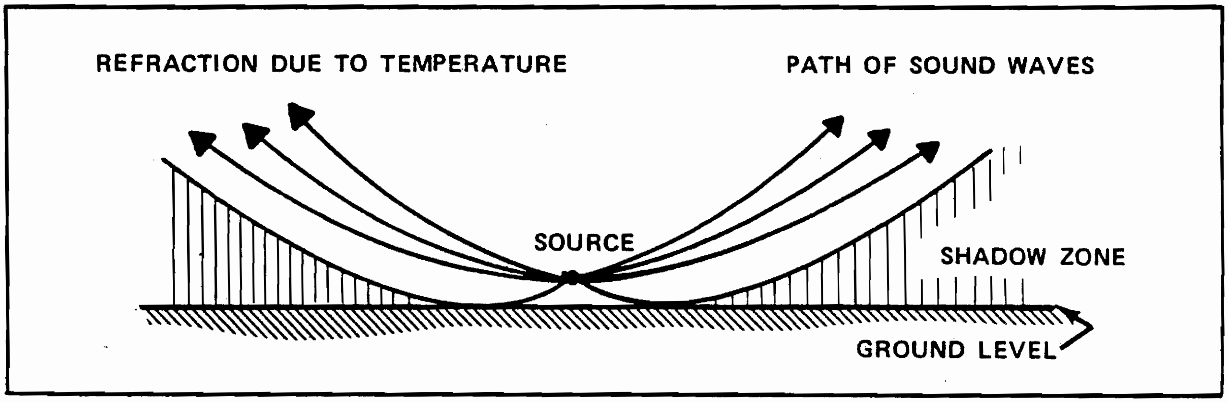


Figure 3. Refraction day temperature effects.

The shadow zone is somewhat analogous to an optical shadow, but it is not as sharply defined. A listener at a point beneath the refracted sound waves would be in a shadow zone where the waves would not directly reach the person; thus, the sound would seem to be less loud. Figures 3 and 4 illustrate the bending of sound waves due to differences in day and night temperatures. At higher elevations, air is cooler during the day and sound waves bend upward (fig. 3); as temperatures drop towards the ground at night, sound waves bend down (fig. 4).

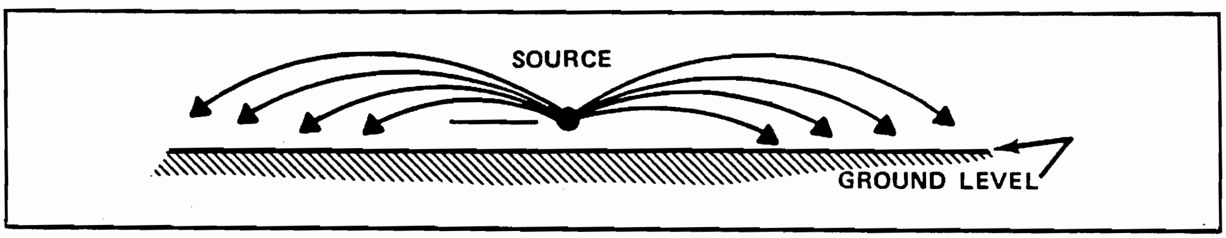


Figure 4. Refraction night temperature effects.

Wind Effects: The wind, similarly, causes refraction of sound waves. If the sound waves and the wind are both traveling in the same direction, the wind speed adds to the speed of the sound waves, and visa-versa. Since wind speed generally increases with altitude, sound traveling downwind will be bent toward the earth and sound traveling upwind will be bent upward (fig. 5).

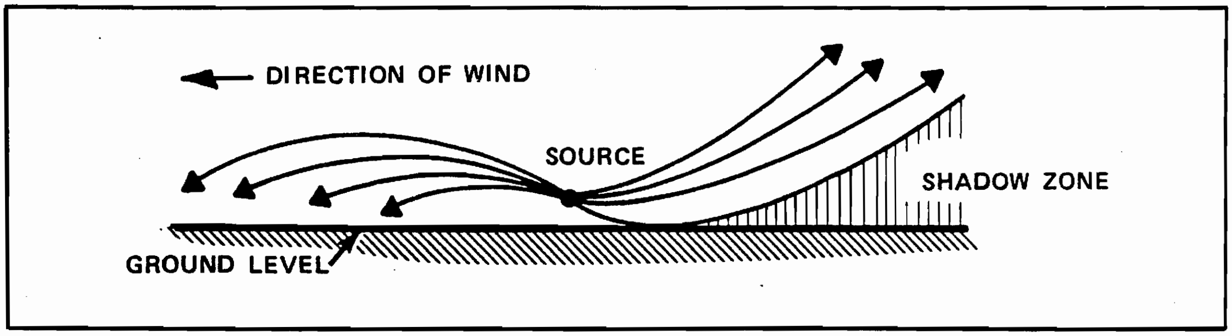


Figure 5. Refraction wind effects.

As with temperature refraction, wind refraction causes shadow zones to be formed, but *only* upwind of the sound source. Thus, an upwind listener in the shadow zone would not hear the sound as being as loud as a downwind listener at an equal distance from the source.

Barrier Effects: Scattering of sound waves around a barrier is called diffraction (fig. 6). The amount of scatter depends on the amplitude and frequency of the sound, the size of the barrier, the distance from the sound source to the barrier, and the distance from the listener to the barrier. Within limits, the higher the barrier between the source and the listener, or the closer the barrier is to the sound source or listener, the more it reduces the level of the sound at the listener location.

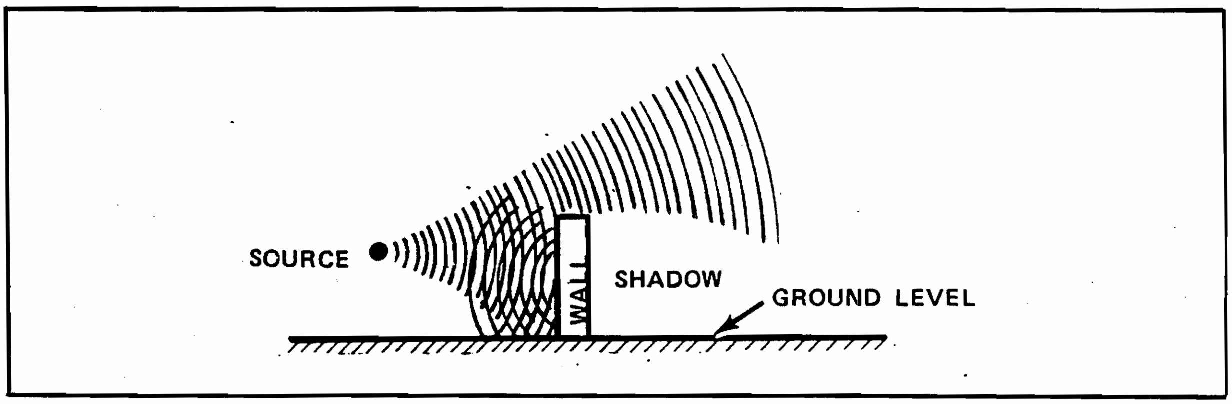


Figure 6. Diffraction barrier effects.

Raising the barrier or moving it closer to the source creates a larger shadow zone. Since sound waves are subject to diffraction, some sound penetration into the shadow zone formed by the barrier is to be expected. SPreAD considers only the highest barrier between the sound source and the listener locations.

Sound Source Detectability

Any particular sound's detectability (or impact) for a listener is a function of more than the sound's "loudness." The "message" carried by that sound (as interpreted by a particular listener), the "background" at the listener location, and the expectations of the listener all contribute to the sound's acoustic impact.

Hearing Threshold

The human ear is differentially sensitive to frequency. The highest frequency that a healthy human ear can perceive is approximately 20,000 Hz; the lowest is approximately 15 Hz. Frequencies lower than 15 Hz are generally felt only as vibrations. The human ear hears all frequencies between the extremes and is most sensitive to frequencies of approximately 1,000 Hz. However, sounds at the very low- or very high-frequency detectability limits must have a much higher amplitude to be heard than sounds that are nearer the middle of the 15 to 20,000 Hz range. When the amplitude of a sound source drops below the human threshold, the sound is no longer heard and its acoustic impact becomes zero.

Background Sound Levels

The "background" at a given listener location is the total sound environment at that location—excluding the impact of the intrusive sound sources that are being considered. The background is a function of the type and extent of the foliage and ground cover that is present, wildlife and other resource sounds in the area, atmospheric conditions (air temperature, humidity, and pressure), wind speed and direction, etc. The louder the background sounds, the less a discreet, intruding sound source will be distinguishable. For example, if a "loud" waterfall is located quite near a listener location, the sound traveling from a source a particular distance away would not have the impact that the same sound at the same distance would have in a "quiet" forest.

Listener Personal Characteristics

Two personal characteristics of a listener affect the impact of a given sound source on the listener—knowledge of the source's presence and attitude towards the source. If a listener has previous knowledge that the source will be emitting sounds, detection is more likely than if the source is completey unexpected.

A basic assumption incorporated into SPreAD is that the listener knows that the sound source is present. Thus, SPreAD may overestimate the degree of impact, particularly under low impact conditions. The other basic assumption underlying SPreAD is that the attitude of the listener—whether a sound is considered appropriate or inappropriate—is largely controlled by the listener's activity. Since this activity is governed by the recreation opportunity that is present, the opportunity controls the maximum acceptable value of **d'**.

The maximum acceptable **d'** values used with SPreAD are presented in table 16 (appendix A). These values have been arrived at empirically; no extensive field testing has substantiated their appropriateness. Underlying table 16 is the premise that in truly primitive opportunity settings, no sound should be audible above the natural background. Thus, for those recreation opportunities that can be characterized by a recreation information management (RIM; see appendix C) campground classification of 1, a maximum **d'** of 1 is assigned since, for all practical purposes, a sound source possessing a **d'** of 1 is not detectable.

At the other end of the scale, for a RIM classification of 5, the acoustic impact equivalent to the maximum acceptable in a quiet, suburban neighborhood is presumed to be appropriate. Thus, a **d'** of 40 was selected for this recreation opportunity. For intermediate recreation opportunities, a straight-line variation was used.

These ***assumptions,*** embodied in table 16 and shown in figure 1, are based on a consensus of experts working in the field; they have not been extensively substantiated by field testing. Remember, when interpreting **d'** results, a calculated **d'** that falls between 0 and 5 will not wake most sleepers. Usually, at the other extreme, a **d'** in excess of 40 can interfere with spoken communication when speakers are as close as approximately 10 ft.

Also remember that SPreAD is an ***estimator.*** Great precision is not possible, and exceptionally sensitive listeners will feel very impacted (under some circumstances) when **d'** = 0 (or is negative), particularly if the sound source is one of which they disapprove. SPreAD can give good guidance, but the sensible discretion of a manager is, in the final analysis, essential to its successful application.

Number of Sources

More than one sound source (e.g., several motorcycles) does not increase **d'** by much. Multiple sources, however, do increase the number of occurrences. The permissible number of noise intrusion occurrences, in excess of the recommended maximum **d'** for a given recreation opportunity, is a matter for managerial judgment. A small number of very high **d'** incidents might be acceptable, depending on their source, in some primitive opportunity areas.

For example, a **d'** greater than approximately 15, caused by two or three aircraft flyovers per day, won't impair the enjoyment of most wilderness users. Since individual situations are so variable, no firm guidelines can be given. If no (or only a few) **d'** incidents in excess of the guidelines are permitted at any given listener location, most recreationists would consider the acoustic environment to be acceptable.

SYSTEM FOR PREDICTION OF ACOUSTIC DETECTABILITY

Use of SPreAD

SPreAD is a method for calculating (1) sound energy losses that occur as sound travels through the air and (2) the estimated acoustic impact of the sound source at a distant listener location.

General Computation Format

SPreAD predicts the detectability (and, thus, the acoustic impact) of one sound source at a particular location on a single listener who is at another particular location—all this with a specific set of atmospheric, terrain, etc. parameters existing between the source and the listener. Therefore, a planner's first task is to determine the set of conditions for which the acoustic impact is to be predicted.

For all practical purposes, use of mean daily atmospheric conditions is good enough and does not produce any serious inaccuracy. Thus, data can be taken from fire weather records, etc. for a location's temperature, relative humidity, wind speed, elevation, etc. and used to good advantage. One does not have to go on-site and gather precise, current information.

For example, if a trail is to be used by motorcycles in the summer and snowmobiles in the winter, but is closed to off-road vehicles (ORV's) at night, and *if* atmospheric parameters for this trail generally are the same from year to year, changing only seasonally; then only two predictions have to be made: One using the daytime seasonal mean conditions for summer, the other using winter data.

Source and Background Sound Levels

The selection of the proper background is important, as detectability (and thus impact) is quite sensitive to background level. The best background spectrum is obtained from in-the-field real-time analysis. Small real-time analysers (commercially available for approximately $3,000) can provide the needed values. If such equipment is not available, the background spectrum that most closely approximates the listener location type should be selected from the A-weighted background level measurements (see appendix C) in the first column of table 15 (appendix A). Very few outdoor backgrounds are less than 35 dB. However, "winter forests" often have backgrounds as low as 25 dB when unbroken snowcover is on the ground and the trees are covered with snow.

In most cases, when the wind blows during the summer, the dominant forest background sound source is the rustling of leaves/needles. This results from the almost constant horizontal and vertical movement of air through tree canopies. In general, background sound levels in forest settings are 10 to 15 dB higher in summer than in winter, because of lower winter wind velocities and, in broadleaf forests, the lack of leaves on the trees.

Accurate estimates of background noise must be made. If a manager feels (based on experience and common sense) that initial calculations are incorrect, the most probable cause is an error in selecting the background sound level.

The detectability (and thus, again, the impact) of a sound source at a given location is controlled by the maximum **d'** in any one of the sound source's one-third octave frequency bands. In other words, only the greatest **d'** of any source at any one listener location really matters. For ***most*** ORV's in ***most*** background situations, the 500-Hz band contains the highest (or very close to the highest) **d'**. Thus, use only the 500-Hz band for ORV first-approach calculations.

The examples that follow indeed use only the 500-Hz frequency. However, the computation sheets and tables (appendix A) allow for calculations at each frequency between 400 and 2,000 Hz, in case an unusual background situation exists or a non-ORV source is of interest. One or two calculations should be made using all the frequencies to substantiate that the 500-Hz band prediction is applicable to the source and background being examined.

Information Needed

The list that follows presents the information needed to predict the impact of each source, at each source location, on each listener location, under each set of atmospheric conditions. This list also contains suggestions on how to obtain this information.

1. Names of both the source and the listener locations from topographical maps or agency records

2. Pertinent data pertaining to conditions at both the source and the listener locations—be sure to select data that relate to a time frame (i.e., day/night or summer/winter) that is appropriate to the recreation opportunity

a. Mean atmospheric temperature (in "^{o}F") from weather records or field measurements

b. Mean relative humidity (in "%") from weather records or field measurements

c. Mean elevation (in "ft") from topographical maps

d. Average sky cover (see table 9, appendix A) from weather records or field observations

e. Mean wind direction (in "degrees") and speed (in "mph") from weather records or field observations

3. Characteristics of sound source

a. Sound level (in "dB") in the one-third octave bands of interest from table 1, appendix A, or field measurements

b. "Base" distance, y (in "ft"), between the sound source and the place where its sound level is measured (y is 50 ft for the sound levels given in table 1, appendix A)

4. One-third octave background sound levels (in "dB") at the listener location from table 15, appendix A, or field measurements

5. Characteristics of the terrain between the sound source and the listener locations

a. Distance, X (in "ft"), between the sound source and the listener locations from topographical maps

b. Highest barrier (such as hill, ridge, manmade wall, etc.) between the sound source and the listener locations—its height, h (in "ft"), above the sound source to the top of the barrier and its distance, R (in "ft"), between the sound source location and the barrier from topographical maps or field observations

c. Vegetation type (e.g., conifer, broadleaf, brush, grass, etc.) predominating between the sound source and listener locations from field observations

6. Recreation opportunity, or RIM classification, of the listener location from a list of management's objectives for the area.

Calculations

Before beginning any calculations, have the following items available:

- **The worksheets and tables (appendix A), removed from this** *Project Record*
- **Calculator having square root capability**
- **Protractor for measuring wind angle**
- **Topographical (or scale) maps covering both the source and the listener locations plus the area between them.**

The maps should have contour lines to help determine the height of the highest barrier between the two locations of concern. The parameters needed for the SPreAD worksheet must be in the units already indicated. Distances on a topographical map, for instance, that are not presented in feet must be converted into feet before entering them on the worksheet.

Round off sound levels to the nearest whole dB. However, not all values should be rounded off to the nearest whole number—see the examples that follow for guidance. The steps presented in examples 1, 2, and 3 are keyed to both the discussion that follows and the appendix A worksheet.

Examples 1 to 3

Example 1

Management wishes to determine the advisability of allowing motorcycles; daytime use only; on a planned ORV trail (dashed line, fig. 2). These motorcycles would not be allowed on the existing hiking trail from the lake. The closest any listener would probably get in relation to the motorcycles is designated L2 (fig. 2), located in a planned semiprimitive opportunity area. Thus, if the acoustic impact of motorcycles is acceptable at L2, it should be acceptable anywhere along the planned ORV trail.

Now, since the planned semiprimitive opportunity area is for summer use only—and since the ORV trail would also only be open in the summer (would be snowbound in winter, and ground damage and erosion could occur in the spring and fall)—midsummer, daytime data should be used in the calculation. Further, since the sound source is an ORV, the SPreAD prediction should be based on only 500-Hz values. Also, recognize that regulations (for some National Forests) prohibit operation of motorcycles louder than 83 dBA at 50 ft and assume that previous surveys show the overall background sound level at the planned trail site is approximately 40 dBA. In summary, let's say we now have gathered the following summer, daytime data to carry out the calculations for example 1:

Sound source location . . . . Closest approach of planned ORV trail to existing hiking trail

Listener location L2

Mean atmospheric temperature	60° F, from weather records
Mean relative humidity	20% from weather records
Mean elevation	2,000 ft, from topographical map
Expected sky cover	Clear, from weather records
Mean wind direction	From NW, from weather records
Mean wind speed	10 mph, from weather records
Sound source level	83 dBA, maximum
Base distance, y	50 ft, basis of sound source level
Background sound source level (500-Hz band)	32 dB, from table 15—since coniferous forest with 10-mph wind at 40 dBA background sound level from field measurements
Distance, X, sound source to listener.	300 ft, from topographical map
Barrier height, h, above sound source	4 ft, old stone wall from field observations
Barrier distance, R, barrier to sound source	6 ft, south of trail's center from field observations
Predominant vegetation type	Conifer, from field observations
Recreation opportunity	Semiprimitive (RIM = 2), from management plans

Now, from table 9, a clear sky in the summer on a "windy" (10 mph) day gives a $\phi = 144^{\circ}$. To find the mean wind direction angle, θ, see figure 7, which focuses on the figure 2 area of interest.

The angle θ, determined by the wind direction relative to the sound source and listener locations, is found by first drawing a line (fig. 7) between the two locations and then a line showing the wind direction in relation to the sound source—with an arrow pointing towards the source to indicate the wind direction. Next, measure the smaller angle between the two lines you have drawn—in this example, $\theta = 142^{\circ}$ (fig. 7). If there is no wind (i.e., dead calm prevails), then $\theta = 180^{\circ}$.

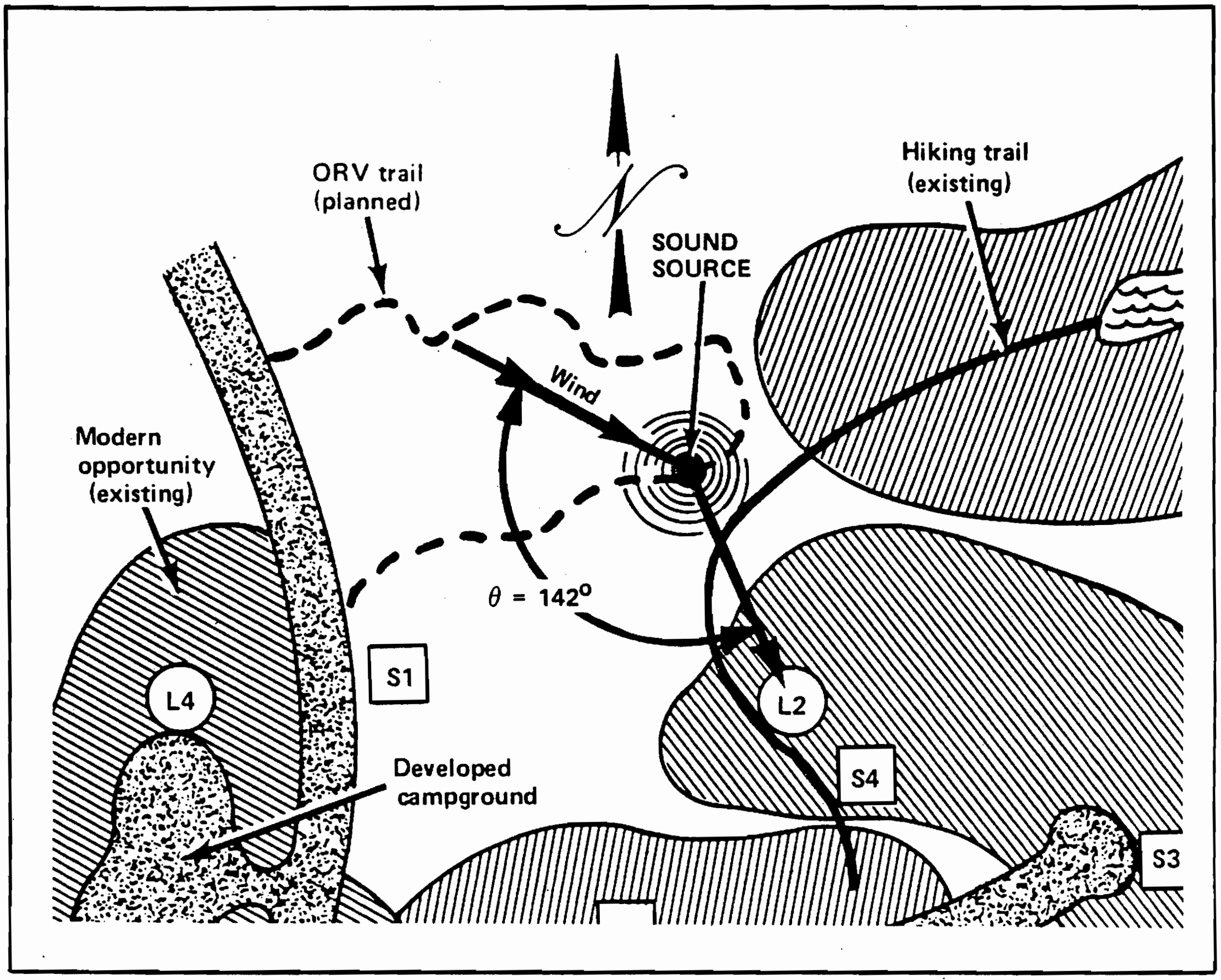


Figure 7. Determining mean wind direction.

Now, we can proceed with the example 1 SPreAD calculation by filling in the appendix A worksheets, using the appendix A tables as directed, as follows:

BASIC DATA

I. Fill-in basic data.

Sound source location ORV trail (planned)-see fig.2

Listener location L2 — see fig.2

Season summer Day/night day

Mean atmos. temp. (°F) 60 Mean relative hum.(%) 20

Mean elevation (ft) 2,000 Exp. sky cover clear

Mean wind direction (°) from NW Wind speed (mph) 10

Sound source description motorcycle, 83 dBA (max)

—*continued*—

BASIC DATA (Continued)

Base distance, y (ft) 50

Background sound source description 32 dB (40 dBA at 500 Hz)

Distance X, sound source to listener (ft) 300

Highest barrier: height, h (ft) 4 distance, R (ft) 6

Predominant vegetation type coniferous forest

Recreation opportunity RIM=2

ϕ, from table 9 (°) 144 Mean wind angle, θ (°) 142

As discussed previously, the best way to determine the sound source level in each frequency band is to use a real-time frequency analyzer. In this example, we only know that the loudest motorcycle allowed on the trail will have a sound level of 83 dBA at 50 ft. From table 1, the 500-Hz level for that motorcycle is 77 dB:

II. Enter sound source levels (measured values, or from table 1.)

Sound Source Levels

	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
Measured or from table 1		77						

The 77-dB sound suffers a spherical spreading loss as it spreads out, over distance, from the source. To calculate this loss' effect, first divide the distance X by the distance y (these are in the basic data list); then using table 2, look up the loss; finally, subtract the loss from the sound source level. For this example, X/y = 300/50 = 6, and table 2 shows the loss in question to be 15 dB—the spherical spreading loss is not dependent on the sound source's frequency. Since 77 – 15 = 62, 62 dB is entered in the 500-Hz column in Block ① :

III. Calculate X/y, write result here 6. From table 2, find the spherical spreading loss (the spherical spreading loss is the same for all frequencies) and write it here 15. Subtract it from the sound source. Enter the results in Block ①.

Spherical Spreading Loss

BLOCK	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
①		62						

The sound level from the source, presently figured to be 62 dB, also suffers an atmospheric absorption loss. Atmospheric absorption coefficients are grouped by elevation (tables 3 through 7) and are also dependent on relative humidity, temperature, and the sound's frequency. Do not interpolate when using these tables to select the appropriate coefficient. Using the mean elevation, relative humidity, and atmospheric temperature in the basic data list, find that place in one of the tables that coincides closest to the values in your entries. If two choices are available, select either one for use.

Now, since we are at 2,000 ft, use table 4. For 20% humidity and 50 or 70°F temperature, the coefficient of interest at 500-Hz is 0.08 dB/100 ft. This is entered on the worksheet, again in the 500-Hz column. Then, 0.08 times the distance X is 0.08 x 300 = 24, which is also entered on the worksheet. Finally, since 24 ÷ 100 = 0.24 and since dB's are to be rounded off to the nearest whole dB, for this short-distance example 1, atmospheric absorption is zero. Subtracting 0 from the 62 dB in Block ① yields 62 dB for Block ②:

IV. Find the appropriate atmospheric absorption coefficient, in dB/100 ft, from tables 3 through 7. Multiply by X. Divide the result by 100. Enter the results on the appropriate lines.

Atmospheric Absorption

	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
dB/100 ft =		0.08						
(dB/100) (X) =		24						
÷100 =		0						

Subtract the results from Block ① above. Write the answers in Block ②.

BLOCK ②	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
		62						

Comparing the 62-dB level to the hearing threshold (the lowest level a human ear can perceive in each frequency band) in section V of the worksheets, we see that 62 is greater than the 6 dB listed for 500 Hz. Hence, our source is not inaudible and we must continue until, perchance, a number in a Block in the remaining sections of the worksheets falls below the threshold of interest. **STOP THE CALCULATIONS AT ANY POINT THAT THE SOUND SOURCE LEVEL FALLS BELOW THE HEARING THRESHOLD!** The threshold values are from American National Standards Institute charts of normal hearing:

V. Compare Block ② values to hearing thresholds at right. For any frequency band, if the threshold value is greater than the Block ② value, the sound will be inaudible. For Block ② values greater than than threshold; continue with next section.

Hearing Thresholds

400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
7	6	5	4	4	3	2	1

To compute the loss resulting from the predominant foliage and ground cover, use table 8. This table shows that the loss in a coniferous forest for a distance X of 300 ft is 14 dB. Note that, while grassland or open brush losses are frequency dependent, conifers and hardwoods are not. Write the 14-dB loss on the appropriate line in section VI and then subtract it from the 500-Hz value in Block ② (62-14), which gives 48 dB for Block ③:

VI. Obtain foliage and ground cover loss from table 8. If X is greater than 350 ft, use the maximum values given. Write the values to the right. Subtract foliage and ground cover loss from Block ②. Write the results in Block ③.

Foliage and Ground Cover Loss

	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
From table 8		14						

BLOCK ③	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
		48						

Compare Block ③ to hearing threshold. For values of Block ③ less than threshold, that frequency band will be audible. For values of Block ③ greater than threshold, continue with section VII.

To calculate the long-distance loss one has to know whether the listener is upwind or downwind of the sound source. To do this, subtract θ from ϕ—these are in the basic data list, section I. Thus, 144° – 142° = 2°:

Long-Distance Loss

VII. Determine whether listener is "upwind" or "downwind" of receiver. Find ϕ from table 9. Subtract θ (mean wind angle) from ϕ. (If calm, θ = 180°.) $\phi - \theta$ = 2°. If $\phi - \theta$ is less than or equal to 0, downwind loss applies, go to section VIII. If $\phi - \theta$ is greater than zero, corrected upwind loss applies, go to section IX.

Now, since 2° is greater than zero, the listener is upwind. (When $\phi - \theta$ is less than or equal to 0, the listener is downwind and one would use section VIII next. However, since this is not the case, go on to section IX to compute the upwind loss. Note that example 3 has a $\phi - \theta$ that is ≤ 0 and, thus, has a downwind loss computation.)

Use table 11 to look up the upwind loss. For $\phi - \theta = 2°$, the loss is seen to be 6 dB; enter this on the worksheet. Next, use table 12 to find the distance, d, from the sound source location to the shadow zone. Since, in our example, the wind speed is 10 mph, d = 48 ft. Enter this on the worksheet. Divide X for our example by this d (300÷48) and enter the result (6.25) on the worksheet.

Now, use table 13 to determine the appropriate shadow zone factor after first rounding off X/d to the nearest whole number. So, for an X/d = 6, the shadow zone factor is 0.68 at 500 Hz; enter this on the worksheet. The next computation is to multiply the shadow zone factor by the upwind loss (0.68 x 6), which provides a corrected upwind loss of 4.08—round this off to the nearest whole number, 4 and enter this on the worksheet. Finally, subtract this corrected upwind loss from the Block③ value (48 dB) and place the result (44 dB) in Block ④:

Upwind Loss

IX. Find the upwind loss from table 11 based on $\phi - \theta$. Write it on the line. Find distance to shadow zone, d, from table 12. Write d on the line. Find X÷d. From table 13, find the shadow zone factors for each frequency. If X÷d is greater than 8 use factor for X÷d = 8. Multiply the upwind loss by its appropriate shadow zone factor to obtain the corrected upwind loss. Write the values on the line.

From table 11 **6** dB Upwind loss

d = **48** ft Distance to shadow zone

X÷d = **6.25**

	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
Shadow zone factors		**0.68**						
(Shadow zone factor) (upwind loss)		**4**						

Subtract the corrected upwind loss values from the values listed in Block③ and write them in Block④.

BLOCK ④	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
		44						

Compare Block④ with hearing threshold. For values of Block④ less than threshold, that frequency band will be inaudible. For values of Block④ greater than threshold, continue with section X.

If there were no natural or manmade barriers in the "line-of-sight" between the sound source and listener locations, we could skip this section. However, we do have an old stone wall; from field observations, h = 4 ft. This is ***not*** the gross height of the wall. But, since the 5½-ft-high stone wall runs the length of the planned ORV trail, 6 ft south of the trail's centerline, and most motorcycle exhaust pipes are 1½ ft off the ground, h = 5½ − 1½ = 4 ft between the sound source and the top of the barrier. To compute the barrier loss, (a) fill in barrier data and then (b) calculate the barrier path difference (BPD):

Barrier Loss

X. If no barriers, barrier loss = 0. Skip to (e). If barriers, calculate the barrier loss.

(a) Fill in barrier data.

X = **300** ft (source to listener distance)
R = **6** ft (source to barrier distance)
h = **4** ft (barrier height above source)

(b) Calculate barrier path difference:

$$BPD = \sqrt{h^2 + R^2} + \sqrt{h^2 + (X - R)^2} - X$$

BPD = **1.2** ft

A BPD of 1.2 ft is obtained as follows:

$$\begin{aligned}
\text{BPD} &= \sqrt{h^2 + R^2} + \sqrt{h^2 + (X-R)^2} - X \\
&= \sqrt{4^2 + 6^2} + \sqrt{4^2 + 294^2} - 300 \\
&= \sqrt{16 + 36} + \sqrt{16 + 86{,}436} - 300 \\
&= \sqrt{52} + \sqrt{86{,}452} - 300 \\
&= 7.21 + 294.03 - 300 \\
&= 301.24 - 300 \\
&= 1.2
\end{aligned}$$

Now, as to (c), look up the correction factor, L, for the frequency of interest and multiply this (0.91 for 500 Hz in our example here) by the BPD just obtained (1.2) to compute the barrier factor, N (0.91 x 1.2 = 1.09). Enter this on the line indicated in the appropriate column on the worksheet and, from table 14, obtain the barrier loss based on this N (in our case, 14 dB):

		400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
(c) Calculate barrier factor N = (L) (BPD)	L =	0.71	0.91	1.1	1.4	1.6	1.8	2.3	3.6
	N = (L) (BPD)	____	1.09	____	____	____	____	____	____
(d) Find barrier loss for each frequency, from table 14. For N greater than 10, use value for N = 10. Write barrier loss values here.	From table 14	____	14	____	____	____	____	____	____

Since the sum of the two shadow zone losses (downwind *or* upwind and barrier) will never—in the real world—exceed 25 dB, we can not compute a total greater than 25 dB for these losses. Thus, look back at section VIII or IX (downwind or upwind loss)—which of these you have depends upon your section VII result. The sum of the loss in your "wind" section (VIII or IX) plus the barrier loss just obtained—for ***each*** frequency, as applicable—can ***not*** exceed 25 dB.

So, for each sum (downwind or upwind, plus barrier) that is less than 25 dB, subtract the sum(s) in question from Block ③ (which is the same, for our example, as subtracting the barrier loss from the value(s) listed in Block ④) and write them in Block ⑤. For each sum greater than 25 dB, subtract only 25 dB from the value(s) listed in Block ③ and write them in Block ⑤. Since our 14 dB barrier loss plus the 4 dB upwind loss (section IX) equals 18 dB, we write it in (e) and then 48 – 18 (or 44 – 14) = 30 dB:

(e) Add the barrier loss to the corrected upwind loss or the downwind loss (section VIII or IX, only one line will be filled in.) Write the sum here 18. The sum of the one loss filled in and the barrier loss for each frequency may not exceed 25 dB. For each sum less than 25 dB, subtract the sum from the values listed in Block ③ and write them in Block ⑤. For each sum greater than 25 dB, subtract 25 dB from the values listed in Block ③ and write them in Block ⑤.

BLOCK ⑤

400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
	30						

Compare Block ⑤ with hearing threshold. For values of Block ⑤ less than threshold, that frequency band will be inaudible. For values of Block ⑤ greater than threshold continue with section XI.

Recalling that, at the beginning of example 1, we determined the background sound source level in the 500-Hz band to be 32 dB (from table 15)—since the planned ORV trail would be in a coniferous forest having a 10-mph wind at a listener location having a 40-dBA background sound level. We write the 32 dB on the appropriate line in the appropriate frequency column and then we subtract this value from Block ⑤ value(s), writing the result(s) in Block ⑥ (negative values are possible); so, since 30 – 32 = –2 dB:

XI. Write the background sound levels to the right, from measurements or table 15.

Background Sound Levels

	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
Measured or from table 15		32						

For each frequency, subtract the background sound levels from Block ⑤. Write the difference in Block ⑥.

BLOCK ⑥

400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
	-2						

This –2 is actually the ratio of the sound source to background levels, since dB ratios are obtained by subtracting (not dividing)—dB's are based on a logarithmic (not arithmetic) scale. We must now adjust this ratio for differences in the amount of energy that different frequency bands carry. This is done with a correction factor, w. Multiply the value(s) in Block ⑥ by the w shown to obtain the **d'** for the sound source of interest at the listener location of interest. For example 1, **d'** = 4.3 x –2 = –8.6 dB:

Multiply the value(s) in Block ⑥ by the appropriate w.

The largest product is the detectability, d', for the selected source at the selected listener location. Compare with table 16.

	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
w =	3.8	4.3	4.8	5.4	6.0	6.8	7.7	8.6
d' =		-8.6						

Now, comparing this -8.6 dB value for the appropriate recreation opportunity in table 16, we see that (for a RIM classification of 2) the "maximum" acceptable **d'** = 5. Since –8.6 is less than 5, the acoustic impact of the motorcycles should be acceptable—in fact, they probably would not be acoustically detectable at all, and the proposed ORV trail (given all the example 1 assumptions) would be acceptable even if L_2 were in a wilderness area.

As a final note, the **d'** values in table 16 are maximums for most situations. However, even more stringent limits may have to be applied if potential listeners harbor a bias towards the proposed noise source, or the limits can be relaxed somewhat if a particular noise souce is known to be favorably perceived. So, having arrived at **d'**, management still has to exercise judgment. While SPreAD is a practical tool that provides valuable information, such information has to be viewed in the light of all the facts being considered in a particular situation.

Example 2

This time around, assume all the facts of example 1 are again the case to be dealt with—except now the old stone wall has suffered from weathering and vandals to the point where it has large gaps and is no longer an effective sound barrier. So, proceeding to section X, barrier loss, we can transfer the previous value(s) in Block ④ directly to Block ⑤ (since, here, barrier loss = 0); thus:

(e) Add the barrier loss to the corrected upwind loss or the downwind loss (section VIII or IX, only one line will be filled in.) Write the sum here 4. The sum of the one loss filled in and the barrier loss for each frequency may not exceed 25 dB. For each sum less than 25 dB, subtract the sum from the values listed in Block ③ and write them in Block ⑤. For each sum greater than 25 dB, subtract 25 dB from the values listed in Block ③ and write them in Block ⑤.

BLOCK ⑤

400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
	44						

Compare Block ⑤ with hearing threshold. For values of Block ⑤ less than threshold, that frequency band will be inaudible. For values of Block ⑤ greater than threshold continue with section XI.

For section XI, the background sound level(s) become 44 – 32 = 12 dB and **d'** = 4.3 x 12 = 51.6:

XI. Write the background sound levels to the right, from measurements or table 15.

Background Sound Levels

	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
Measured or from table 15		32						

For each frequency, subtract the background sound levels from Block ⑤. Write the difference in Block ⑥.

BLOCK ⑥

400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
	12						

Multiply the value(s) in Block ⑥ by the appropriate w.

The largest product is the detectability, d', for the selected source at the selected listener location. Compare with table 16.

	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
w =	3.8	4.3	4.8	5.4	6.0	6.8	7.7	8.6
d' =		51.6						

From table 16, any **d'** greater than 40 is unacceptable—even for a highly developed, modern campground. Example 2 shows us that, once initial calculations have been made, the magnitude of the affect of any changes from original or baseline conditions can be ascertained without much effort. Further, we can test the criticality of various factors (such as a barrier) and parameters (such as the barrier's height and its distance from the sound source) by "plugging in" tentative values and determining the affect on a portion or on the whole SPreAD calculation.

Example 3

Again, assume all the conditions of example 1—only this time let there be two exceptions. First, the wind is now from the north by northwest (i.e., the listener location is directly downwind from the sound source location; $\theta = 180^{\circ}$). Second, the listener location is now 500 yd from the planned ORV trail, not just 300 ft.

Proceeding to section III (and being sure to use required units; e.g., feet not yards), divide the new X by y (1,500÷50 = 30 dB).

This is now used to find the spherical spreading loss in table 2. For X/y = 30, the loss = 30 dB and 77 – 30 = 47 dB, which is entered in the 500-Hz column in Block ① :

III. Calculate X/y, write result here 30. From table 2, find the spherical spreading loss (the spherical spreading loss is the same for all frequencies) and write it here 30. Subtract it from the sound source. Enter the results in Block ① .

BLOCK ①

Spherical Spreading Loss

400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
	47						

To determine atmospheric absorption, we again use 0.08 dB/100 ft as the coefficient—we are still at the 2,000 ft elevation. However, now X = 1,500 and 0.08 x 1,500 = 120, which when divided by 100 is 1.2, rounded off to 1 dB. So, since 47 – 1 = 46 dB, this is entered in Block ② :

IV. Find the appropriate atmospheric absorption coefficient, in dB/100 ft, from tables 3 through 7. Multiply by X. Divide the result by 100. Enter the results on the appropriate lines.

Atmospheric Absorption

	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
dB/100 ft =		0.08						
(dB/100) (X) =		120						
÷100 =		1.2						

Subtract the results from Block ① above. Write the answers in Block ② .

BLOCK ②

400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
	46						

And, since 46 dB is greater than 6 dB, motorcycles would still be audible and the calculation must continue as stated in section V:

V. Compare Block ② values to hearing thresholds at right. For any frequency band, if the threshold value is greater than the Block ② value, the sound will be inaudible. For Block ② values greater than than threshold; continue with next section.

Hearing Thresholds

400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
7	6	5	4	4	3	2	1

REPEAT THIS COMPARISON AFTER EACH LOSS IS CALCULATED IN SECTIONS VI THROUGH X THAT FOLLOW, STOPPING THE COMPUTATION IF THE SOURCE BECOMES INAUDIBLE!

From table 8, 14 dB is again the foliage and ground cover loss, since the table indicates that, in a coniferous forest, this is the loss at all X's over 300 ft. Thus for Block ③ we now have 46 – 14 = 32 dB:

VI. Obtain foliage and ground cover loss from table 8. If X is greater than 350 ft, use the maximum values given. Write the values to the right. Subtract foliage and ground cover loss from Block ② . Write the results in Block ③ .

Foliage and Ground Cover Loss

	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
From table 8		14						

BLOCK ③

400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
	32						

Compare Block ③ to hearing threshold. For values of Block ③ less than threshold, that frequency band will be audible. For values of Block ③ greater than threshold, continue with section VII.

As to the long-distance loss, 144° − 180° = −36°:

Long-Distance Loss

VII. Determine whether listener is "upwind" or "downwind" of receiver. Find Φ from table 9. Subtract θ (mean wind angle) from Φ. (If calm, θ = 180°.) $\Phi - \theta$ = −36°. If $\Phi - \theta$ is less than or equal to 0, downwind loss applies, go to section VIII. If $\Phi - \theta$ is greater than zero, corrected upwind loss applies, go to section IX.

A negative difference in the angles means the listener is downwind. So, this time we make that calculation using section VIII (instead of section IX, upwind). Frequency times distance (as required for each frequency of concern in section VIII) for our case is 500 x 1,500 = 750,000. From table 10, the downwind loss is 3 dB; subtract this from the value in Block ③ (32 − 3 = 29) and place the result (29 dB) in Block ④ :

Downwind Loss

VIII. Multiply each frequency by X. Write the results on the proper line. For each frequency, find the downwind loss from table 10. Write it on the proper line. Subtract the downwind loss from the values listed in Block ③. Write the results in Block ④.

	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
(Frequency) (x) =		750,000						
Downwind loss =		3						

BLOCK ④	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
		29						

Compare Block ④ with hearing threshold. For values of Block ④ less than threshold, that frequency band will be inaudible. For values of Block ④ greater than threshold, continue with section X.

The barrier loss calculation for the old stone wall has to be redone, since we have a different X. However, we discover after adding the new square root (1,494) to the previous one of $h^2 + R^2$ (7.2) and subtracting our new X of 1,500 ft, that the BPD is again 1.2 ft. Thus, N is still 1.09 and the barrier loss is still 14 dB. This, plus our downwind loss of 3 dB, gives 17 dB. This sum, when subtracted from the Block ③ value of 32 dB, gives a Block ⑤ value of 15 dB:

Barrier Loss

X. If no barriers, barrier loss = 0. Skip to (e). If barriers, calculate the barrier loss.

(a) Fill in barrier data.

X = 1,500 ft (source to listener distance)
R = 6 ft (source to barrier distance)
h = 4 ft (barrier height above source)

(b) Calculate barrier path difference:

$$BPD = \sqrt{h^2 + R^2} + \sqrt{h^2 + (X - R)^2} - X$$

BPD = 1.2 ft

(c) Calculate barrier factor N = (L) (BPD)

(d) Find barrier loss for each frequency, from table 14. For N greater than 10, use value for N = 10. Write barrier loss values here.

	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
L =	0.71	0.91	1.1	1.4	1.6	1.8	2.3	3.6
N = (L) (BPD)		1.09						
From table 14		14						

CONTINUED–

(e) Add the barrier loss to the corrected upwind loss or the downwind loss (section VIII or IX, only one line will be filled in.) Write the sum here 17. The sum of the one loss filled in and the barrier loss for each frequency may not exceed 25 dB. For each sum less than 25 dB, subtract the sum from the values listed in Block ③ and write them in Block ⑤. For each sum greater than 25 dB, subtract 25 dB from the values listed in Block ③ and write them in Block ⑤.

BLOCK ⑤

400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
	15						

Compare Block ⑤ with hearing threshold. For values of Block ⑤ less than threshold, that frequency band will be inaudible. For values of Block ⑤ greater than threshold continue with section XI.

The background sound level is still 32 dB; subtracting this from the 15 dB in Block ⑤ gives a Block ⑥ value of 15 – 32 = –17 dB. This, times our w of 4.3, gives a **d′** = 73.1–an acoustic impact that would be quite acceptable even for primitive recreation opportunities:

XI. Write the background sound levels to the right, from measurements or table 15.

Background Sound Levels

	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
Measured or from table 15		32						

For each frequency, subtract the background sound levels from Block ⑤. Write the difference in Block ⑥.

BLOCK ⑥

400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
	-17						

Multiply the value(s) in Block ⑥ by the appropriate w.

The largest product is the detectability, d′, for the selected source at the selected listener location. Compare with table 16.

	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz
w =	3.8	4.3	4.8	5.4	6.0	6.8	7.7	8.6
d′ =		-13.1						

A quick scan of the SPreAD computations in example 3 shows that, even if the barrier loss were not present, our **d′** would be less than zero, since the Block ⑥ value would be –3 dB (29 – 32).

APPENDIX B–ESTIMATE OF X WHEN d' IS KNOWN

A four-step method for determining the "buffer" distance, X_{n+1}, that should be interposed between the sound source and the listener locations so as to have an acceptably quiet recreation opportunity is presented here. For instance, consider example 2 in this *Project Record*. We calculated a **d'** of 51.6 at a distance $X_1 = 300$ ft. We can now compute the X_{n+1} to reduce the **d'** to 10–the "maximum" acceptable for remote, dispersed recreation in undeveloped roadside campgrounds (table 16).

Step 1

Let d'_n = Original detectability (from example 2, 51.6),

d'_{n+1} = Desired detectability (our goal, 10),

and L_1 = First approximation of the loss needed to reduce d'_n to d'_{n+1}.

Then $L_1 = \dfrac{d'_n - d'_{n+1}}{w}$,

where w is given in section XI of appendix A (for 500 Hz, 4.3).

Now $L_1 = \dfrac{51.6 - 10}{4.3} = \dfrac{41.6}{4.3}$

$= 9.7.$

Step 2

Turn to table 2, appendix A, and look down the loss columns for the dB closest to 9.7 (the L_1 computed in step 1). This is seen to be 10, at which point X/y = 3 (to be used in step 3).

Step 3

Let X_1 = Original distance (from example 2, 300 ft),

and X_{n+1} = Desired distance (our unknown).

Then $X_{n+1} = (X_1)\ (X/y)$

$X_2 = (300)\ (3)$

$= 900$ ft.

Step 4

Repeat the SPreAD computation for **d'**, using the calculated sound source to listener locations distance X_2, etc. until **d'** approaches the desired **d'** of 10. Seldom will more than three iterations be needed to achieve this.

For example, substituting X_2 = 900 ft for X_1 = 300 ft, **d'** = 21.5. Repeating steps 1 through 3 yields X_3 = approximately 1.3 x 900 = 1,170 ft (interpolation was necessary). Repeating once more yields $\mathbf{d'}_3$ = 12.9, which is close enough. (One more iteration yields a $\mathbf{d'}_4$ of 4.3 at 1,404 ft.) Thus, a buffer distance of approximately 1,200 ft is appropriate.