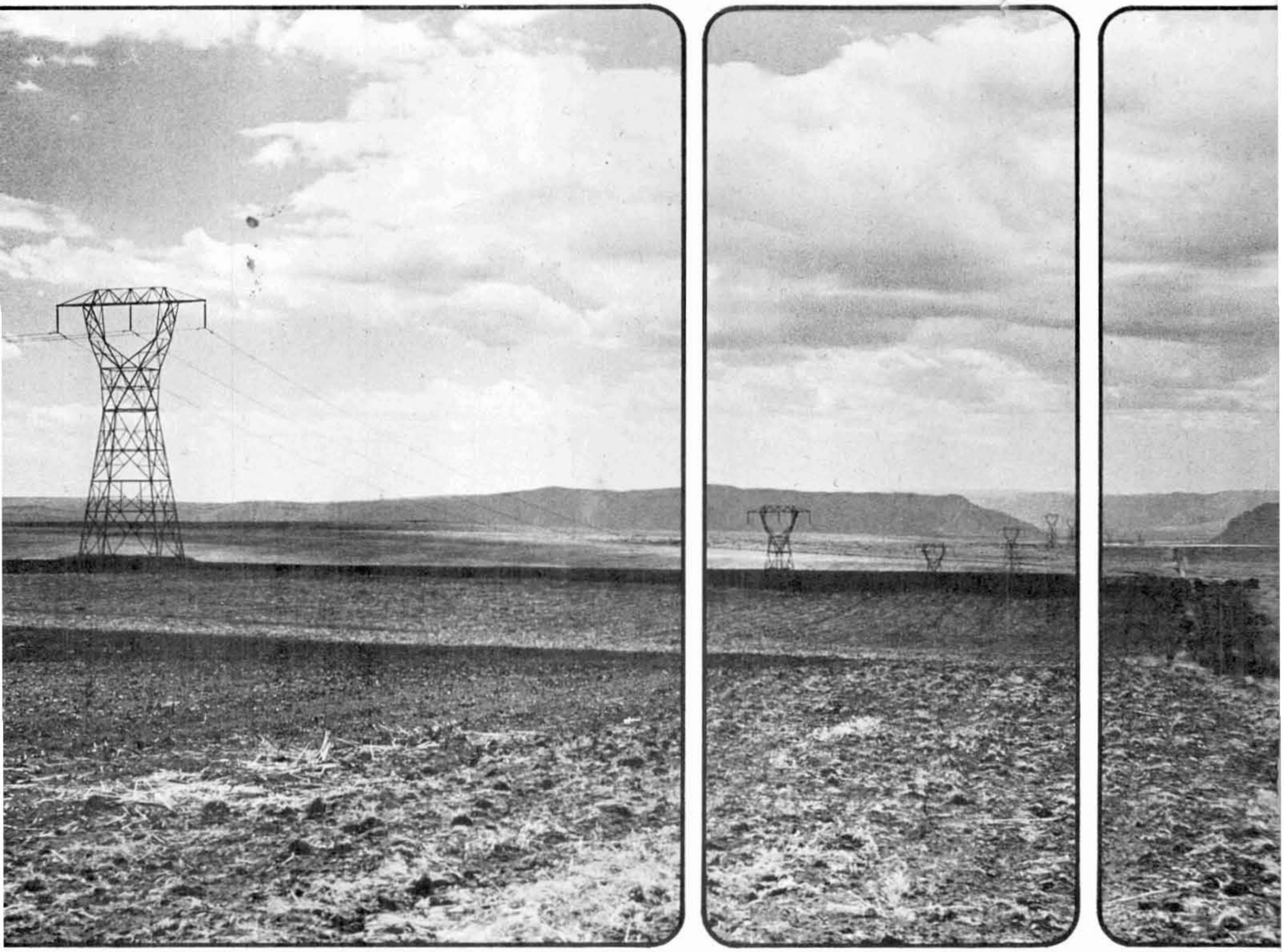


Measuring the Visibility of H.V. Transmission Facilities

in the Pacific Northwest

by JONES & JONES

for the BONNEVILLE POWER ADMINISTRATION

BIBLIOGRAPHIC DATA SHEET

1. Report No. BPA-VIS-76-1

2.

3. Recipient's Accession No. PB272404

4. Title and Subtitle
Measuring the Visibility of High Voltage Transmission Facilities In The Pacific Northwest

5. Report Date
November 30, 1976

6.

7. Author(s) Edward C. Driscoll, Jr., Brian A. Gray, William G.E. Blair, John F. Ady

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Jones & Jones
105 South Main Street
Seattle, Washington 98104

10. Project/Task/Work Unit No.

11. Contract/Grant No.
14-03-6017N

12. Sponsoring Organization Name and Address
Bonneville Power Administration
P. O. Box 3621
Portland, Oregon 97208

13. Type of Report & Period Covered
Final Report

14.

15. Supplementary Notes

16. Abstracts

Ten transmission tower configurations with various associated corridor widths were identified for field observation in this study. Fifteen landscape setting types (different combinations of landform and landcover) were also identified and fieldwork carried out in August 1976. Judgments of thresholds between three relative visibility levels were made, and the viewing distance for each of these thresholds recorded, along with facility/landscape setting information. The angular height (or width) of towers (or corridors) was also recorded at each threshold, and a check was made comparing the apparent brightness of the tower or corridor clearing and setting. Some 150 observations were made under acceptable viewing conditions.

Analysis of the observations reveals consistency between observed angular heights (or widths) and relative visibility threshold judgments. The explanation for this consistency may be grounded in the physiology of the eye; the high-medium threshold appears to be related to the size of the fovea, the retinal locus of detailed perception. Transmission facility type and landscape setting also appear to affect relative visibility. Predicted visibility threshold distances for all facility-setting combinations are presented, and recommendations are made for determining the effective zone of visual influence.

17.

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement
Release Unlimited

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)
UNCLASSIFIED

22. Price
PC A04 - A01

INSTRUCTIONS FOR COMPLETING FORM NTIS-35 (Bibliographic Data Sheet based on COSATI Guidelines to Format Standards for Scientific and Technical Reports Prepared by or for the Federal Government, PB-180 600).

1. **Report Number.** Each individually bound report shall carry a unique alphanumeric designation selected by the performing organization or provided by the sponsoring organization. Use uppercase letters and Arabic numerals only. Examples FASEB-NS-73-87 and FAA-RD-73-09.

2. Leave blank.

3. **Recipient's Accession Number.** Reserved for use by each report recipient.

4. **Title and Subtitle.** Title should indicate clearly and briefly the subject coverage of the report, subordinate subtitle to the main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific volume.

5. **Report Date.** Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected (e.g., date of issue, date of approval, date of preparation, date published).

6. **Performing Organization Code.** Leave blank.

7. **Author(s).** Give name(s) in conventional order (e.g., John R. Doe, or J.Robert Doe). List author's affiliation if it differs from the performing organization.

8. **Performing Organization Report Number.** Insert if performing organization wishes to assign this number.

9. **Performing Organization Name and Mailing Address.** Give name, street, city, state, and zip code. List no more than two levels of an organizational hierarchy. Display the name of the organization exactly as it should appear in Government indexes such as Government Reports Index (GRI).

10. **Project/Task/Work Unit Number.** Use the project, task and work unit numbers under which the report was prepared.

11. **Contract/Grant Number.** Insert contract or grant number under which report was prepared.

12. **Sponsoring Agency Name and Mailing Address.** Include zip code. Cite main sponsors.

13. **Type of Report and Period Covered.** State interim, final, etc., and, if applicable, inclusive dates.

14. **Sponsoring Agency Code.** Leave blank.

15. **Supplementary Notes.** Enter information not included elsewhere but useful, such as: Prepared in cooperation with . . . Translation of . . . Presented at conference of . . . To be published in . . . Supersedes . . . Supplements . . . Cite availability of related parts, volumes, phases, etc. with report number.

16. **Abstract.** Include a brief (200 words or less) factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.

17. **Key Words and Document Analysis. (a). Descriptors.** Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.
    (b). Identifiers and Open-Ended Terms. Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.
    (c). COSATI Field/Group. Field and Group assignments are to be taken from the 1964 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the primary Field/Group assignment(s) will be the specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).

18. **Distribution Statement.** Denote public releasability, for example "Release unlimited", or limitation for reasons other than security. Cite any availability to the public, other than NTIS, with address, order number and price, if known.

19 & 20. **Security Classification.** Do not submit classified reports to the National Technical Information Service.

21. **Number of Pages.** Insert the total number of pages, including introductory pages, but excluding distribution list, if any.

22. **NTIS Price.** Leave blank.

MEASURING THE VISIBILITY OF HIGH VOLTAGE TRANSMISSION FACILITIES IN THE PACIFIC NORTHWEST

FINAL REPORT TO THE BONNEVILLE POWER ADMINISTRATION,

UNITED STATES DEPARTMENT OF INTERIOR

CONTRACT 14.03.6017N

30 November 1976

Edward C. Driscoll, Jr.
Brian A. Gray
William G.E. Blair
John F. Ady

JONES & JONES
105 SOUTH MAIN STREET
SEATTLE, WASHINGTON 98105

ABSTRACT

This study is an outgrowth of a previous study by Jones & Jones for Bonneville Power Adminstration, Visual Impact of High Voltage Transmission Facilities in Northern Idaho and Northwestern Montana (Blair, Gray, Hebert and Jones, 1976). That study developed a model for assessing visual impact to be utilized in BPA's experimental computerized transmission facility location process titled "PERMITS". One element of the visual impact model utilizes the Forest Service "VIEWIT" program to map "seen areas" from different observation points, requiring a specification of visibility search distance as an input. A preliminary investigation of viewing distance was made in the above study but BPA decided a more specific study of transmission line visibility, which would be applicable to its entire service area, was required to provide visibility information not only for PERMITS, but for conventional location methods.

Ten transmission tower configurations with various associated corridor widths were identified for field observation in this study. Fifteen landscape setting types (different combinations of landform and landcover) were also identified and fieldwork carried out in August 1976. Judgments of thresholds between three relative visibility levels were made, and the viewing distance for each of these thresholds recorded, along with facility/landscape setting information. The angular height (or width) of towers (or corridors) was also recorded at each threshold, and a check was made comparing the apparent brightness of the tower or corridor clearing and setting. Some 150 observations were made under acceptable viewing conditions.

Analysis of the observations reveals consistency between observed angular heights (or widths) and relative visibility threshold judgments. The explanation for this consistency may be grounded in the physiology of the eye; the high-medium threshold appears to be related to the size of the fovea, the retinal locus of detailed perception. Transmission facility type and landscape setting also appear to affect relative visibility. Predicted visibility threshold distances for all facility-setting combinations are presented, and recommendations are made for determining the effective zone of visual influence.

ACKNOWLEDGMENTS

We are pleased to have been able to carry out this project for the Bonneville Power Administration. Although it is a small study, performed over a brief period of time, we believe it is also a significant first effort in the systematic and empirical investigation of the relationship between distance and the visibility of man-made structures - transmission facilities, in this instance.

We would like to thank John Hooson, BPA Environmental Coordinator, and Timothy Murray, BPA Environmental Systems Coordinator, who developed and oversaw the initial study from which this is an offshoot, and who recognized the need for this investigation. We also thank Bob Beraud, Branch of Transmission Design, for his help in locating and providing data on the transmission facilities surveyed. He and Dennis Maxwell, in the BPA Environmental Coordinator's Office, reviewed the drafts of this report, and their comments and assistance are gratefully acknowledged.

Thanks are also due our helicopter pilots for this and the initial study, Roger Hamlin and Bruce Stratton of Pacific Crown Aviation. Their skill was both reassuring and invaluable during our fieldwork.

On the staff of Jones & Jones, Bill Blair and Brian Gray devised the initial study outline. Brian Gray, John Ady, Ted Driscoll, and Rick Kimball then did the fieldwork. Ted Driscoll took most of the field photographs, analyzed the data and prepared the first draft of the report, edited and revised by Brian Gray and Bill Blair. John Ady has reviewed and commented on the successive drafts.

TABLE OF CONTENTS

TABLE OF ILLUSTRATIONS

PLATES

FIGURES

FIGURES (Continued)

TABLES

I. INTRODUCTION

I A. PURPOSE OF THE STUDY

This study was performed to investigate how the visibility of transmission lines is affected by tower type and corridor width, landscape setting, and viewing distance. Specifically, the Bonneville Power Administration asked Jones & Jones to provide answers for the following questions:

1) Generally, how large is the effective zone of transmission line visual influence? This information would assist BPA planners in determining study area boundaries.

2) More specifically, how far away from an observer's viewpoint in a particular kind of landscape setting is a tower of a given type or corridor of a given width recognizable? This information would assist BPA planners in establishing cut-off distances for sightline visibility studies, whether determined by field observation, by hand "viewshed" techniques using topographic maps, or by the computerized Forest Service VIEWIT program.

3) At what distances do significant thresholds between visibility levels occur for a tower or corridor? This data would assist BPA planners in assigning visibility level weights related to viewer distance for those areas from which various types of transmission facilities would be visible.

Other practical considerations guided the conduct of the study. BPA asked Jones & Jones to gather visibility data on ten tower types, as well as on various widths of corridors, in landscape settings typically found across the five physiographic sub-regions of the BPA service area. Limited study time availability and the fact that several tower types are not found in all landscape settings required that principal factors contributing to visibility be identified to allow interpolation of observed visibility data for facility/landscape combinations where field observations could not be made.

Over 150 field observations of visibility were made in central and western Washington and Oregon during August 1976. The landscape setting of each transmission line surveyed was first classified into one of five landform classes: flatland, valley floor, hillside, secondary ridge and primary ridge. Landcover was then classified into one of three categories: grassland, open forest and closed forest. The tower type and/or cleared right-of-way size was identified. Field observations were then made of transmission visibility, tower angular height (or angular width for cleared right-of-way) and, when possible, the brightness ratio between tower (or cleared right-of-way) and the backdrop. Analysis of the field data appears to yield consistent relationships between relative visibility levels, apparent facility size (a direct function of distance) and landscape setting.

I B. THE BPA "PERMITS" VISUAL IMPACT MODEL

BPA currently has two methods for selecting routes for transmission facilities. The conventional siting approach, involves proposing alternate routes based on available information, and then determining their environmental impacts. BPA is also experimenting with a computer-based siting method with the acronym "PERMITS". This method begins with the collection of extensive amounts of pertinent study area data prior to route selection; this mapped data base is then analyzed carefully by several "determinant models" to identify alternative transmission routes on the basis of least overall impact.

The present study is an extension of Jones & Jones' previous work assisting BPA to develop a visual impact model for this experimental siting program. The visual impact model is one of nine subregional determinant models within PERMITS. Five distinct subregions are delineated within the BPA service area (see Figure 1). The PERMITS process develops a different set of determinant models for each subregion, but the concerns addressed by the models are the same throughout the BPA service area. The nine subregional PERMITS models are:

MODEL 1 = GREATEST DISRUPTION TO HUMAN POPULATIONS
MODEL 2 = DISRUPTION TO THE NATURAL SYSTEM
MODEL 3 = VISUAL IMPACT
MODEL 4 = DISRUPTION TO RECREATIONAL ACTIVITIES
MODEL 5 = DISRUPTION TO AGRICULTURAL LAND USE
MODEL 6 = DISRUPTION TO FORESTRY LAND USE
MODEL 7 = DISRUPTION TO EXTRACTIVE AND OTHER NON-URBAN INDUSTRIES
MODEL 8 = POTENTIAL RIGHT OF WAY SHARING
MODEL 9 = TRANSMISSION FACILITY PROBLEMS

The BPA PERMITS visual impact model is structured around two major components: 1) landscape visual characteristics and 2) potential viewer characteristics (see Figure 2). Landscape visual characteristics include an evaluation of the landscape's existing visual quality and a detailed analysis of the visual compatibility between the landscape and an introduced transmission facility. In other words, landscape scenic resources are identified and the ease or difficulty of achieving an acceptable fit between those landscape resources and a new transmission facility is determined. Maps exhibiting both landscape visual quality and transmission visual compatibility are then combined to produce a map of the relative severity of potential visual alternation of the landscape resulting from the introduction of transmission facilities.

Viewer characteristics considered in the visual impact model include sight-line analyses to determine those areas of the surrounding landscape which may be seen from selected observer viewpoints, and determination of the viewing distance between these viewpoints and the seen areas. Maps of the seen areas or "viewsheds" are produced by analysis of topographic maps using the Forest Service VIEWIT computer program. Potential viewer sensitivity is determined by identifying

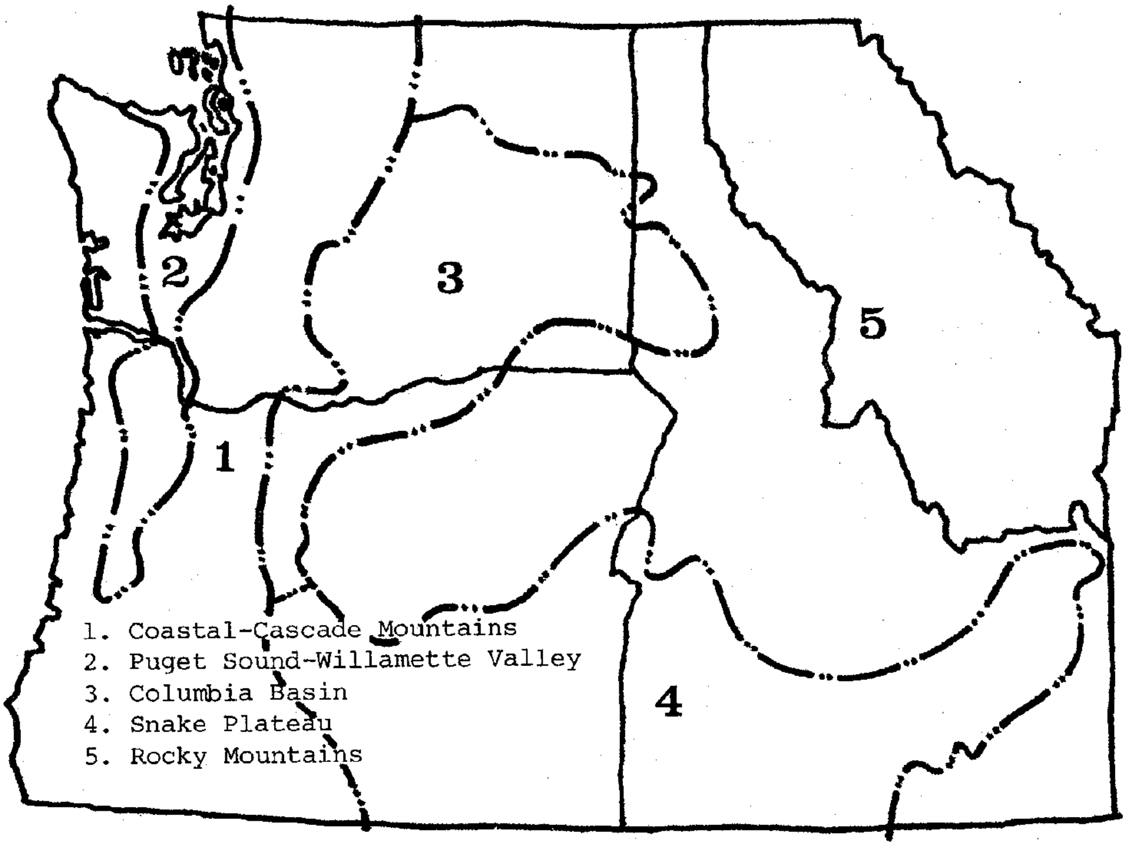


FIGURE 1. BPA SERVICE AREA AND SUBREGIONS

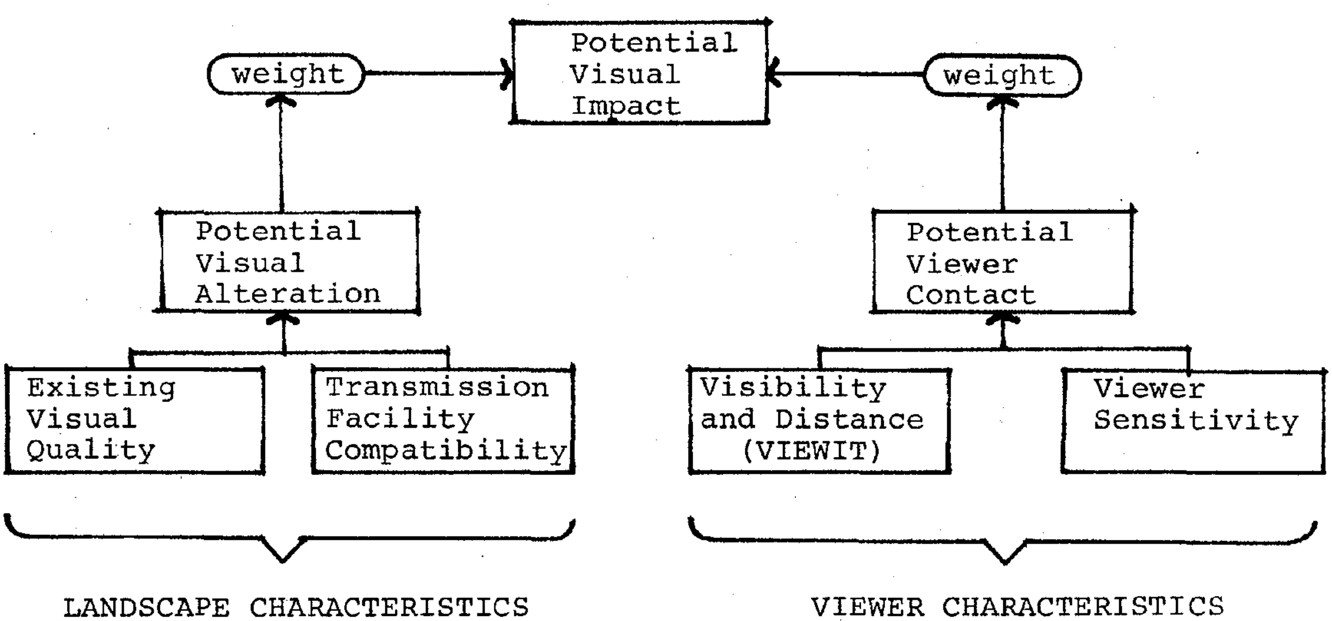


FIGURE 2. CONCEPTUAL STRUCTURE OF THE "PERMITS" VISUAL IMPACT MODEL

the number of observers at each viewpoint, their probable visual awareness and expectation levels related to their activity, and their duration of view. A potential viewer contact map is thus produced exhibiting the relative visibility of the landscape, rated by viewing distance and viewer sensitivity.

Finally, a map of the potential visual impact of a new transmission facility is produced by combining the potential visual alternation map with that of potential viewer contact. Transmission corridors of least visual impact may then be proposed and compared with routes suggested by other subregional determinant models. The visual impact of a corridor selected on the basis of all subregional models may also be determined.

This follow-up study is primarily intended to help quantify the relationship between viewing distance and viewer sensitivity for the tower types (and corridor widths) most frequently used by BPA. The study also confirms a definite relationship between certain landscape setting characteristics and transmission facility visibility. Confirmation of the existence of these effects further supports the concept, developed in the previous report, of differential compatibility between different landscape settings and transmission facilities. Thus the present study bridges across "viewer characteristics" and "landscape characteristics" in the PERMITS visual impact model. It must be emphasized that this study does not address all the factors necessary to model visual impact, for the visual quality of landscape settings was not considered in making visibility observations. Instead, this study was designed to provide additional detailed information to assist BPA in applying the already-developed PERMITS visual impact model throughout the service area.

Further information about the PERMITS visual model and its practical application may be found in the report, Visual Impact of High Voltage Transmission Facilities in Northern Idaho and Northwestern Montana, prepared by Jones & Jones for Bonneville Power Administration. Although this study, Measuring the Visibility of High Voltage Transmission Facilities in the Pacific Northwest, is an extension of that study, its findings are intended to be applicable to conventional transmission facility siting methods as well as to computerized impact evaluation.

II. METHODOLOGY

II A. HYPOTHESES AND STUDY DESIGN

As mentioned in the introduction, the purpose of this study is to investigate the interrelationships between four parameters:

1) Degree of visibility
2) Type of transmission tower and width of corridor
3) Landscape setting
4) Viewing distance

A discussion of how each of these parameters affected the design of the study is presented below.

1) Degree of Visibility. In dealing with visual perception of an object, there are obviously three major participants: the observer, the object, and its setting. From the outset it is emphasized that the degree of visibility depends upon the interaction between viewer, object and setting. This study makes no attempt to model the sensitivities of different observers. Admittedly, an observer's awareness is related to his viewing location, his activity, his visual acuity, the intensity of his visual exploration of the landscape, and his state of mind; and an observer's expectation depends upon the preconceived landscape images that he anticipates seeing, how he values those landscape images, and his familiarity with the location and appearance of the particular object he is looking for. This study in fact illustrates conditions in which viewer sensitivity is at its highest extreme. Field observations of transmission towers and corridors were made by two observers with similar visual training and backgrounds (in architecture and landscape architecture) who sought optimal unobstructed stationary viewpoints on the ground, and who were not distracted with other activities. Both observers had excellent eyesight, and both were intently scanning the landscape for transmission towers and corridors, the appearance and location of which they knew in advance.

To use the terminology of the literature on acuity (Dember, pp. 25-26), the observers were peering into the farthest distance where they knew a transmission facility was sited, trying to detect its presence as a tell-tale vertical object or as an interruption of the vegetation cover. At a certain distance, they could recognize with assurance that this object was in fact a tower, or the interruption a right-of-way. This threshold, from detection to recognition, was regarded as the limit of visibility and its distance recorded. However, for observers who are not instructed to look for transmission facilities, but merely to scan the landscape and report what they see, the towers or right-of-way would have to be considerably closer before they would be spontaneously identified. These are three distinct visual "tasks": detection is picking up the first stimulus in a predefined location; recognition is being certain that this stimulus is the predefined stimulus; identification is spontaneously registering the stimulus without having been instructed what to look for.

Since the visual sensitivity (defined both by awareness and expectation) of the viewers who performed this study is no doubt higher than that of most potential observers of transmission lines, it is probable that the absolute limits of tower or corridor visibility determined here occur well beyond the distances at which most viewers would cease to identify or recognize a tower or corridor. The recommended cutoff distances for visibility analysis of lines in various landscape settings are presented in the conclusions, Section III.

To measure degree of visibility, it was hypothesized from previous observation of transmission towers and corridors that three levels of visibility can be consistently and reliably judged by an observer: high, moderate, and low visibility levels. The trained observers who carried out the field study made careful judgments of the threshold between high-moderate, moderate-low, and low-detection visibility levels in the field, without a preconceived or predetermined idea about any psychological or physiological basis for doing so. Threshold visibility judgments were made on the basis of agreement between the two observers as to what appeared to be a breakoff point between two visibility levels, similar to the judgments made using slides in the preceding Jones & Jones study for BPA. Review of the data revealed a consistent correlation between visibility thresholds and apparent size of towers and corridor, measured in degrees of angular height for towers and degrees of angular width for corridor clearings. The consistency of relationships between angular size and visibility threshold judgments reinforces the reliability of these judgments and invites speculation that there is a psychophysiologic relationship between the perceived angular size of an image and the size of the most sensitive spot in the center of the human retina known as the "fovea". A more thorough discussion of visibility is presented in Section II.B.

2) Type of Transmission Tower and Width of Corridor. An effort was made to consider all the object-related variables which affect the visibility of a range of transmission tower types and corridor widths. The variables of primary importance to this study are tower type and corridor width; the effects of these variables were measured in this study by recording separate visibility observations for each type of tower and for the range of corridor widths being observed. Other object-related factors also contribute to visibility. Variables which were considered but not tested in this study include the following tower and corridor-related factors: angle of view, use of dead end structures, random variations in tower type within an alignment, tower height variations, minor topographic variations affecting tower screening, specular reflection from towers, sunlighted versus shadowed towers, tower age, tower color, corridor clearing practices, and appearance of an access road in the corridor. Every attempt was made in the study to hold these variables constant by recognizing their contribution to transmission

line visibility and carefully limiting the range of conditions under which visibility observations would be made. These primary and secondary object-related factors are discussed in greater detail in Section II.C.

3) Landscape Setting. Setting-related variables considered in this study include the type of landscape in which transmission lines occur and ephemeral conditions. Landscape settings for transmission lines were classified as a combination of five landform conditions (flatland, valley floor, hillside, secondary ridge and primary ridge) with three vegetative patterns (grassland, open forest and closed forest), yielding fifteen landscape setting types which may be found within the five physiographic regions of the BPA service area (see Figure 1). The effects of these fifteen landscape settings upon transmission facility visibility were measured by seeking as many different tower types located in each landscape setting as the study period allowed, and recording visibility observations within each landscape setting. Other significant setting-related variables which were identified include special absorptive backgrounds not classified in the landscape setting, atmospheric clarity and seasonal variables. An attempt was made to hold untested factors constant by carefully limiting the conditions under which visibility observations were made. All these setting factors are discussed more thoroughly in Section II.D.

4) Viewing Distance between an observer and the tower or corridor being observed was recorded at each threshold between visibility levels as part of the field observations. Viewing distance is a key parameter in determining visual impact and it becomes a practical tool for mapping visibility zones for a given tower type or corridor on the surrounding lands. Viewing distances related to visibility thresholds are presented and discussed in greater detail in Section III.

II B. DETERMINATION OF DEGREE OF VISIBILITY

How well we see a specific object in the landscape is determined by the visual characteristics of the object relative to its setting, and by the psychology and physiology of the observer's visual perception. We can define visibility of a given object as our ability to visually differentiate that object from its setting. Although there are many contributing factors, two major parameters contribute to the visibility of an object: its apparent size and the apparent contrast between the object and its surroundings.

The apparent size of an object as perceived by an observer is related to viewing distance. An object's apparent size determines the area of the human retina stimulated by the light which comes from the object and forms the object's image. For this study, it was decided that the most reliable way to measure the apparent size of a transmission tower from an observation point was to measure its angular height in degrees of arc. This study recognizes the fact that apparent tower height is only part of apparent tower size. Since all tower types do not have the same proportions between height and width, degree of visibility will vary somewhat between different tower types of the same apparent height when viewed from an observation point at a given distance. Actual field observations of a range of ten tower types made in this study do reveal a degree of variance in the relative visibility of each. Nevertheless, since all tower types surveyed are taller than they are wide, and since their apparent width depends upon the angle from which they are viewed (i.e., a tower's apparent width is less as viewed from the side than it is viewed from the front), we decided that apparent tower height is the most consistent factor contributing to overall apparent size and selected it for measurement in this study. Similarly, the apparent size of a transmission corridor clearing is measured in degrees of angular width in this study, since a corridor's width is greater than its height and since its actual height varies with the type of bordering vegetation.

It should be mentioned that the vertical orientation of transmission towers seems to play an important role in their visibility. The human visual system, like that of most dry-land animals, is tailored to accommodate the horizontal nature of the earth's surface. Depth perception requires binocular vision; the positioning of our eyes in a horizontal plane has the result that our field of vision is not really circular but rather is a horizontal oval. Because of its horizontal adaptation, our visual system tends to exaggerate the apparent size of vertical objects; this phenomenon reinforces the appropriateness of using angular height to measure the apparent size of transmission towers in this study.

The apparent contrast of reflected light between an object and its surroundings is the other major parameter contributing to object visibility. Indeed, it is the difference in intensity of light reflected from the surfaces of objects of different shape, form, line, color and texture which allows our vision to perceive these objects. Visual perception is predicated on differential light intensity, i.e., contrast.

Optically, a uniform square of constant brightness in a dark field varies only in its apparent area as the observer moves away from it. Although it would seem that this square should also become dimmer as the observer recedes, in reality this is not the case. It is true that the further the observer moves away, the fewer are the photons reflected from the square which actually impinge upon the eye. However, although fewer photons pass through the pupil of the eye, they are also concentrated on a smaller retinal area since the image of the square on the retina becomes smaller as the observer recedes. The greater concentration of photons by the lens in our eye exactly cancels the effect of fewer photons being received. Discounting for a moment the atmospheric effects of haze or dust, the brightness of the image of the square on the human retina remains constant regardless of how close or how far away an observer is from the square, within the limits of resolution of the human visual system. The only change is the apparent area of that image.

One might expect that increasing the brightness of the image by increasing the level of illumination would improve the performance of the eye. This is true only to a point. Above a baseline condition of adequate illumination, visual acuity is at or near its maximum level. Figure 3 illustrates this. The units of visual acuity--technically described as the amount of spatial visual information processed or extracted from a given stimulus--are defined in terms of the specific visual task set in the laboratory experiment which furnished this data and are of no particular significance for the current study. The units of luminance are log (milliLamberts), and the significance of this graph is the leveling off of acuity above a base level of illumination of approximately 2 log (milliLamberts).

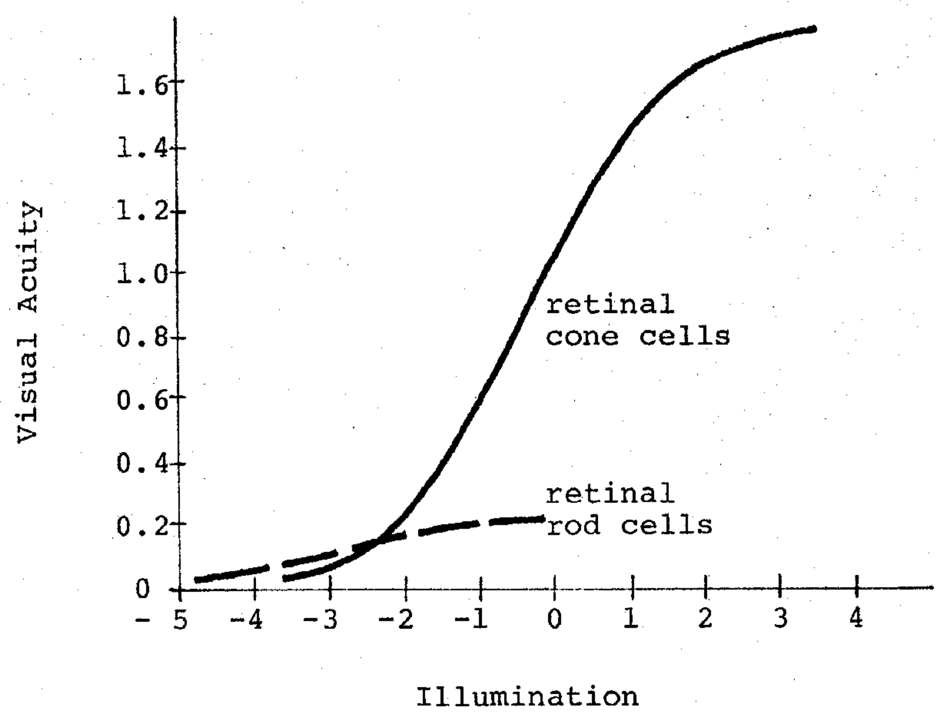


FIGURE 3. ILLUMINATION AND VISUAL ACUITY (after Graham, 1965)

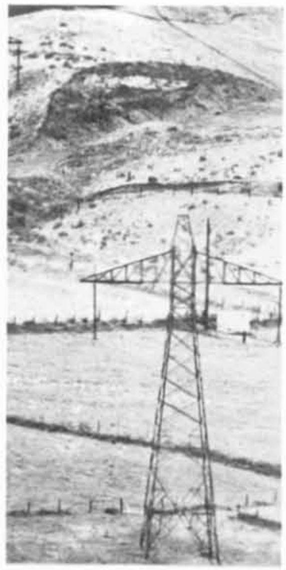
To control the effects of variable atmospheric clarity, we made visibility observations only in clear or partly cloudy conditions. Light reflected from transmission facilities in these conditions varied from 500 to 1500 Lamberts, or from 5.7 to 6.2 log (milliLamberts). Clearly, this is luminance beyond the point where the graph levels off and we can assume that acuity is constant at or near its maximum level.

The ratio between the brightness of an object and the brightness of its setting or background is a direct measure of apparent contrast. As with illumination, above a baseline condition the contrast between object and setting makes a constant contribution to visibility. Our intent was to study transmission facility visibility under optimal viewing conditions, so field observations were not made if lighting was poor or if atmospheric conditions were so hazy that apparent contrast between towers or corridors and their landscape setting fell below this baseline condition. Exceptional viewing conditions which were avoided in this study are discussed in Section II.C.

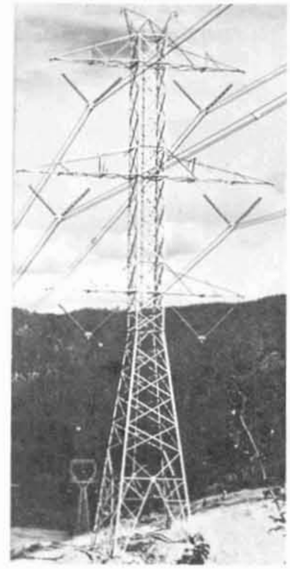
Although we avoided unfavorable viewing conditions, the contrast ratio between object and setting can be manipulated to reduce tower or R.O.W. visibility (by tower surface treatment or clearing practice, for example). Therefore, we attempted to identify the baseline contrast ratio. There are two figure-ground brightness extreme conditions: light object on dark field or dark object on light field. Light figures against dark backgrounds typically had ratios of 2.2 to 1 for corridors and 2.4 to 1 for towers. Dark figures against light backgrounds had ratios of as much as 3 to 1 for corridors (forested ridges against the sky) and 2 to 1 for towers. Basically, above a figure-ground brightness ratio of about 1.4 to 1, relative visibility was directly tied to apparent image size. This contrast ratio appears to be the baseline for maximum acuity. Within our limitation on acceptable weather conditions, this minimal brightness ratio almost always was exceeded. Special cases where there was a smaller ratio are discussed as part of the setting variables, Section II.C.

In addition to measuring apparent image size and apparent contrast, field judgments of the relative visibility of transmission facilities were made. Our hypothesis, already mentioned, was that these judgments would be consistent and reliable. The data on apparent image size and apparent contrast was gathered to test that hypothesis. From our earlier experience in measuring transmission line visibility, the authors chose to segment visibility into zones of high, medium, and low visibility. Previous observations made in the field and from slides confirmed that a high-medium-low breakdown was easy to apply to visibility judgments; of course, this scale has been used very widely in psychological and sociological testing. In application, we recorded the distance at which the breakpoint between zones of relative visibility occurred. These three breakpoints or thresholds were: high to medium (H-M), medium to low (M-L), and low to detection (L-D). Past this last threshold transmission facilities could not be recognized with certainty, although it was still possible to detect a stimulus in the known vicinity of a transmission line that "might be" a tower or a right-of-way.

1100 KV (AC)

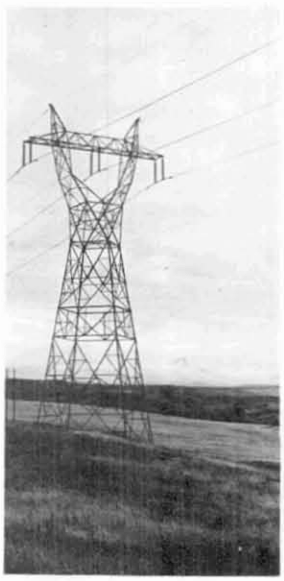


800 KV (DC)

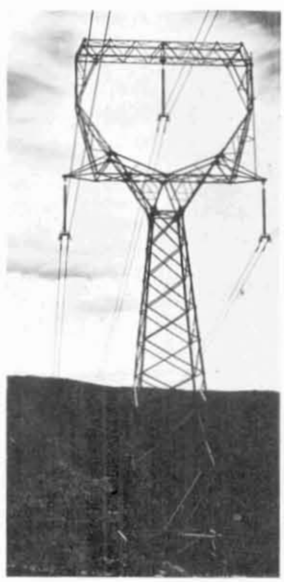


500 KV (AC) DS

500 KV (AC) DD



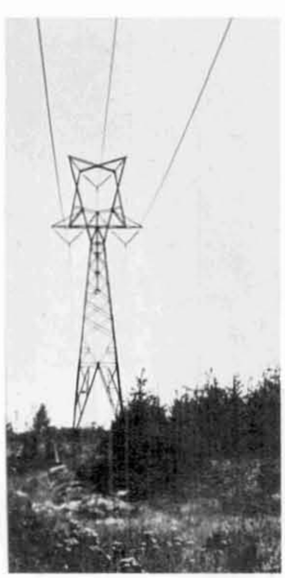
500 KV (AC) SF



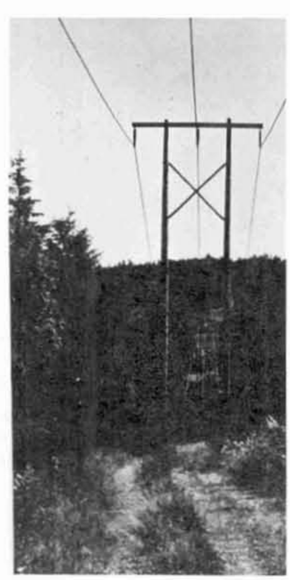
500 KV (AC) SD

230 KV (AC) DS

230 KV (AC) SF



230 KV (AC) SD



115 KV (AC) H

PLATE 1; Tower Configurations

II C. TOWER AND CORRIDOR-RELATED VARIABLES

Field survey visibility data was collected for the ten different tower configurations listed below and illustrated in Plate 1. Tower height and right-of-way width listed are the general rule, but do vary with specific site conditions and location.

TABLE 1. TOWER CONFIGURATIONS SURVEYED

Voltage	Current	Tower Configuration	Typical Height	Typical R.O.W.
1100 KV	AC	Test Line (Lyons, Ore.)	200'	180'
800 KV	DC	(Celilo-Mead)	150'	150'
500 KV	AC	Double Stacked (DS)	176'	140'
		Double Delta (DD)	143'	165'
		Single Flat (SF)	102'	160'
		Single Delta (SD)	123'	135'
230 KV	AC	Double Stacked (DS)	120'	100'
		Single Flat (SF)	77'	125'
		Single Delta (SD)	98'	90'
115 KV	AC	Wood "H" Frame	80'	90'

Because some of these towers are much more common than others, the number of observations made for each tower type varies accordingly. The 230 KV SF and 500 KV SD are the two most frequently observed configurations. On the other hand, one of the most visible tower configurations, the 500 KV DD, and one of the least visible, the 230 KV SD, were so infrequent that few observations were possible. Single and multiple-line corridors were observed and visibility measurements made for a range of corridor widths.

Tower type and corridor width are the primary factors being evaluated in this study. Other object-related variables also contribute to visibility. Variables which were considered but not tested include the following tower and corridor-related factors. These variables were held constant by carefully limiting the range of conditions under which observations would be made, as discussed in each factor. The purpose of identifying and controlling these additional variables is primarily to define the criteria for conditions under which we made observations in the field. It has been our intention to provide information on potential transmission visibility, given optimum viewing conditions. We have also noted some of the variables which could be investigated in the future, either to minimize transmission visibility or to further refine predictions of potential visibility.

Angle of View

This was perhaps the most commonly met and most important unquantified variable of the survey. It affects both towers and corridors. Towers viewed from the side appear less substantial, but in general the visibility of a given tower type remains constant because its height is unaffected by the angle of view. However, from a side view it is almost impossible to distinguish different tower types, and certain types, notably, the 500 KV DD, are distinctly more visible when seen "front on". In addition, a view parallel to the right of way often causes the towers to "stack up" and consequently become apparently darker or lighter depending on the conditions. A third aspect of parallel views may be termed the "necklace effect". A line of clearly recognizable middle-distance towers lead an observer's eye to a far-distant tower that he might have been able to detect but probably would not have recognized. Therefore the recognition distance can be increased by the orientation of the observer to the line. In forest conditions it is rare to encounter a view of the towers against a background of trees and not down their own corridor. As a result, whenever possible we endeavored to make tower observations about 1/2 to 1 mile off center of the line. Through this, we tried to eliminate as much of the variation due to angle of tower view as possible.

With corridors, we had the opposite problem: by going off center we diminished their visibility. Figure 4 attempts to show that the visibility of corridors in forest conditions is greater when looking down one than when looking perpendicular to one. If we were to draw contour lines of visibility, they might appear as in Figure 5. We chose to take the typical worst case and presume an observer could get above or in line with each corridor. Our observations are generally made looking parallel to the corridor.

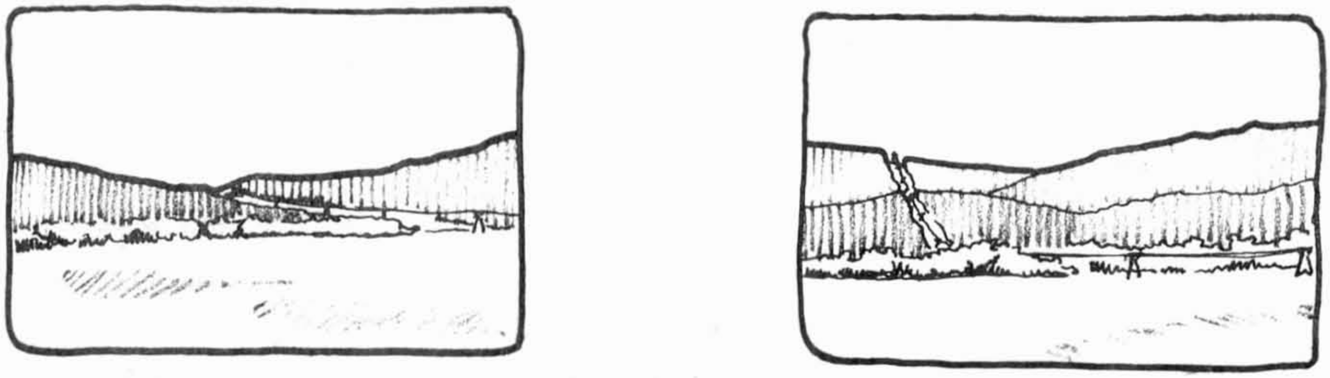


FIGURE 4. CORRIDOR VISIBILITY AND ANGLE OF VIEW

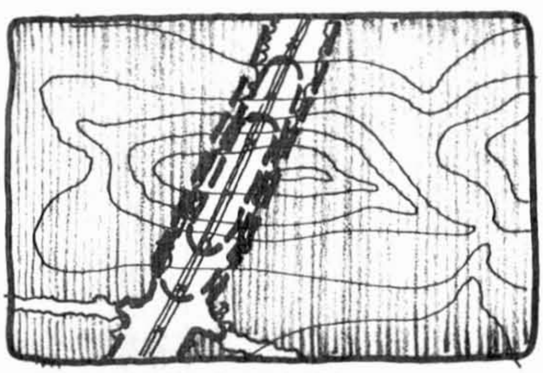


FIGURE 5. HYPOTHETICAL CONTOURS OF EQUAL VISIBILITY

Clearing Practices

BPA tree cover clearing practices are changing to allow growth of woody vegetation in the right-of-way as long as it does not interfere with circuit reliability. These changed practices are not yet fully apparent throughout the service area; shrub growth is present in certain corridor clearings (Plate 2), while others are still devegetated. Our observation for corridors cleared through wooded stands is "the more corridor vegetation, the less contrast", particularly if the corridor vegetation includes shrubs and low trees similar to the adjacent vegetation. These vegetation types also generate shadows that can help to blend in with surrounding forest. The most critical siting condition in this regard is the hillside corridor; we observed the situation to be most pronounced in dry woodland hillsides where the surrounding dark forest pines contrast sharply with the lighter (more reflective) dry surface grasses in the corridor clearing. Promoting limited pine growth or similar dark vegetation in the corridor would dramatically diminish corridor visibility.

Access Roads

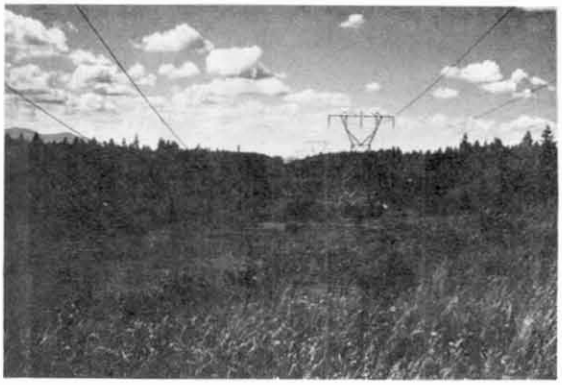
In some cases we found that the access road dramatically increases corridor visibility. One particular example is a ridge crossing by the Chief Joseph-Monroe Line near Deer Creek Flat where the exposed earth of an access road makes the corridor visible at 18 miles in the hills above Skykomish (Plate 2). Exposed road cuts are much lighter than the scrub-deciduous vegetation that often grows in corridors. Furthermore, the switchbacking of some steep hillside access roads seems to call attention to the huge scale of the corridor; this can be an argument in favor of helicopter installation and maintenance in some locations. The potential contrast ratio between the color of the existing vegetation and exposed soil color may also be worth mapping as an element of visual compatibility in location studies.

Minor Topographic Variations

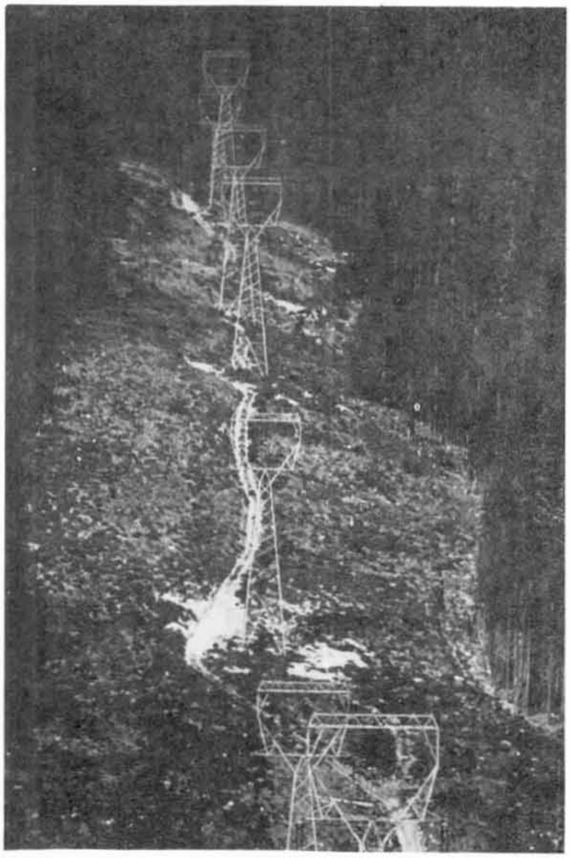
Even small changes in topography can have the effect of putting some towers on a pedestal while obscuring others (Plate 2). Major variations of this sort are taken into account in the landform/cover classification, but minor variations can still have a significant effect, especially when viewed at close distances. When a line is located at the base of a long hill on the side of a valley, the towers, rising and falling over relatively small swales, can become even more prominent at close range. During our survey we avoided making observations in extreme conditions of this sort.

Sunlighted vs. Shadowed Towers

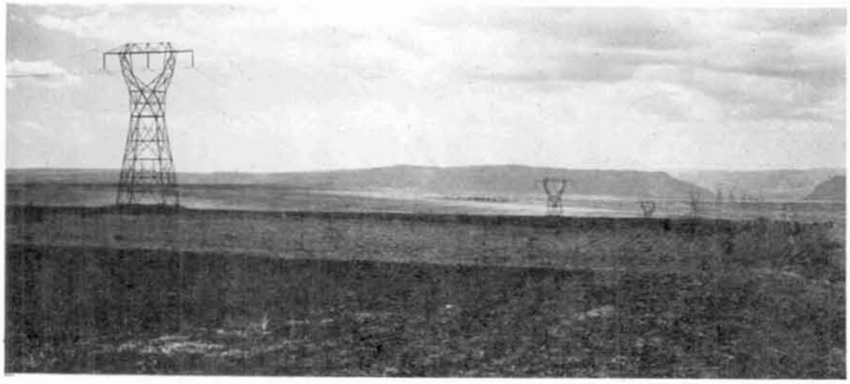
In bright sunlight each tower has a light side and a dark side (Plate 2). Standing adjacent to a transmission line, tower visibility can be radically different looking in either direction. We defined our observation criteria in terms of seeking the "typical worst case"; here, that meant looking at the background and, if it was dark, observing only lighted towers, and vice versa. This simplified decision criterion was easy to use in the field. Location studies would be well advised to take into account solar aspect as well as landform. Towers on north facing slopes are not normally as well lighted as those on south facing slopes, and when viewing backlit towers from below against forested landcover the contribution of aspect to reducing lighting contrasts is both appreciable and worth quantifying. The previous study prepared for BPA by Jones & Jones included this consideration as "landform aspect", a factor contributing to the evaluation of visual compatibility between landscape setting and proposed transmission facility.



Clearing Practices



Access Roads



Minor Topographic Variations

PLATE 2; Additional Corridor-Related Variables

Specular Reflection

This has the opposite effect of haziness in that it normally increases contrast between reflecting towers and conductors with the background. Its magnitude is a function of the respective positions of the observer and the sun in relation to the tower and lines (Plate 3). Specular reflection can dramatically increase the visibility of transmission facilities. However, nonspecular conductors and tower finishes are available and are presently utilized in areas of high viewer sensitivity to reduce visibility from the time of their installation. As aluminum conductors and galvanized towers age, their specular reflectance is also diminished (see below). In general we eliminated observations of brightly reflecting towers and lines because this condition is usually encountered only during low morning or evening sun and is relatively uncommon. Nevertheless, the effect, when observed, is striking.

Age of the Transmission Line

This variable was noted to have a dramatic effect on both tower brightness and susceptibility to specular reflection and, to a lesser extent, corridor contrast. Galvanized steel takes about 5-8 years to weather to a matte gray, and while still "fresh" it is markedly more visible. We noted this variation and attempted to avoid observing very new transmission installations. Corridor clearing contrast with surrounding vegetation is increased where revegetation after construction is slow. In general we found the older the corridor, the less contrast between it and the surrounding landcover; however, this is also dependent on clearing and maintenance practices.

Color of Tower

The use of painted towers in the BPA system is not widespread and time was too limited to allow detailed analysis of color as a variable. However, we can offer some recommendations concerning the most effective use of color. Probably the most visible towers observed were the Washington Water Power towers along the Spokane River about 7 miles northwest of Spokane. These steel single pole towers were painted sky blue (Plate 3). They contrast strongly with the surrounding pine forest and therefore have a much higher visibility than darker towers. We have concluded that the best camouflaging color choice would be that which most diminishes the figure-field tonal contrast, e.g. usually dark gray or gray-green. This blends in much better with all forest landcovers and tends to vanish sooner in all conditions except on ridges. In ridge conditions a dark gray tower would have nearly the same effect as a white tower because neither tower could appear as bright as the sky. In essence the sky is a light source and no tower can consistently reflect enough light to blend in. Perhaps the best advice is to paint towers dark when they are to be seen against ground or vegetation. The only exception might be towers viewed against light-colored grass, such as along the Columbia, where a light khaki might slightly improve on their unpainted color. In all cases, the goal should probably be to reduce the ratio of apparent contrast between tower and landscape background to less than 1.4:1 (see page 10).

Dead End Towers

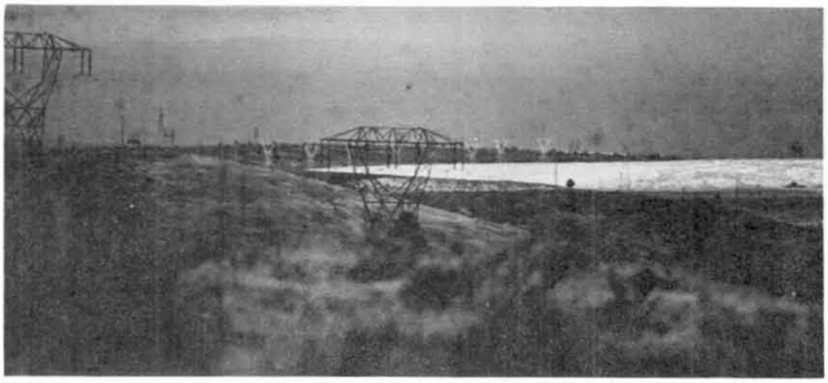
These towers are often larger and designed with heftier structural members than the normal tangent towers. The resulting increased visual density of the tower lattice allows less of the tower background to show through. This tends to increase apparent contrast. Added to this is the common use of dead ends at critical points of visibility and topography such as at ridge crossings. Dead ends show less consistency in design because they are individually designed to deal with specific eccentric loads. In general we tried to exclude dead ends so as not to add any inconsistency into our data. Also, because of their rather specific designs, we abandoned trying to deal with them as a uniform class of towers. We can only note that their greater visual density and commonly prominent placement should be considered in impact assessment, especially at ridge crossings and other points of heightened visibility.

Random Variations of Tower Type Within an Alignment

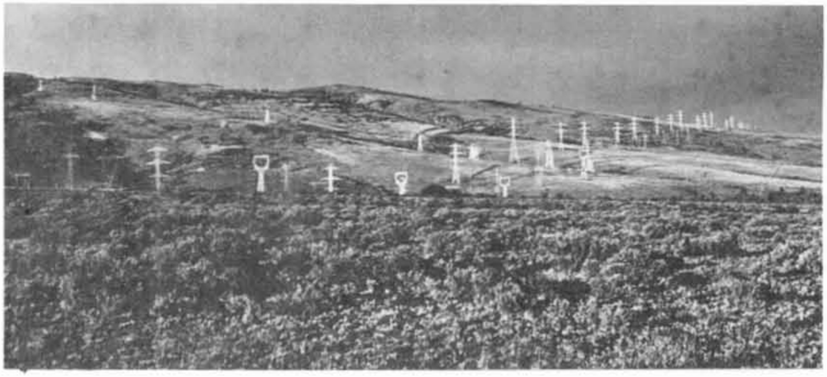
Occasionally within a stretch of transmission line with little or no apparent change in other conditions, slight or even major changes in tower type may occur, only to change back a few towers later. This did not affect relative visibility where we observed it, but it might elsewhere.

Tower Height Variations

Adjustments to varying topography and spans necessitate variable leg lengths. Thus, towers with a "textbook" height of 125 feet may actually only be 105 feet high. When modeling potential visibility it might be useful to consider how heights are expected to vary across the planned terrain.



Sunlighted vs. Shadowed Towers



Specular Reflection - Towers

Specular Reflection - Lines

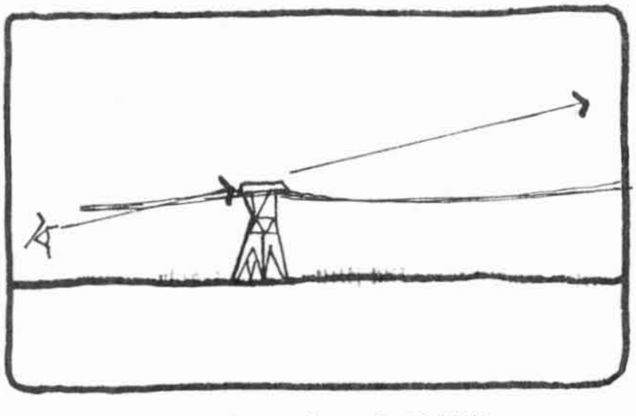
Color of Tower

PLATE 3; Additional Tower-Related Variables

II D. LANDSCAPE SETTINGS AND EPHEMERAL CONDITIONS

At the beginning of this study, analysis of landform variations with respect to transmission line routing suggested four broad classes of landform; a fifth class was added during fieldwork. These landform classes naturally fall into two types of tower background conditions: towers in flatland and primary ridge settings are in silhouette along the skyline boundary, while valley floor, hillside and secondary ridge settings each provide a degree of landform screen behind the towers. Note that secondary ridges are those ridges backdropped by distant landform, usually a primary ridge, rather than by the sky. This class was added because the difference in ridgetop tower background reversed the figure-ground relationship: primary ridge = dark tower on light background, secondary ridge = light tower on dark background. This reversal seemed an important distinction in the field.* In effect, flatland and primary ridge differ mainly in the topographic prominence afforded the transmission facility. Valley floor and secondary ridge are also similar in that the background is usually at considerable distance from the line; in the hillside condition the tower is backdropped by the hill on which it is sited.

Each of the five landform classes can be further subdivided according to landcover type. For this study, the BPA service area was categorized within three generalized vegetation zones: grassland, occuring throughout most of eastern Oregon and Washington, and southern Idaho; open forest (less than approximately 50% treecover--coniferous or riparian deciduous), common on the lower east side of the Cascades and on southern and eastern exposures in the Northern Rockies; and closed forest (primarily coniferous), which covers most of the Cascades and Olympics and much of the Northern Rockies.** Agricultural land was placed into either of the first two categories depending on the amount of treecover or the presence of orchards.* A brief discussion of the characteristics of each of the 15 landform/landcover classes is presented below.

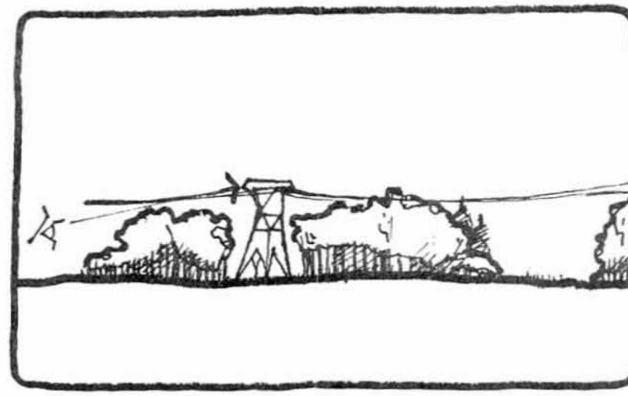


F1 Flatland/Grass; Much of eastern Washington and Oregon, and southern Idaho, is included in this category. Because the landform is so flat and dry, surface haze often tends to cause the towers to vanish somewhat sooner than might be expected. Rights-of-way are virtually indistinguishable from their surroundings, since the surrounding vegetation cover carries through the right-of-way without interruption.

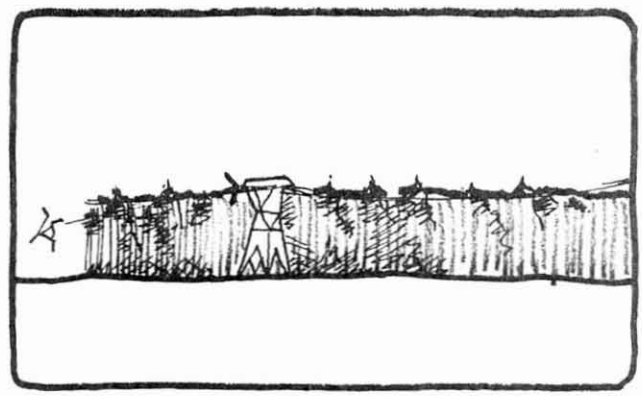
* However, review of the field observation data reveals that the visibility differences between towers sited on primary and secondary ridges are probably not significant enough to warrant their separate distinction.

** The reader should appreciate that the northwestern coniferous forest is essentially uniform in height, color and density, very different in appearance from the more diverse eastern hardwoods; care should be taken in adapting the findings of this study to such different landcover conditions without proper testing.

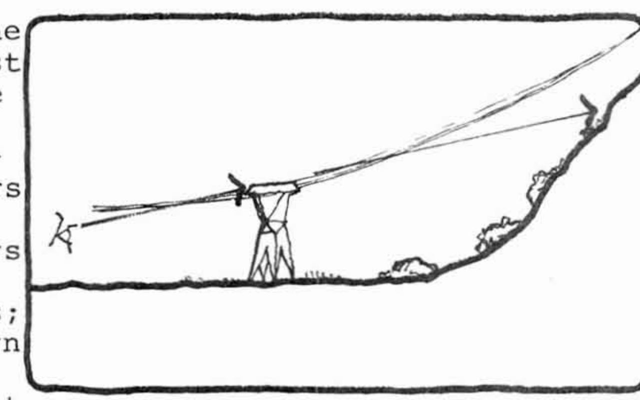
F2 Flatland/Open Forest; this category was not surveyed because an observer on the ground can very rarely see a corridor or towers unless he is standing in or very near to the corridor. From this viewing angle the towers appear to stack up upon each other and the right-of-way clearing tends to trail off toward infinity. Because visibility is uniformly high and does not diminish with distance, this landform/landcover class was dropped from consideration.



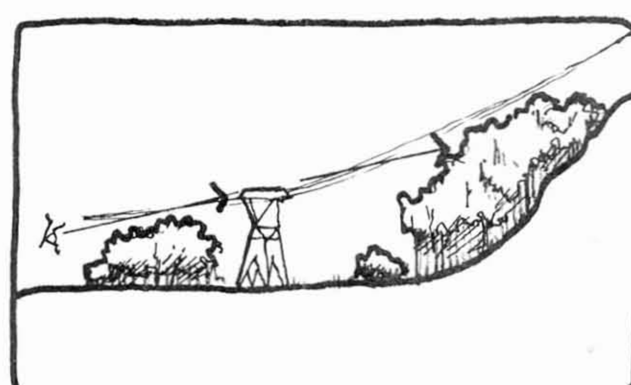
F3 Flatland/Closed Forest; observations not made for reasons stated in F2 above.



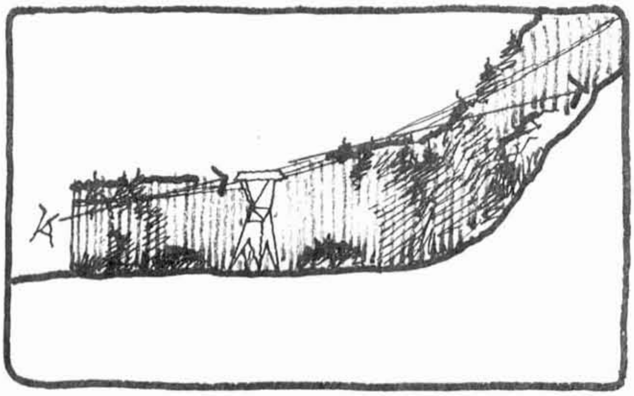
V1 Valley Floor/Grassland; this zone is typified by the broad valleys east of the Columbia River on either side of Saddle Mountain, Washington. A setting very capable of visually absorbing transmission corridors occurs in this zone where the predominant vegetation is sage and scrub. Towers and rights-of-way in this zone have lower visibility than in other zones; the rough-textured vegetation pattern absorbs the structural outline of the towers and reduces their apparent contrast.



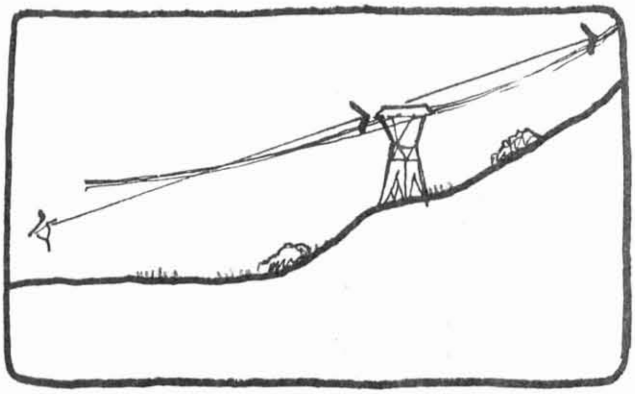
V2 Valley Floor/Open Forest; transmission lines in this zone also have lower than normal visibility, mainly due to the alternating pattern of trees and open areas which help both to screen towers and absorb corridor clearings.



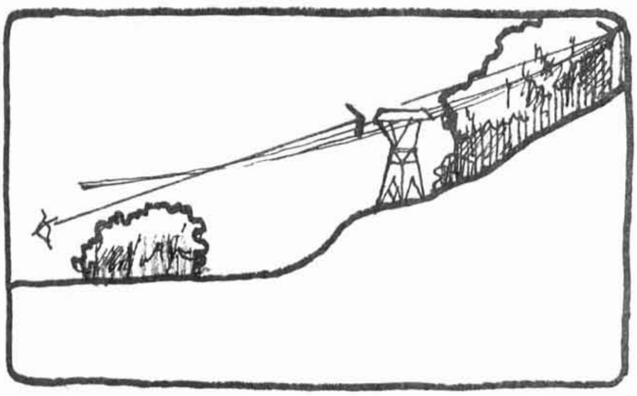
V3 Valley Floor/Closed Forest; examples of this zone occur when approaching the major passes in the Cascade Mountains. Tower line visibility is lower than normal, due partly to obscuring vegetation and fairly lush corridor vegetation.



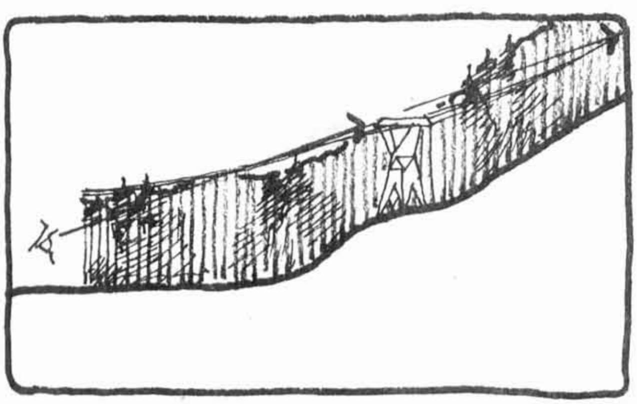
H1 Hillside/Grassland; examples of this zone occur on the dry major east-west trending ridges in eastern Washington and near Plains, Montana. Characteristics are similar to V1, although tower line visibility is about average in comparison to all other zones.



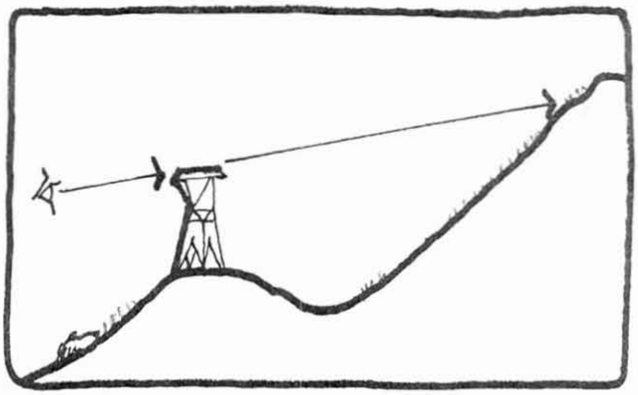
H2 Hillside/Open Forest; occuring in the eastern Cascades and on dry exposures in the Northern Rockies. This zone is typified by above-average visibility of towers due to their tonal contrast with grassed right-of-way, but below average visibility of corridors due to the presence of natural clearings.



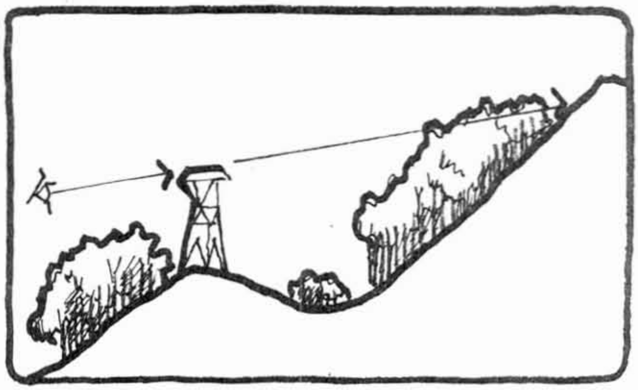
H3 Hillside/Closed Forest; very common in western Washington and Oregon. Towers have about average visibility here since they are frequently viewed against their cleared corridors; the cleared corridors are most visible in this zone due to their striking contrast with the surrounding solid masses of forest.



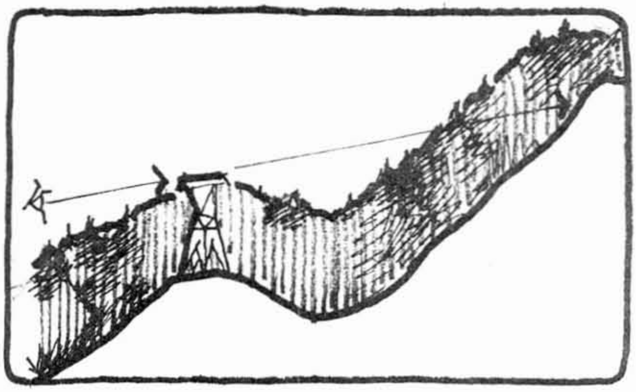
SR1 Secondary Ridge/Grassland; occurring in the same zone mentioned in H1. Visibility in this situation does not differ significantly from the Primary Ridge/Grassland discussed below. Towers in this setting have higher than average visibility because of their contrast with the generally lighter tone of the distant primary ridge beyond.



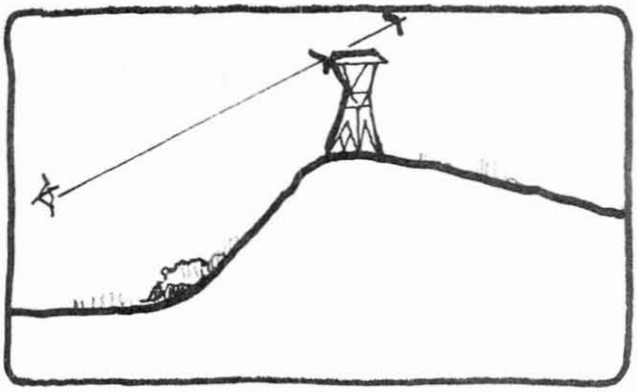
SR3 Secondary Ridge/Open Forest; occurring the the same areas mentioned in H2. In this zone, corridors often were not distinguishable due to the open nature of the vegetation. Therefore towers are the only significant contributors to visibility and, in general, tower visibility is above average for the same reasons as SR3 below.



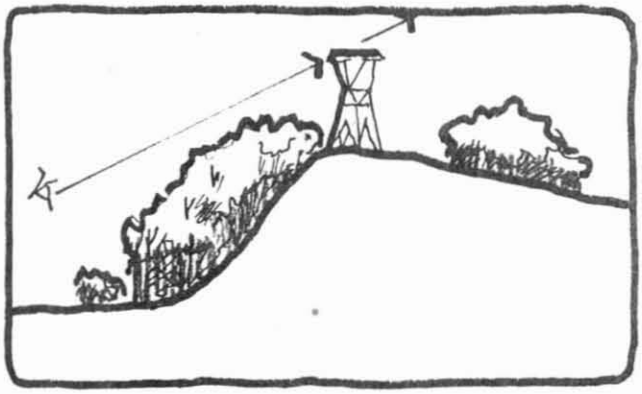
SR3 Secondary Ridge/Closed Forest; occurring in the same areas mentioned in H3. Cleared corridors are normally most visible in this zone where atmospheric haze lightens the background ridges, providing contrast against the right-of-way notch. Towers are also quite prominent because their background is darker and more uniform than their own corridor.



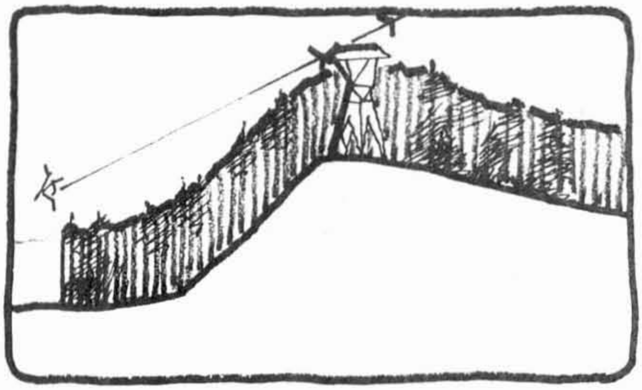
PR1 Primary Ridge/Grassland; in this zone towers appear dark against the light-filled sky. The smooth profile of the grassy hill makes the interruption of the skyline profile by the tower very apparent; consequently, tower visibility is above average in this class. Rights-of-way are not distinguishable.



PR2 Primary Ridge/Open Forest; this zone is similar to SR2 in that the corridor is not very apparent due to the irregular skyline profile of the open forest. Nonetheless a dark tower silhouetted against the light sky often makes the corridor notch more recognizable.



PR3 Primary Ridge/Closed Forest; this and SR3 are the conditions in which corridor visibility is greatest: the classic notch cut in the otherwise fairly smooth skyline. This notch is probably the most distant visible feature of transmission corridors. Tower visibility in this condition was recorded under PR1, because the tower is seen rising from the immediate grassed R.O.W.



The above landform/landcover conditions were the landscape variables tested in this study. There are other factors in the landscape, as well as ephemeral conditions, which contribute to transmission line visibility; those considered are discussed below. As with the object-related variables discussed in Section II.C, these setting-related variables were held constant in this study by limiting the range of conditions under which field visibility observations could be made, as discussed in each category.

Atmospheric Clarity

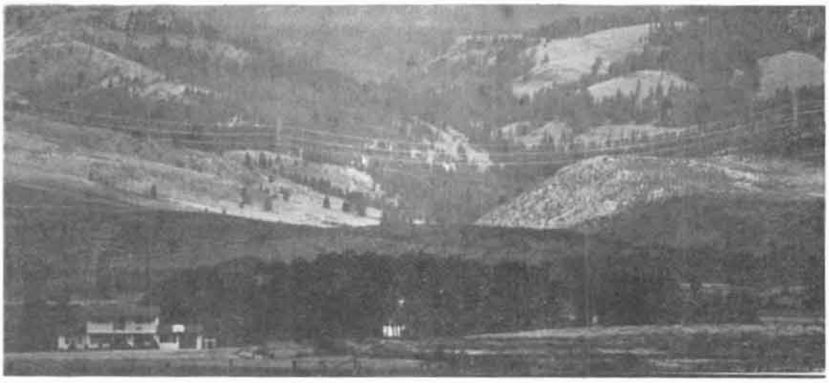
Haziness exists even on the clearest of days because the atmosphere is not perfectly transparent. This manifests itself through increasing dimunition of contrast at greater distances (Plate 4). We found haze to be unimportant at high and medium visibilities, but a predominant factor causing towers and corridors to vanish sooner than expected at distances in excess of 12 miles. Accordingly, we endeavored to make observations only in conditions where haze was not pronounced, in what is commonly referred to as "20-mile visibility".

Exceptionally Absorptive Backgrounds

In the course of our study we occasionally came across settings where the towers seemed to be very quickly absorbed into their backgrounds. This occurs most typically in the presence of sagebrush, which at moderate distance and the correct light has an exceptionally effective masking texture and tone (Plate 4). This special grassland texture was not common enough to warrant a unique landscape classification for this study, so we noted the conditions but did not use the data in our final compilation. However, the potentially absorptive textures of particular landcover patterns can be mapped and modeled in detail for specific siting studies.

Seasonal Variables

The most obvious of these is snowcover in the corridor (Plate 4), since most forest cover in the BPA's area is coniferous. Snowcover (combined with the dormancy of deciduous scrub vegetation) can raise the contrast ratio of a corridor from 2 to 1 up to as much as 16 to 1. The contrast-diminishing effect of haze that seems to put an upper limit on the visibility distance of corridors is a less effective buffer against contrast this great, and visibility thresholds of 30 miles or more for snow-covered corridors in coniferous forests are possible. The timing of our survey in the summer prevented investigation of snow. However, this study could be useful as a baseline against which seasonal variations can be measured.



Atmospheric Clarity

Exceptionally Absorptive Backgrounds

Seasonal Contrast - Summer

Seasonal Contrast - Winter

PLATE 4; Additional Landscape and Ephemeral Variables

II E. FIELD SURVEY PROCEDURE

The field survey was performed in central and western Washington and Oregon in August 1976 by two staff members of Jones & Jones. Our initial intent was to visit all physiographic subregions in the BPA service area, but study time and the location of tower types precluded this. Nevertheless, from our previous study for BPA and other experience, we believe the landform/landcover classification is applicable to the landscape characteristics of the entire service area.

Approximately one week was devoted to an automobile survey, while three days of surveying were performed with the aid of a helicopter. All observations were made from ground-level, stationary viewpoints. Typically a prospective viewpoint was located on a 1:250,000 USGS map with an overlay locating BPA's transmission corridor network. The two observers found an optimum viewpoint and then checked the view-conditions to ensure that the criteria for lighting and angle of view were met (see II.B and II.C above). If conditions were acceptable, a survey form was filled out for each combination of landform/landcover class and tower type or corridor size for which the observation was being made. Figure 6 exhibits the tower and corridor visibility survey forms used. It was quite common to fill out a number of forms from a single viewpoint, especially when overlooking a multiple corridor.

Distances to tower or corridor thresholds were scaled from the USGS maps when greater than about 7 miles. Otherwise the tangent of the angular height was used to determine distance, in conjunction with the standard dimensions between major cross-members for each tower type, taken from engineering drawings furnished by BPA. Angular size was measured using a telephoto lens with a diagonal field of view of 6^{o}, mounted on a Nikon camera. The lens had previously been calibrated with a target in the office and divisions of 3 minutes (0.05^{o}) were ink-ruled on the removable viewfinder screen. Distances determined by this method agreed ± 5% with map-scaled distances.

Brightness ratios were taken using a Soligor 1^{o} field telescopic reflectance meter. Landscape setting brightness measurements were taken directly. Tower brightness measurements were taken from a "gray card" found to be equivalent in tone to galvanized steel, since the tower lattice members were too small to measure at great distances. The accuracy of the gray card measurements was around±10% which was considered adequate to determine whether the contrast ratio was high enough to make an observation (page 10).

Visibility threshold judgments were made as a consensus between the two observers. These thresholds were recorded as the distances at which the visibility changed from high to medium, medium to low, or low to detection levels; this last threshold was the observers' recognition level threshold (see pages 5 and 6). In most cases, there was close agreement. The threshold of absolute visibility

TOWER SURVEY FORM   Location Salem - Portland Road

230SF Type Tower   Roll M   Exp. 31

F3 Landform/Landcover Class

1. Visibility Parameters

.55	1.1			Distance (miles)
1.2°	.45°			Angular Size (degrees)
2.1:1	-			Figure/Field Brightness (ratio)
H-M	M-L			Relative Visibility Threshold (H-M;M-L;L-D)

2. Limit of Recognition

- Tower (miles)

.7 Lattice (miles)

3. Viewing Conditions

15+ Atmospheric Clarity in Miles

5:45P Time

NNE Direction of View (N,S,E,W)

- SLIGHT HAZE
- GOOD LIGHTING

CORRIDOR SURVEY FORM   Location Jumpoff Ridge - Malaga

175' Size of Corridor   Roll Q   Exp. 10-11

SR2 Landform/Landcover Class

1. Visibility Parameters

1.75	5.5	12.7		Distance (miles)
1.1°	.35°	.15°		Angular Size (degrees)
1.8:1	-	-		Figure/Field Brightness (ratio)
H-M	M-L	L-D		Relative Visibility Threshold (H-M;M-L;L-D)

2. Limit of Recognition

✓ Right-of-Way without Access Road (miles)

____ Right of Way with Access Road (miles)

3. Viewing Conditions

20+ Atmospheric Clarity in Miles

2:30 Time

NNW Direction of View (N,S,E,W)

- RECENTLY CLEARED R.O.W.
- FOREST GRADING INTO SR3 ABOVE

FIGURE 6. TYPICAL FIELD SURVEY FORMS

(detection level) was noted where possible, as well as a judgment on where the "lattice" of a tower appeared to dissolve and be lost.

Finally, atmospheric clarity was noted, along with the time and direction of view; these factors were used during data analysis to evaluate the acceptability of marginal observations.

III. CONCLUSIONS

III A. SUMMARY OF FIELD DATA

The following five tables summarize the field survey visibility data on the relationships between observed relative visibility thresholds and angular size. The angular size at each threshold is the mean of observations made under acceptable viewing conditions for that tower type or landscape setting. Approximately 150 observations were used to produce these tables; conditions for which no values are recorded were either dropped from the survey for reasons explained earlier (F2,F3, and PR3 towers; see II.D), or could not be acceptably surveyed during the course of the necessarily brief fieldwork, e.g., the L-D threshold for towers in SR2 settings.

Note the striking consistency in angular size at each threshold in Tables 2, 3 and 4. Tables 5 and 6 are included to illustrate the mean observed distances for observed tower visibility thresholds, considered first by tower type, and then by landscape setting. No distance table is included for corridors, because observed corridor widths varied too widely to be tabulated. However, predicted distances for corridor visibility thresholds at specific corridor widths are presented in III.C, and these are generated from the relationships between mean observed corridor angular widths and relative visibility thresholds presented in Table 5.

Initially, the contrast ratio between apparent transmission facility brightness (tower and/or right-of-way) and landscape setting brightness was considered as a potential explanatory variable. However, it became clear (page 10) that above a ratio of 1.4:1, increasing contrast did not increase relative visibility. This ratio was nearly always exceeded, unless a special treatment were applied to the transmission facility. While such treatments are very worthy of study, they were not the focus of this effort. Therefore, the 1.4:1 contrast ratio became a baseline for acceptable viewing conditions and its variations are not tabulated here.

Note that Table 5 includes the point at which the tower members ("lattice") could no longer be discriminated. This was also considered initially as a potential breakpoint between foreground and middleground, analogous to the distinctions used by Litton to differentiate forest visual zones. While the lattice threshold distance agrees rather well with the H-M threshold, angular size proved a more useful measure for all three relative visibility thresholds.

TABLE 2. OBSERVED RELATIVE VISIBILITY THRESHOLDS: MEAN ANGULAR TOWER HEIGHT, BY TOWER CONFIGURATION

Tower Configuration	Relative Visibility Threshold H-M	M-L	L-D
1100 KV AC	.99°	.37°	.07°
800 KV DC	1.12	.35	.07
500 KV DS	1.04	.41	.09
500 KV DD	.81	.30	.06
500 SF SF	.93	.35	.06
500 KV SD	1.24	.38	.09
230 KV DS	1.12	.38	.08
230 KV SD	1.14	.45	.08
230 KV SF	1.12	.48	.07
115 KV H	.94	.45	.10
MEAN	1.05	.39	.08

TABLE 3. OBSERVED RELATIVE VISIBILITY THRESHOLDS: MEAN ANGULAR TOWER HEIGHT, BY LANDSCAPE SETTING

Landscape Setting	Relative Visibility Threshold H-M	M-L	L-D
F1	1.16°	.39°	.10°
F2	*	*	*
F3	*	*	*
V1	1.08	.47	.13
V2	1.18	.43	.11
V3	1.28	.43	.12
H1	1.26	.36	.08
H2	.95	.31	.09
H3	.87	.42	.08
SR1	1.20	.35	.06
SR2	.80	.35	-
SR3	.85	.30	.07
PR1	1.00	.39	.08
PR2	-	.30	.09
PR3	*	*	*
MEAN	1.05	.39	.08

* not surveyed; see II.D

TABLE 4. OBSERVED RELATIVE VISIBILITY THRESHOLDS: MEAN ANGULAR R.O.W. WIDTH, BY LANDSCAPE SETTING

Landscape Setting	Relative Visibility Threshold H-M	M-L	L-D
F1	**	**	**
F2	*	*	*
F3	*	*	*
V1	**	**	**
V2	1.22°	.50°	.20°
V3	1.05	.40	.10
H1	**	**	**
H2	1.28	.45	.20
H3	1.00	.32	.10
SR1	**	**	**
SR2	1.50	.60	.20
SR3	1.03	.33	.10
PR1	**	**	**
PR2	1.10	.47	.15
PR3	0.70	.30	.10
MEAN	1.11	.42	.14

* not surveyed; see II.D
** R.O.W. not apparent in grasslands

TABLE 5. OBSERVED RELATIVE VISIBILITY THRESHOLDS: MEAN TOWER DISTANCE, BY TOWER CONFIGURATION

Tower Configuration	Relative Visibility Threshold H-M	M-L	L-D	Lattice
1100 KV AC	2.3 mi.	5.3 mi.	20.0 mi.	2.5 mi.
800 KV DC	1.4	4.8	17.0	1.5
500 KV DS	2.3	5.3	20.0	1.8
500 KV DD	2.3	5.3	20.0	1.8
500 KV SF	1.2	3.4	14.0	1.4
500 KV SD	1.2	4.2	15.0	1.2
230 KV DS	1.6	4.5	14.0	1.7
230 KV SD	0.7	1.7	12.0	0.5
230 KV SF	0.9	1.9	13.0	1.0
115 KV H	0.8	1.8	14.0	N/A

TABLE 6. OBSERVED RELATIVE VISIBILITY THRESHOLDS: MEAN TOWER DISTANCE, BY LANDSCAPE SETTING

Landscape Setting	Relative Visibility Threshold H-M	M-L	L-D	Lattice
F1	1.2 mi.	3.5 mi.	10.9 mi.	1.3 mi.
F2	*	*	*	*
F3	*	*	*	*
V1	1.1	2.2	10.2	1.2
V2	1.0	4.4	14.8	2.2
V3	1.2	4.3	14.8	1.3
H1	.6	4.2	10.0	-
H2	1.1	4.0	15.5	-
H3	1.8	3.8	14.2	1.1
SR1	.9	6.0	14.0	1.7
SR2	1.3	4.0	-	-
SR3	2.3	7.0	15.0	-
PR1	1.0	4.1	15.0	1.3
PR2	-	7.0	12.5	1.3
PR3	*	*	*	*

* not surveyed; see II.D

III B. ANGULAR IMAGE SIZE AND THE EYE

When reviewing the field data after field observations were completed, it was immediately obvious that the range of observed angular sizes corresponding to each of the three relative visibility threshold judgments was very small. This was particularly true of the high-medium threshold. The consistency of the data led the authors to search for a possible physiological explanation; we tried looking at the variable receptivity pattern of the human eye.

In this connection, an interesting characteristic of our visual system is the variable density of the two retinal receptors, rod cells and cone cells. Rods are our most sensitive detectors of light and provide us both our peripheral vision and our night vision. However, rods are not capable of distinguishing colors. Moreover, rod cells are clustered in groups of as many as two dozen which connect to a single neural passage to the brain called a ganglion cell. As a result, the ability for rods to spatially locate a stimulus or resolve two closely adjacent stimuli is very limited; that is, the visual acuity provided by rod cells is very low.

The other type of receptor in our retina is the cone cell. There are normally thought to be three types of cones, which are sensitive to red, green or blue light, the optical primaries. Besides color sensitivity, cones differ from rods in that there is only one cone cell connected to each ganglion cell. In other words, the cones provide maximum visual acuity, since the information gathered by each receptor cell is transmitted to the brain by a discrete pathway.

Figure 7 is a sketch of the major components of the left eye; Figure 8, a graph of its horizontal distribution of rods and cones. Virtually all the cones are located in the center of the retina in an area called the fovea. Figure 9 shows the differential acuity that results from this clustering of cones. The human visual system devotes only a small proportion of its area to maximum acuity and the gathering of detailed information. The remainder of the retina is devoted to detecting what to examine next.

The concentration of acuity in the fovea may provide an explanation of the high-medium relative visibility threshold. While in the field we noticed that, in general, the point where our visibility judgment went from high to medium was approximately at the point where it was possible to look at the entire tower in a single "glance". At this point it was no longer necessary to "look the tower up and down"; here the tower seemed to be entirely perceivable in a single stationary look and filled our field of detailed perception. Figure 6 is a graph of acuity vs. retinal location. It is difficult to clearly define the size limits of the fovea, but if we arbitrarily define the fovea as that area of the retina where visual acuity is over half the maximum acuity attained at the foveal center, then the fovea is about 1.5° across. At a visual acuity of

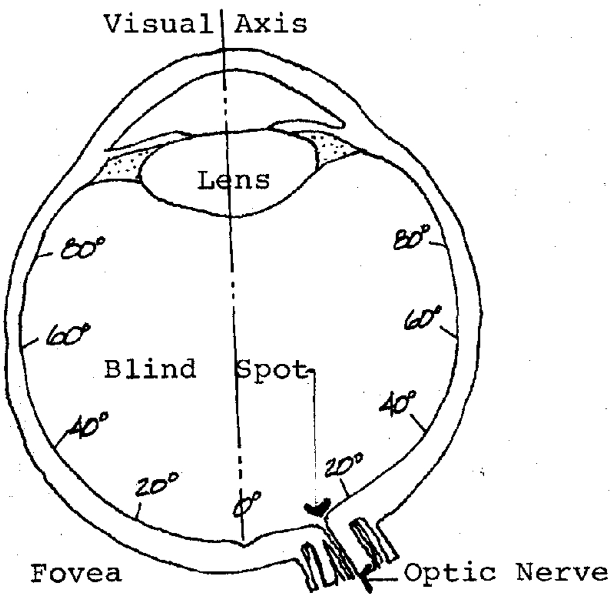


FIGURE 7. TOP VIEW OF THE LEFT EYE (after Cornsweet, 1970)

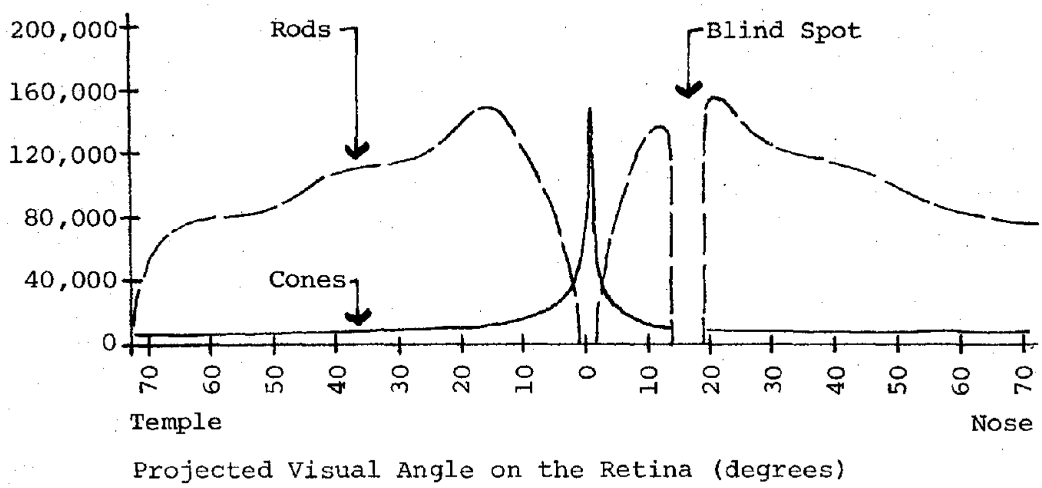


FIGURE 8. RETINAL DISTRIBUTION OF ROD AND CONE CELLS (after Cornsweet, 1970)

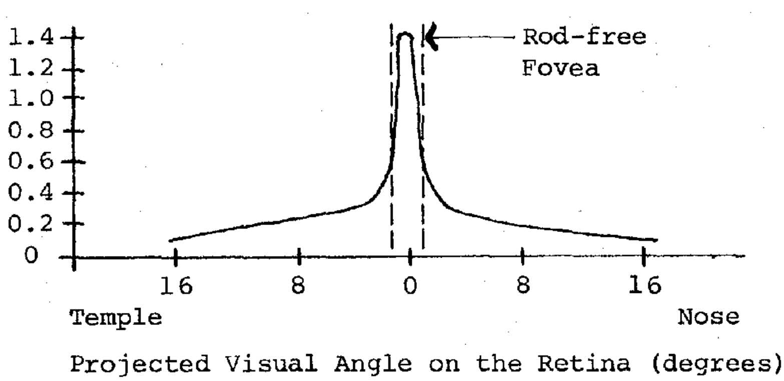


FIGURE 9. RETINAL LOCATION AND VISUAL ACUITY

0.8-1.0, the foveal size is almost exactly 1.15° (again, the units of acuity in this graph are defined in terms of a specific laboratory test; they are not the same as those in Figure 3).

The clear inference is that high visibility images are those that are too large to be contained in the fovea and so require scanning movements of the eye for detailed perception. As the image size drops with increasing distance, the point at which the object can be perceived in single glance or fixation of the eye is the threshold between high and medium relative visibility. We could predict this threshold to correspond to an image size of 1.0 to 1.5°, based on the size of the fovea.

Possible physiological bases for the medium-low and low-detection level thresholds are not immediately obvious, however. We may surmise that an object over 0.5° in apparent size impinges on a predominant number of our foveal neurons and therefore largely occupies our visual cortex. As that object image becomes smaller, other stimuli fill the fovea as well. These other detailed inputs begin to draw off attention. For example, the observer is no longer looking at just a tower, but rather is looking at a tower in a forest. There is not quite so much consistency in our observations of angular height related to the medium-low threshold for a given tower type, but our data locates the medium-low visibility threshold at approximately 0.4° of angular height (or corridor width).

The low-detection threshold, our field-observed recognition level threshold, occurs at approximately 0.1° of angular size. At this point, only the most simplified outline and color of the image are available to distinguish it from other images of the same general size: "It that a tower or a tree?" A very tentative suggestion is that this threshold may be tied to the angular size of an array of cone cells sufficient to register shape and color with certainty. As for detection level, the eye can detect a light source or highly reflective object equal or smaller in visual angle than a cone cell itself; for example, a star. Of course, all that is registered is the existence of a point (or line) of very high contrast and its location; distance and apparent size information cannot be extracted from such a stimulus. This type of phenomenon was encountered in the field with specular reflection from conductors in the very far distance; in one case, the computed angular width of these conductors was 0.5 seconds of arc, approximately equal to 0.0006°.

While the physiological bases for the M-L and L-D relative visibility thresholds are highly speculative, the data for angular size at the H-M threshold does appear to be linked to the size of the fovea. Together with the marked consistency of the angular size observations at all three thresholds, the significance of this finding is that it appears to ground relative visibility judgments in the psychophysiology of the eye and helps to dispel the specter of "subjective evaluation".

III C. PREDICTING RELATIVE VISIBILITY THRESHOLD DISTANCES

The field data summarized in III A. (Tables 2-6) consisted of some 150 observations. Our study design is a matrix of ten tower configurations, arrayed against twelve applicable landscape settings, plus corridor width arrayed against eight applicable settings. While we attempted to fill this matrix as far as possible with direct observations, we were constrained by time limitations and viewing conditions. Moreover, the tower configurations are not equally common throughout the BPA service area (see page 11); some tower/landscape setting combinations do not now exist. For these reasons, we were unable to obtain direct observations for approximately 30% of the facility/setting combinations. We anticipated this and hoped that our data would allow these gaps to be interpolated.

As we have seen, the measurements of angular size at the three observed relative visibility thresholds are quite consistent and at least one of these thresholds seems to be grounded in the physiology of the eye. Nevertheless, tower configuration and landscape setting definitely appear to affect observed relative visibility, for some of the reasons mentioned in II.C and II.D. To predict relative visibility thresholds for all facility/setting combinations, we have utilized the trigonometric function relating angular size to tower height (or R.O.W. width) and distance, modified by constants to account for the variation introduced by tower type and landscape setting.

These "relative visibility constants" derive from analysis of our field observations and are an index of the extent of deviation from the mean angular size, at a given threshold, attributable to a specific tower or setting type. There are three of these relative visibility constants, tabulated in Tables 7-9:

C_t = index of deviation due to tower type

C_{ts} = index of deviation due to tower setting

C_{rs} = index of deviation due to R.O.W. setting.

For an example, consider C_t for a 500 KV SD tower. From Table 2, page 27, mean apparent angular height of this tower at the H-M threshold was 1.24°; the mean for all observations of all towers was 1.05°. This indicates that the relative visibility of the 500 KV SD tower, compared to that of all tower types, decreased faster than would be predicted by angular height alone. The constant C_t is equal to $1.24° \div 1.05° = 1.18$ for the H-M threshold; the three threshold means are weighted for the number of observations at each, and the overall mean C_t for the 500 KV SD tower is 1.10 (Table 7).

Utilizing these three constants, we can predict the angular size of a particular facility/setting combination at each relative visibility threshold, based on these overall mean angular sizes ($\bar{\theta}$) for towers and rights-of-way:

Threshold	Towers	Rights-of-Way
H-M	$\bar{\theta} = 1.05^\circ$	$\bar{\theta} = 1.11^\circ$
M-L	$\bar{\theta} = 0.39^\circ$	$\bar{\theta} = 0.42^\circ$
L-D	$\bar{\theta} = 0.08^\circ$	$\bar{\theta} = 0.14^\circ$

The predicted angular size is then:

$$\text{Towers} = \bar{\theta}_{pt} = \bar{\theta} \times (C_t \times C_{ts})$$

$$\text{R.O.W.} = \bar{\theta}_{pr} = \bar{\theta} \times C_{rs}$$

The predicted tower or corridor distance at each relative visibility threshold is then determined by the tangent function:

$$\text{Towers} = D_{pt} = (\text{tower height}) \div (\tan \bar{\theta}_{pt})$$

$$\text{R.O.W.} = D_{pr} = (\text{R.O.W. width}) \div (\tan \bar{\theta}_{pr})$$

Tables 10-15 contain these predicted relative visibility threshold distances, tabulated by tower type and landscape setting; there is one table for each of the six thresholds. Some of the predicted distances at the L-D threshold are very great, e.g., for very wide multiple corridors (Table 15). We recommend an absolute cutoff in such cases at 25 miles; we will discuss other cutoff distances in the next section.

TABLE 7. RELATIVE VISIBILITY CONSTANTS: TOWER CONFIGURATION (C_t)

Tower Configuration	Relative Visibility H-M	M-L	L-D	Mean Constant
1100 KV AC	0.94	0.95	0.91	0.93
800 KV DC	1.07	0.90	0.91	0.96
500 KV DS	0.95	1.05	1.16	1.05
500 KV DD	0.77	0.77	0.78	0.77
500 KV SF	0.88	0.90	0.78	0.85
500 KV SD	1.18	0.97	1.16	1.10
230 KV DS	1.09	0.97	1.04	1.03
230 KV SD	1.07	1.15	1.04	1.09
230 KV SF	1.07	1.23	0.91	1.07
115 KV H	0.90	1.15	1.30	1.18

Note: towers with higher constants are less visible

TABLE 8. RELATIVE VISIBILITY CONSTANTS: TOWER LANDSCAPE SETTING (C_{ts})

Landscape Setting	Relative Visibility H-M	M-L	L-D	Mean Constant
F1	1.10	1.00	1.25	1.12
F2	*	*	*	*
F3	*	*	*	*
V1	1.03	1.21	1.62	1.29
V2	1.12	1.10	1.37	1.20
V3	1.22	1.10	1.50	1.27
H1	1.20	0.92	1.00	1.04
H2	0.90	0.80	1.12	0.94
H3	0.83	1.08	1.00	0.97
SR1	1.14	0.90	0.75	0.93
SR2	0.76	0.90	**	0.83
SR3	0.81	0.77	0.87	0.82
PR1	0.95	1.00	1.00	0.98
PR2	**	0.77	1.12	0.94
PR3	*	*	*	*

Note: towers in landscape settings with higher constants are less visible.

* not calculated; see II.D.

** not calculated; no survey data.

TABLE 9. RELATIVE VISIBILITY CONSTANTS: R.O.W. LANDSCAPE SETTING (C_{rs})

Landscape Setting	Relative Visibility H-M	M-L	L-D	Mean Constant
F1	**	**	**	**
F2	*	*	*	*
F3	*	*	*	*
V1	**	**	**	**
V2	1.10	1.19	1.39	1.23
V3	0.94	0.95	0.70	0.86
H1	**	**	**	**
H2	1.15	1.07	1.39	1.20
H3	0.90	0.76	0.70	0.79
SR1	**	**	**	**
SR2	1.35	1.43	1.39	1.39
SR3	0.93	0.79	0.70	0.81
PR1	**	**	**	**
PR2	0.99	1.12	1.04	1.05
PR3	0.63	0.71	0.70	0.68

Note: rights-of-way with higher constants are less visible.
* not calculated; see II.D.
** not applicable; rights-of-way not visible in grasslands.

TABLE 10. PREDICTED RELATIVE VISIBILITY THRESHOLDS: TOWER DISTANCE IN MILES, AT HIGH-MEDIUM THRESHOLD

Landscape Setting	115 KV H	230 KV SF	230 KV SD	230 KV DS	500 KV SD	500 KV SF	500 KV DD	500 KV DS	800 KV	1100 KV
F1	0.6	0.7	0.8	1.1	1.0	1.1	1.7	1.5	1.4	2.2
F2	*	*	*	*	*	*	*	*	*	*
F3	*	*	*	*	*	*	*	*	*	*
V1	0.5	0.6	0.7	0.9	0.9	1.0	1.5	1.3	1.3	1.9
V2	0.5	0.6	0.8	1.0	1.0	1.0	1.6	1.4	1.3	2.1
V3	0.5	0.6	0.7	0.9	0.9	1.0	1.5	1.4	1.3	2.0
H1	0.6	0.7	0.9	1.2	1.1	1.2	1.8	1.7	1.6	2.4
H2	0.7	0.8	1.0	1.3	1.2	1.3	2.0	1.8	1.7	2.7
H3	0.7	0.8	1.0	1.2	1.2	1.3	2.0	1.8	1.7	2.6
SR1	0.7	0.8	1.0	1.3	1.2	1.3	2.1	1.9	1.7	2.7
SR2	0.8	0.9	1.1	1.4	1.4	1.5	2.3	2.1	1.9	3.0
SR3	0.8	1.9	1.1	1.5	1.4	1.5	2.3	2.1	2.0	3.0
PR1	0.7	0.8	1.0	1.2	1.2	1.3	2.0	1.8	1.6	2.6
PR2	0.7	0.8	1.0	1.3	1.2	1.3	2.0	1.8	1.7	2.7
PR3	*	*	*	*	*	*	*	*	*	*
MEAN	0.7	0.7	0.9	1.2	1.2	1.2	1.9	1.7	1.6	2.5

Tower Configuration (column group heading)

* Threshold not predicted; see II.D.

TABLE 11. PREDICTED RELATIVE VISIBILITY THRESHOLDS: TOWER DISTANCE IN MILES, AT MEDIUM-LOW THRESHOLD

Landscape Setting	Tower Configuration: 115 KV H	230 KV SF	230 KV SD	230 KV DS	500 KV SD	500 KV SF	500 KV DD	500 KV DS	800 KV	1100 KV
Fl 1	1.6	1.8	2.2	2.9	2.8	3.0	4.6	4.2	3.9	6.0
F2	*	*	*	*	*	*	*	*	*	*
F3	*	*	*	*	*	*	*	*	*	*
V1	1.4	1.6	1.9	2.5	2.4	2.6	4.0	3.6	3.4	5.2
V2	1.5	1.7	2.1	2.7	2.6	2.8	4.3	3.9	3.6	5.6
V3	1.4	1.6	2.0	2.5	2.5	2.6	4.1	3.7	3.4	5.3
H1	1.7	1.9	2.4	3.1	3.0	3.2	5.0	4.5	4.2	6.5
H2	1.9	2.1	2.7	3.4	3.3	3.5	5.5	5.0	4.6	7.2
H3	1.8	2.1	2.6	3.3	3.2	3.4	5.3	4.8	4.5	6.9
SR1	1.9	2.2	2.7	3.5	3.3	3.6	5.6	5.0	4.7	7.2
SR2	2.1	2.4	3.0	3.9	3.7	4.0	6.2	5.6	5.2	8.1
SR3	2.2	2.4	3.1	3.9	3.8	4.1	6.3	5.7	5.3	8.2
PR1	1.8	2.0	2.6	3.3	3.2	3.4	5.3	4.8	4.4	6.9
PR2	1.9	2.1	2.7	3.4	3.4	3.5	5.5	5.0	4.6	7.2
PR3	*	*	*	*	*	*	*	*	*	*
MEAN	1.8	2.0	2.5	3.2	3.1	3.3	5.2	4.7	4.3	6.7

* Threshold not predicted; see II.D.

TABLE 12. PREDICTED RELATIVE VISIBILITY THRESHOLDS: TOWER DISTANCE IN MILES, AT LOW-DETECTION THRESHOLD

Landscape Setting	115 KV H	230 KV SF	230 KV SD	230 KV DS	500 KV SD	500 KV SF	500 KV DD	500 KV DS	800 KV	1100 KV	
	Tower Configuration										
F1	7.7	8.7	10.9	14.1	13.5	14.5	22.5	20.3	18.9	(29.3)	
F2	*	*	*	*	*	*	*	*	*	*	*
F3	*	*	*	*	*	*	*	*	*	*	*
V1	6.7	7.6	9.5	12.2	11.8	12.6	19.5	17.6	16.4	(25.4)	
V2	7.2	8.1	10.2	13.2	12.6	13.6	21.0	18.9	17.7	(27.3)	
V3	6.8	7.7	9.6	12.4	11.9	12.8	19.8	17.9	16.7	(25.8)	
H1	8.3	9.4	11.8	15.2	14.6	15.6	24.2	21.8	20.4	(31.5)	
H2	9.2	10.4	13.0	16.8	16.1	17.3	(26.8)	24.2	22.5	(34.9)	
H3	8.9	10.1	12.6	16.3	15.6	16.8	(26.0)	23.4	21.8	(33.8)	
SR1	9.3	10.5	13.1	17.0	16.3	17.5	(27.1)	24.4	22.8	(35.3)	
SR2	10.4	11.8	14.7	19.0	18.3	19.6	(30.4)	(27.4)	(25.5)	(39.5)	
SR3	10.5	11.9	14.9	19.2	18.5	19.8	(30.7)	(27.7)	(25.8)	(40.0)	
PR1	8.8	10.0	12.5	16.1	15.5	16.6	(25.7)	23.2	21.6	(33.5)	
PR2	9.2	10.4	13.0	16.8	16.1	17.3	(26.8)	24.2	22.5	(34.9)	
PR3	*	*	*	*	*	*	*	*	*	*	*
MEAN	8.6	9.8	12.2	15.8	15.2	16.3	(25.2)	22.7	21.2	(32.8)	

* Threshold not predicted; see II.D.

( ) Parentheses enclose predicted distances exceeding our recommended 25-mile effective detection threshold resulting from atmospheric haze. See discussion pages 50-52.

TABLE 13. PREDICTED RELATIVE VISIBILITY THRESHOLDS: R.O.W. DISTANCE IN MILES, AT HIGH-MEDIUM THRESHOLD

Landscape Setting	Right-of-Way Width in Feet										
	80	100	120	140	160	180	220	280	360	480	640
F1	*	*	*	*	*	*	*	*	*	*	*
F2	*	*	*	*	*	*	*	*	*	*	*
F3	*	*	*	*	*	*	*	*	*	*	*
V1	*	*	*	*	*	*	*	*	*	*	*
V2	0.6	0.8	1.0	1.1	1.3	1.4	1.8	2.2	2.9	3.8	5.1
V3	1.0	1.2	1.5	1.7	2.0	2.2	2.7	3.5	4.5	5.9	7.9
H1	*	*	*	*	*	*	*	*	*	*	*
H2	0.7	0.8	1.0	1.2	1.3	1.5	1.8	2.3	3.0	3.9	5.3
H3	1.0	1.2	1.5	1.7	2.0	2.2	2.7	3.5	4.5	6.0	8.0
SR1	*	*	*	*	*	*	*	*	*	*	*
SR2	0.6	0.7	0.9	1.0	1.1	1.3	1.6	2.0	2.6	3.4	4.5
SR3	1.0	1.2	1.5	1.7	1.9	2.2	2.7	3.4	4.4	5.8	7.8
PR1	*	*	*	*	*	*	*	*	*	*	*
PR2	0.8	0.9	1.1	1.3	1.5	1.7	2.1	2.6	3.4	4.5	6.0
PR3	1.2	1.4	1.7	2.0	2.3	2.6	3.2	4.1	5.2	7.0	9.3
MEAN	0.8	1.0	1.2	1.4	1.6	1.8	2.2	2.8	3.6	4.7	6.3

* Threshold not predicted; R.O.W. not visible in grassland, or see II.D.

TABLE 14. PREDICTED RELATIVE VISIBILITY THRESHOLDS: R.O.W. DISTANCE IN MILES, AT MEDIUM-LOW THRESHOLD

Right-of-Way Width in Feet

Landscape Setting	80	100	120	140	160	180	220	280	360	480	640
F1	*	*	*	*	*	*	*	*	*	*	*
F2	*	*	*	*	*	*	*	*	*	*	*
F3	*	*	*	*	*	*	*	*	*	*	*
V1	*	*	*	*	*	*	*	*	*	*	*
V2	1.7	2.1	2.5	2.9	3.4	3.8	4.6	5.9	7.6	10.1	13.4
V3	2.4	3.0	3.6	4.2	4.8	5.4	6.6	8.4	10.8	14.4	19.2
H1	*	*	*	*	*	*	*	*	*	*	*
H2	1.7	2.1	2.6	3.0	3.4	3.9	4.7	6.0	7.8	10.3	13.8
H3	2.6	3.3	3.9	4.6	5.2	5.9	7.2	9.2	11.8	15.7	20.9
SR1	*	*	*	*	*	*	*	*	*	*	*
SR2	1.5	1.9	2.2	2.6	3.0	3.3	4.1	5.2	6.7	8.9	11.9
SR3	2.6	3.2	3.8	4.5	5.1	5.7	7.0	8.9	11.5	15.3	20.4
PR1	*	*	*	*	*	*	*	*	*	*	*
PR2	2.0	2.5	2.9	3.4	3.9	4.4	5.4	6.9	8.9	11.8	15.7
PR3	3.1	3.8	4.6	5.3	6.1	6.8	8.4	10.6	13.7	18.2	24.3
MEAN	2.1	2.6	3.1	3.6	4.1	4.7	5.7	7.2	9.3	12.4	16.5

* Threshold not predicted; R.O.W. not visible in grassland, or see II.D.

TABLE 15. PREDICTED RELATIVE VISIBILITY THRESHOLDS: R.O.W. DISTANCE IN MILES, AT LOW-DETECTION THRESHOLD

Landscape Setting	Right-of-Way Width in Feet: 80	100	120	140	160	180	220	280	360	480	640
F1	*	*	*	*	*	*	*	*	*	*	*
F2	*	*	*	*	*	*	*	*	*	*	*
F3	*	*	*	*	*	*	*	*	*	*	*
V1	*	*	*	*	*	*	*	*	*	*	*
V2	5.1	6.3	7.6	9.8	10.1	11.3	13.9	19.6	22.7	(30.2)	(40.3)
V3	7.7	9.0	10.8	12.6	15.4	16.2	19.8	(25.2)	(36.5)	(43.3)	(57.6)
H1	*	*	*	*	*	*	*	*	*	*	*
H2	5.2	6.4	7.7	9.0	10.3	11.6	15.2	18.1	23.3	(31.0)	(45.3)
H3	7.9	9.8	11.8	13.7	15.7	17.7	21.6	(27.5)	(35.3)	(47.1)	(62.7)
SR1	*	*	*	*	*	*	*	*	*	*	*
SR2	4.5	5.6	6.7	7.8	8.9	11.0	12.3	15.6	20.1	(26.8)	(35.6)
SR3	7.7	9.5	10.5	13.4	15.3	17.2	23.1	(26.8)	(34.5)	(45.9)	(57.1)
PR1	*	*	*	*	*	*	*	*	*	*	*
PR2	5.4	7.4	8.8	10.3	11.8	13.3	16.3	20.7	(26.6)	(35.4)	(47.2)
PR3	9.1	11.4	13.7	15.9	18.2	22.5	(25.1)	(31.9)	(41.0)	(54.7)	(72.8)
MEAN	6.2	7.7	9.3	10.8	12.4	14.0	19.1	21.7	(27.9)	(37.2)	(53.5)

* Threshold not predicted; R.O.W. not visible in grassland, or see II.D.

( ) Parentheses enclose predicted distances exceeding our recommended 25-mile effective detection threshold resulting from atmospheric haze. See discussion pages 50-52.

III D. FINDINGS AND RECOMMENDATIONS

We will present the findings and recommendations of this study under the four headings introduced on page 5:

1) Degree of visibility
2) Type of transmission tower and width of corridor
3) Landscape setting
4) Viewing distance

We are offering a number of recommendations along with these findings, so that the visual effects of transmission facility development and operations may be given full consideration. These recommendations must of course be balanced against other considerations when siting, design, construction and maintenance decisions are made.

1) Degree of Visibility. Visual perception is an interactive process in which both object/setting characteristics and viewer characteristics play important roles. In this study we concentrated on the characteristics of object and setting that contribute to relative visibility. Viewer characteristics were held constant in that we examined the consensual observations of a small number of specially-trained observers, who were set the explicit visual tasks of recognition of transmission facilities and judgment of their relative visibility under optimum viewing conditions.

Our hypothesis that these "expert" judgments of relative visibility would be highly consistent and stable was confirmed by measuring optical characteristics of the visual images of the transmission facilities. These characteristics were apparent size and apparent contrast (ratio of apparent brightness between facility and setting). As described earlier, apparent angular size at observed relative visibility thresholds was very consistent, while apparent contrast above a baseline condition did not increase relative visibility.

Apparent contrast is in part a function of the landscape setting (see below); it can also be manipulated by modifying the light-reflective characteristics of the transmission structure or right-of-way. Since almost all transmission facilities surveyed exceeded the baseline contrast ratio of 1.4:1, we did not make detailed observation of contrast variation. However, below this ratio, decreasing apparent contrast definitely does affect relative visibility. A study of the effectiveness of contrast-reducing treatments could be very useful to the industry, and is recommended. Such a study might have to rely heavily on simulation or small scale sample testing because of the limited number and dispersion of suitable examples.

Apparent angular image size is directly related to object-observer distance and object dimensions. Because tower and R.O.W. dimensions vary widely, angular size provided a much more stable and easily examined body of data than the raw relative visibility threshold distances. Apparent angular size explained much of the variance in these distances. However, landscape setting and facility characteristics were also confirmed as having considerable effect on relative visibility.

With more time and resources, viewer characteristics might also be investigated. Perhaps the most important and difficult parameters to examine would be those connected with the identification threshold. This threshold varies with viewer sensitivity, and its study would require public testing, since any investigator would by definition be precluded from "spontaneously" identifying transmission facilities (see page 5). Despite the difficulties, the identification threshold(s) is of great importance in visual impact assessment and can only be surmised from recognition level studies. The counter-balancing argument is that a recognition level study does not underestimate the visual influence of transmission facilities; relative visibility levels based on the visual task of recognition are "conservative". Moreover, these relative visibility levels can be judged reliably and shown to be related to image characteristics, several of which are capable of being managed.

2) Type of Transmission Tower and Width of Corridor. Relative visibility observations were made on ten different tower configurations and varying right-of-way widths. From analysis of this data, predicted thresholds or breakpoints between relative visibility levels were developed over a complete range of landscape settings for the ten tower types and a range of discrete corridor (right-of-way) widths.

The tower configurations studied were steel lattice tangent structures, plus a wooden H-frame tangent configuration. These include the most frequently encountered structures in the BPA service area, and those most likely to be widely installed in the future. For reasons of time and resources, single-pole "improved appearance" structures were not studied; nor were dead-end structures, which are less standardized in design and fewer (though larger) than the tangent structures. These and other tower-related variables which we attempted to control in our observations are discussed in section II.C. Corridor-related variables are also discussed there; the primary corridor variable studied here was width (as well as landscape setting, discussed below).

Since nine of the ten tower configurations are typically constructed of unpainted galvanized steel, differences in relative visibility are not related to material, but to tower size and design. We used tower height as an index of tower size, both because of the dominant verticality of transmission towers and because of the difficulty of measuring the visual area - apparent and absolute - of an open lattice structure seen at varying angles. While we therefore cannot prove with certainty that apparent height is more closely related to relative visibility than apparent area, the distance data seems to suggest this (see below). Tower design also plays a role in relative visibility, however, and apparent area could well be related to this factor. The tower configuration of greatest relative visibility (see Tower Constraints, Table 7, page 37) is the 500 KV Double Delta which is both wider and heavier in construction than other configurations (Plate 1, facing page 10). Its apparent visual area, though difficult to quantify, is undoubtedly greater than the 800 KV DC tower, similar in height.

Corridor width was treated in a manner analogous to tower height. Apparent angular width was a good predictor of relative visibility, and is directly determined by actual width and distance. A third determinant is angle of view, however, and we attempted to contrast this variable by taking "worst case" observations of corridors in which we were parallel to the distant right-of-way, as in the illustrations of seasonal contrast in Plate 4. In previous work on the PERMITS visual impact model, we found it very difficult to consider angle of view at the corridor location phase. It is a very important consideration, however, as various transmission facility siting guidelines make clear. Probably, angle of view is best considered at the route alternative and centerline design phases when the orientation to various viewing points can be determined.

Landscape setting is also strongly related to corridor visibility; while it will be discussed below, clearing practices and access road construction are right-of-way variables which can strongly affect visibility (pages 13-14). These largely determine the apparent contrast ratio between the corridor and its setting. We controlled for these variables in this study, but their importance should be recognized and reflected in visual management decisions.

3) Landscape Setting. As with the example just mentioned, the visibility of transmission facilities is strongly affected by their relationship to their landscape setting. We identified fifteen landscape setting types, as a combination of five landform types (flatland, valley floor, hillside, secondary ridge and primary ridge) and three landcover patterns (grassland, open forest and closed forest). These settings, described on pages 17-21, are a simplification of the landscape setting classification utilized for the compatibility analysis in our previous PERMITS visual impact model study. Our purpose in this study is the investigation of relative visibility, hence the simplification, but several of the setting factors we identified previously as affecting the visual compatibility of transmission facilities are confirmed here as contributing to relative visibility. These are: background screening by landform or landcover (tower visibility, due to apparent contrast); right-of-way/landcover continuity (right-of-way visibility, due to definition of right-of-way boundary); right-of-way/landcover contrast (right-of-way visibility, due to apparent contrast).

For towers, the significance of the landscape settings appears to be largely the result of the apparent contrast ratio between apparent brightness of tower and setting. Referring to Table 8, towers seen against landform/landcover combinations are generally much less visible than those seen against the sky. In the field, we introduced a distinction between secondary ridge and primary ridge, because of the reversal of the tower-background brightness relationship (dark tower against light sky, versus light tower r against dark background ridge). We later found the distinction unnecessary and less significant than the distinction between towers with immediate backgrounds (on hillsides, or seen against valley walls) and those with distant backgrounds. This is probably due to the absence of visual texture in the sky and on distant ridges. The presence of such texture seems to help reduce the visibility of towers, particularly in open forest conditions, by what has been termed "visual absorption". In addition, it is possible to reduce the apparent contrast ratio between tower and setting below the baseline value in these instances for critical applications; paint or other surface treatments are unlikely to effectively reduce contrast with the sky (page 15).

We experienced difficulty with flatland/open forest (F2) and flatland/closed forest (F3) observations, because of foreground screening. We could only make tower observations within the right-of-way in these conditions, and relative visibility distinctions were very difficult to make due to the "stacking" of towers and the "necklace" effect; the entire right-of-way and line of towers became the visual setting, and visibility appeared to be uniformly high. Therefore observations were not recorded for these zones. Visual impact will largely depend on observer/right-of-way angle of view in these settings and can be dealt with on this basis in route and design phases. In corridor location phases, these settings are likely to be embedded in a larger region and the visibility distances are likely to be set by valley, hill or ridge settings. In the previous study, the flatland settings were identified as the most compatible areas because of the foreground screening effects; views down rights-of-way in F2 or F3 settings are also easily cut off by screen planting and/or centerline shifts in the design phase; this is rightly becoming standard practice.

Corridor visibility is highly related to apparent contrast between the right-of-way surface - soil and vegetation - and the adjacent setting. Observed corridor vegetation was generally grassland or low shrubs, which contrast in color and value with forest settings. In grassland settings, however, the corridor itself is indistinguishable from adjacent lands (with the exception of access road construction and management practice, discussed above and on page 14). Therefore observations of grassland corridors were not collected. In open forest settings, existing natural or man-made openings adjacent to the R.O.W. can materially help in obscuring the linear pattern of the corridor - this is clearly reflected in the corridor visibility constants in Table 9, page 39. The linear pattern may also be modified by clearing practice, for example, varying the distance of clearing and borrowing the form of natural openings. Similarly, the apparent contrast of the right-of-way with its setting can be modified by allowing woody vegetation of the same type as adjacent vegetation to remain or to revegetate. While observed corridor vegetation generally contrasted highly with adjacent settings, we realize the BPA vegetation management program is changing, along the lines just suggested, and corridor appearance will gradually reflect improved practices.

4) Viewing Distance. We have developed evidence that apparent angular size goes far to explain relative visibility judgments, and angular size in turn is related directly to transmission facility viewing distance. With the aim of assisting BPA's visual impact management decisions, we have produced tables of predicted distances for the relative visibility thresholds of the various tower/setting and R.O.W./setting combinations (pages 40-45). As we have explained, these are based on the visual task of "recognition", under optimum viewing conditions. They provide a very conservative basis for visual impact studies, since the public will generally be concerned with the distance at which transmission facilities can be spontaneously identified as major visual elements. However, particular subgroups of the public or particularly critical landuse areas may call for reliance on visibility distances approaching the recognition threshold (which we have also identified as the breakpoint between low visibility and detection).

We have used angular height (or width) as an index of visibility, but have acknowledged that angular area is another possible measure. In an appendix to our previous study we discussed the question of whether visibility decreases as the inverse of distance (angular height) or as the inverse of distance squared (angular area). Based on our field observations, it appears that visibility persists longer than would be predicted by the geometric relationship of either height or area to distance. The proportions between distances at the three relative visiblity thresholds are approximately 1:2.5:10.0. If we assume that visibility is on an equal interval scale (which we cannot demonstrate from this study, but which is also a conservative position in relation to visual impact management decisions), we would predict the proportions between the three threshold distances to be 1:1.4:1.7 for angular area and 1:1.6:3 for angular height. Angular height appears to be closer to the observed proportional relationships but still does not explain the persistence of visibility at very far distances. In our previous study, we used slides to determine visibility distances and found a proportional threshold distance relationship close to that predicted by angular height. However, while those H-M and M-L breakpoints agree well with our more recent field study findings, the L-D threshold for towers was considerably "closer-in" than the present study indicates (this was probably due to loss in film and projector resolution at very small image size).

While this affects our ability to theorize about the shape of a visibility-distance curve, the far-distance recognition threshold is undoubtedly very conservative. We propose the simple generalized distance weighting function in Figure 10 for use with VIEWIT, the threshold distances or turning points to be determined by reference to Tables 10-15 for the predominant landscape setting type within a

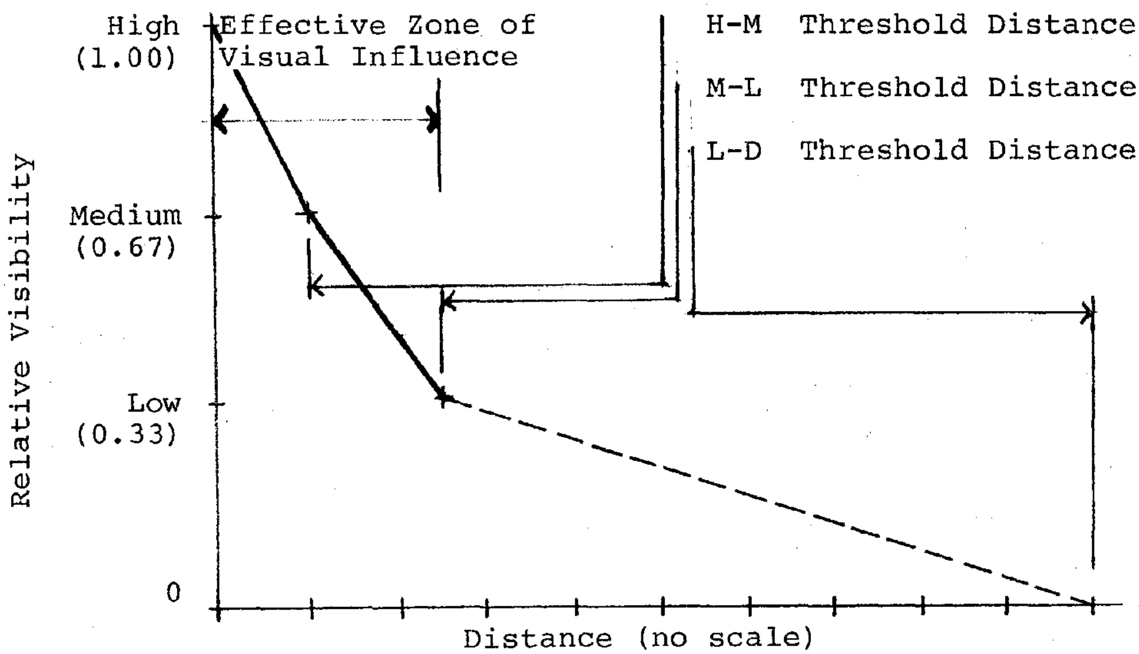


FIGURE 10. VISIBILITY/DISTANCE WEIGHTING FUNCTION

study area, with the "worst case" controlling between-tower and corridor visibility distances. We would recommend using 25 miles as a maximum cutoff distance in all cases, and in general recommend that the medium-low (M-L) threshold be used for computer visibility searches or resource data gathering efforts, as indicated in the graph by a dotted line. We believe this to be adequate because of the distinction between "identification" and "recognition" that we have made above, and believe that this threshold defines the effective zone of transmission line visual influence. If BPA managers wish to be more conservative, the cutoff might be extended by a mile or two past the M-L threshold breakpoint.

We recommend that a 25-mile maximum distance be considered the effective detection threshold for transmission facilities. Beyond that distance, atmospheric haze tends to diminish the apparent contrast ratio between a tower or corridor clearing and its setting, even though its apparent angular size may still be large enough to make it visible. There may be exceptional cases which can extend this detection distance, such as bright snowcover on a broad corridor cut through dark green coniferous forest as viewed on a clear winter day. Under such conditions, clearcuts in the Olympic Mountains are detectable from Seattle, a viewing distance exceeding 40 miles. In our field observations, a 500 KV double stacked tower (176' high) sited on a grassy ridge was detectable at 23 miles, and a 640'-wide corridor cleared through coniferous forest was detectable at 22 miles; beyond these distances, haze tended to diminish the apparent contrasts. Therefore we feel that 25 miles is a conservative estimate for the effective detection threshold of transmission facilities.

In conclusion, this study was brief and relatively informal; the findings are based on examination of a limited number of observations gathered in a total period of a week and a half in one season by four individuals with specialized design training and experience. Having acknowledged these limitations, we can also point out that as far as we are aware, it is among the first efforts to empirically measure, in the field, the relationship between distance and the relative visibility of a class of man-built structures. That this has not been done previously may seem rather odd when one considers the controversies sometimes generated over the visual effects of land use and land development. Logically, a limit analysis of visibility is one of the first steps in identifying the extent and severity of visual impacts.

This study grew out of the development of a methodology for "modeling" the visual impact of transmission facilities. The methodology relies in part on a computer visibility program which requries a specification of potential visibility distance as preliminary input. BPA is to be commended for having substituted this systematic (if not completely rigorous) investigation of visibility distance for the "guesstimate" approach. While this study can be improved on in many ways, it _is_ a step forward. We believe it will be useful to BPA and other electrical utility organizations, and hope it will also be helpful to a wider range of planners, engineers and designers who manage the effects of other elements of our visual environment.

VI. BIBLIOGRAPHY

Blair, William G.E., Brian A. Gray, John A. Hébert and Grant R. Jones, Visual Impact of High Voltage Transmission Facilities in Northern Idaho and Northwestern Montana, for the Bonneville Power Administration, Jones & Jones, Seattle, 1976.

Brindley, G.S., Physiology of the Retina and Visual Pathway, Williams & Wilkins Co., Baltimore, 1960.

Cornsweet, Tom, Visual Perception, Academic Press, New York, 1970.

Daniel, Terry C. and Ron S. Boster, Measuring Scenic Beauty: The Scenic Beauty Estimation Method (draft), USDA Forest Service. Rocky Mountain Forest & Range Experiment Station (undated - 1975?).

Dember, William N., The Psychology of Perception, Holt, Rinehart and Winston, New York, 1964.

Elsner, Gary H., "Computer Management of Recreation Data: Terrain and Usage Studies for Land-Use Planning", Paper presented at Systems Analysis and Forest Resource Management Workshop, Society of American Foresters, Athens, Georgia, 1975 (in press).

Elsner, Gary H., "Visual Impact Assessment of Alternative Land Uses - A Computer Method to Assist in Planning", Paper submitted to 1974 Annual Conference, American Institute of Planners, Denver, 1974 (in press).

Elsner, Gary H. and Michael R. Travis, "The Role of Landscape Analytics in Landscape Planning", Proceedings of Research Applications Workshop, USDA Forest Service, Southeast Forest & Range Experiment Station, 1975 (in press).

Graham, C.H. and Lorrin A. Riggs, et al., Vision and Visual Perception, John Wiley & Sons, Inc., New York, 1965.

Gregory, R.L., The Intelligent Eye, McGraw-Hill Book Co., New York, 1970.

Haber, R.N. and M. Hershenson, The Psychology of Visual Perception, Holt, Rinehart & Winston, Inc., New York, 1973.

Hendrickson, P.L., R.W. Bahl, B.A. Gray and W.S. Maynard, Measuring the Social Attitudes and Aesthetic and Economic Considerations which Influence Transmission Line Routing, Battelle Pacific Northwest Laboratories and Jones & Jones, BNWL-1837, Richland, Washington, 1974.

Iverson, W.D., "Visual Absorption Capability; California Region Supplement to National Forest Landscape Management, Vol. 2, Chapter 1, The Visual Management System", USDA, California Region, San Francisco, 1975.

Jacobs, P. and D. Way, Visual Analysis of Landscape Development, Department of Landscape Architecture, Harvard Graduate School of Design, 1969.

Jones & Jones, "Quantification of Aesthetic Values", in A Technique for Environmental Decision Making Using Quantified Social and Aesthetic Values, with J. B. Burnham, et al., Battelle Pacific Northwest Laboratories, BNWL-1787, Richland, Washington, February 1974.

Jones, G., I. Jones, B. Gray, N. Parker, J. Coe, N. Geitner and J. Burnham, "A Method for the Quantification of Aesthetic Values for Environmental Decision Making," Nuclear Technology, Vol. 25, No. 4, pp. 682-713, April 1975.

Kaufman, Lloyd, Sight and Mind, Oxford University Press, New York, 1974.

Knode, James, "Landscape Management Survey, Northwest Kuiu Island", USDA Forest Service, Tongass National Forest, Juneau, Alaska (undated).

Landscapes Limited, PERMITS METHODOLOGY: Process of Energy Routing to Minimize Impact from Transmission Systems, USDI Bonneville Power Administration, 1974.

Litton, R. Burton, Jr., Forest Landscape Description and Inventories - A Basis for Land Planning and Design, U.S.D.A. Forest Service Research Paper PSW-49, Berkeley, 1968.

PERMITS Methodology - Phase 2, USDI Bonneville Power Administration, 1974.

Stanton, Boles, Maguire & Church, A Report on Appearance Planning, for the Bonneville Power Administration, Portland, 1966.

Steinitz, Frederick and William G.E. Blair, "Visual Quality Model", The Interaction Between Urbanization and Land: Quality and Quantity in Environmental Design; Progress Report for Years One and Two, Proposal for Years Three and Four, N.S.F. Grant GI-32603, Landscape Architecture Research Office, Harvard University, Cambridge, Massachusetts, 1973.

Travis, Elsner, Iverson and Johnson, VIEWIT: Computation of Seen Areas, Slope, and Aspect for Land-Use Planning, Technical Report PSW-11, USDA Forest Service, Pacific Southwest Forest & Range Experiment Station, Berkeley, 1975.

USDA Forest Service, National Forest Landscape Management, Volume 2, Chapter 1, The Visual Management System, USDA, Agriculture Handbook No. 462, 1974.

USDA Forest Service, National Forest Landscape Management, Volume 2, Chapter 2, Utilities, USDA, Agriculture Handbook No. 478, 1975.

USDI Bonneville Power Administration, Final Environmental Statement, General Construction and Maintenance Program, Portland, 1974.

USDI Bureau of Land Management, "Visual Resource Management", BLM Manuals 6300, 6310, and 6320, Washington, D.C., 1975.

U.S. Department of the Interior, U.S. Department of Agriculture, Environmental Criteria for Electric Transmission Systems, Washington, D.C., 1970.

Zube, E.H., D.G. Pitt, and T.W. Anderson, Perception and Measurement of Scenic Resources in the Southern Connecticut River Valley, Northeast Utilities Service Company, Hartford, 1974.