

ELECTRIC TRANSMISSION VISIBILITY AND VISUAL CONTRAST THRESHOLD DISTANCES IN WESTERN LANDSCAPES

Robert G. Sullivan, Jennifer M. Abplanalp, Sherry Lahti,
Kevin J. Beckman, Brian L. Cantwell, and Pamela Richmond^{1,2}

ABSTRACT

The advent of large-scale renewable energy development in the western United States requires the construction of new high-voltage electric transmission facilities to transport electricity from renewable energy generation facilities to load centers. Electric transmission facilities may cause substantial visual impacts to high-value scenic resources. The visibility and potential visual contrasts associated with electric transmission facilities are dependent on complex interactions of a variety of visibility factors, but little systematic study of visibility in real landscape settings has been conducted. In a study sponsored by the U.S. Department of Interior's Bureau of Land Management, field observations of 11 transmission facilities in Idaho, Nevada, and California were made. Study objectives included identifying the maximum distances at which the facilities could be seen and assessing the effect of distance on the visual contrast associated with the facilities. Observed facilities included three 500 kV lattice tower facilities, two 500-kV monopole facilities, five 230-kV H-frame facilities, and one 230-kV monopole facility. A total of 232 observations from 123 study observation points were made in a variety of lighting and weather conditions during 14 days of observations. Skylined facilities with 500-kV lattice towers were visible to the unaided eye at a maximum distance of approximately 17 mi (27 km), and 500-kV lattice tower facilities were visible at or beyond 10 mi (16 km) in 16 observations. The 500-kV lattice tower facilities were judged to be noticeable to casual observers at distances of up to 10 mi (16 km). They also were judged to strongly attract visual attention at distances of up to 3 mi (5 km). The 500-kV monopole facilities were visible at distances up to 11 mi (18 km), with two observations beyond 10 mi (16 km). The facilities were judged to be noticeable to casual observers at 5 mi (8 km), and a major attractant of visual attention at 2.5 mi (4.0 km). Skylined 230-kV H-frame tower facilities were observed at distances up to 8 mi (13 km). Facilities with 230-kV H-frame towers were judged to be noticeable to casual observers at distances of up to 3.5 mi (5.6 km). They were judged to strongly attract visual attention at distances of up to 1.5 mi (2.4 km). The results of this study have important implications for determining appropriate distances from transmission facilities for visual impact assessments, and for the siting of transmission facilities to reduce visual impacts on visually sensitive lands. The authors recommend that the limit of visibility for casual

¹ *Affiliation of authors:* Robert G. Sullivan, Jennifer Abplanalp, Kevin Beckman, Brian Cantwell, and Pamela Richmond, Environmental Science Division, Argonne National Laboratory, Argonne, IL; Sherry Lahti, U.S. Bureau of Land Management.

Address correspondence to: Robert G. Sullivan, Cultural and Visual Resources Team Leader, Environmental Science Division, Argonne National Laboratory, 9700 South Cass Avenue, EVS/240, Argonne, IL 60439; (phone) 630-252-6182; (fax) 630-252-6090; (e-mail) Sullivan@anl.gov.

² Argonne National Laboratory's work was supported by the U.S. Department of the Interior Bureau of Land Management, under interagency agreement, through U.S. Department of Energy contract DEAC02-06CH11357.

observers be used as a minimum distance for visual impact assessments. The recommended minimum distance from the project for visual impact analysis for 500 kV lattice tower facilities is 10 mi (16 km), and a more conservative distance would be 12–13 mi (19–21 km). The recommended minimum distance for impact analysis for 230 kV H-frame tower facilities is 3.5 mi (5.6 km), and a more conservative distance would be 4–5 mi (6–8 km). Beyond the minimum distances specified, the facilities would not likely be noticed by casual viewers. Beyond the more conservative distances specified, the facilities would not likely be seen, except in unusual circumstances.

ELECTRIC TRANSMISSION VISIBILITY AND VISUAL CONTRAST THRESHOLD DISTANCES IN WESTERN LANDSCAPES

1 Introduction

The increasing demand for energy and the expansion of utility-scale renewable energy in the United States necessitates the construction and operation of new high-voltage electric transmission facilities and the upgrading of existing transmission facilities (Glicksman 2013). In part, new and upgraded transmission is needed to transport electricity from the renewable energy generation facilities to the electrical grid, and eventually to load centers that may be located hundreds or thousands of miles from the generation facilities.

Transmission facilities are visually conspicuous linear features that can extend for many miles across open western landscapes. The large size of transmission towers, their strongly vertical visual character, and obviously non-natural geometry may contrast strongly with surrounding more natural-appearing landscapes. As a result, in some settings, transmission facilities may be visible for long distances and are a source of visual impacts. Opposition from the public and other stakeholders to the construction or upgrading of transmission facilities based on potential visual impacts is a routine occurrence, and, in some cases, delays transmission projects, requires more expensive alternate routes to be selected, or results in expensive litigation (Furby et al. 1988).

The U.S. Department of the Interior Bureau of Land Management (BLM) faces increasing interest in the use of BLM-administered public lands for transmission rights-of-way (ROWs), and continues to conduct studies necessary to evaluate and process an expanding number of applications for transmission ROWs. The BLM must ensure that proposed projects meet all applicable environmental laws and regulations. A programmatic environmental impact

statement (PEIS) pertaining to the authorization of energy ROW projects (for both electric and non-electric energy transmission) on BLM- and other federally administered lands was completed in 2008. The *Programmatic Environmental Impact Statement for the Designation of Energy Corridors on Federal Land in the 11 Western States* stated that in some circumstances, the visual impacts resulting from electric transmission facilities can be large, and that the presence of transmission facilities may also impact the visual settings of cultural resources (DOE and DOI 2008).

Electric transmission facilities involve large and very tall tower structures, and the facilities can be hundreds of miles long, stretching completely across the field of view in some viewing situations, particularly where topography and vegetation are not of sufficient height to screen long distance views. The visibility of transmission facilities in the landscape depends on the effects of *visibility factors*, that is, the set of situational variables that affect the visual perception of objects in the landscape.

Visibility factors include screening elements such as landforms, vegetation, and structures, as well as earth curvature and atmospheric refraction; viewer characteristics; lighting; atmospheric conditions; viewing geometry (the spatial relationship between the viewer and viewed object); the visual characteristics of the viewed object; the visual backdrop of the viewed object (e.g., sky, ground, or vegetation); and the distance between the viewer and the viewed object. Interactions among these visibility factors are extremely important to determining the actual visibility of an object, such as a transmission facility, and some of the factors are highly variable. Visibility factors are discussed in detail in BLM's renewable energy visual impact mitigation publication, *Best Management Practices for Reducing Visual Impacts of Renewable Energy Facilities* (BLM 2013).

A visibility factor of particular importance to accurate optimal facility siting and also to accurate visual impact assessment (VIA) is distance. Optimal siting requires an understanding of how the appearance of the proposed facility and the nature and magnitude of the visual contrasts it would create would vary with distance. A critical component of a high-quality VIA is analyzing the impacts over the spatial extent of the area in which impacts occur. However, there is no standard distance for analysis of impacts for transmission projects, and given that the tower types and sizes vary, as do the number of conductors, the types of insulators, and so forth, it is unlikely that one distance for analyses would be appropriate.

The only major published study to examine the issue of transmission facility visibility and determine appropriate distances for impact analyses based on field observations was conducted by Jones and Jones for Bonneville Power Administration (1976). The study assessed the visibility of high-voltage transmission line visibility in the Pacific Northwest. This study was conducted primarily in forested landscapes in the state of Washington. No studies have ever examined these issues in the context of the more open shrublands, grasslands, and deserts common to BLM-administered lands.

The field study discussed in this paper used trained observers to systematically evaluate visibility and visual contrast threshold distances for 500-kV and 230-kV transmission lines using lattice, monopole, or H-frame towers on lands in the western United States. The observed facilities were located in Idaho, Nevada, and California on lands that are generally similar in landscape character to many BLM-administered lands, (i.e., scrublands and grasslands with long sightlines and little screening vegetation). The study examined the visual contrasts associated with the various transmission facilities in a variety of weather and lighting conditions. The purpose of the study was to improve the understanding of the effect of distance and other

variables on the visual contrasts associated with transmission facilities. The study also provided information that can be used to establish *visual contrast threshold distances* for use in conducting VIAs. Visual contrast threshold distances are specified distances at which the visual contrast caused by a facility reaches a specified magnitude, such as the distance at which the project first becomes visible, or the distance at which it strongly attracts and holds visual attention. Visual contrast threshold distances can be used to determine the spatial extent of the area to be included in a VIA for a proposed project.

The study consisted of three main phases:

1. **Maximum transmission visibility determination:** In this phase, trained observers determined the maximum distances at which 500-kV and 230-kV transmission facilities could be seen under favorable viewing conditions.
2. **Facility visibility rating:** In this phase, trained observers judged the degree of visibility of the various types of transmission facilities under a variety of weather and lighting conditions at distances ranging from 0.1 mi (0.2 km) to beyond 17 mi (27 km), and photographed them.
3. **Database compilation and data analysis:** In this phase, data collected from Phase 2 were entered into a database and compiled into a Google Earth KMZ (Keyhole Markup language Zipped) file for data analysis purposes, and the data were analyzed to determine visual contrast threshold distances for the various types of transmission facilities observed in the study.

A full report for the study is available by contacting the lead author at sullivan@anl.gov.

The full report has a complete set of facility maps, additional figures, and a more complete discussion of the study results.

2 Literature Review

The impact of visual thresholds (e.g., “minimal quantity that can be perceived; a boundary one crosses from not detecting to detecting”) was tested by Shang and Bishop (2000) using computer-simulated images. They developed a systematic procedure for the assessment of three visual thresholds, including detection (i.e., is it visible?), recognition (i.e., can the object be identified?), and visual impact (i.e., what effect does the object have?). Their study was based upon concepts found within the field of psychophysics, in which the visual threshold is the minimal quantity that can be perceived. The thresholds were analyzed through controlled slide-viewing using computer-simulated images with modified visual attributes such as size, contrast, object type, and landscape type. While the study did not specifically address distance thresholds, the authors provided a basis for understanding the impact of contrast on an object’s visibility. Contrast for this study was defined as a measurement of target luminance relative to the background luminance.

It is well established that distance is a key variable that determines the magnitude of potential visual impacts from a proposed development (Bishop and Miller 2007; Hull and Bishop 1988; Jones and Jones 1976). Benson (2005) discusses distance as a visibility factor affecting the visibility of wind energy facilities. He conducted field observations of wind facilities to ascertain whether the distances used for wind facility impact assessments in VIAs were sufficiently long to reflect the actual visibility of built projects in the real landscape (University of Newcastle 2002).

Building on these studies, and particularly the work of Benson (University of Newcastle 2002), Sullivan et al. (2012) conducted an extensive field study for the BLM of wind facility visibility in the short grass prairies of Wyoming and Colorado. For this project, the authors developed a six-point visibility scale for rating the visibility of operating wind facilities by

trained observers. Several hundred observations were made of five wind facilities in various lighting and weather conditions, and with a variety of visual backdrops for the facilities. The study examined the distance-visibility relationship for the various wind facilities (i.e., the degree to which increasing view distance decreased the visibility of wind turbines in the landscape) and also attempted to measure the maximum distance the facilities could be seen in optimal viewing conditions. The study identified visual contrast threshold distances for the observed wind facilities that served as the basis for recommendations for distances to be used in wind facility VIAs for similarly sized facilities in that region. The transmission facility visibility study reported here uses a very similar approach for the determination of visibility and visual contrast threshold distances for transmission facilities in non-forested lands in the western United States.

Published literature specifically addressing the *visibility* (rather than public perception) of transmission facilities is limited, although studies examining public perception of visual impacts of transmission facilities have considered important visibility issues, including the effects of distance on visibility. Bishop et al. (1985) used visual simulations of transmission towers to assess the impacts of tower design, viewing distance, and landscape setting on perceived visual impacts from transmission facilities. The distances used in the study were relatively short: 125 m (410 ft), 250 m (820 ft), and 500 m (1,640 ft). The study found that perceived impacts decreased with distance, but it did not discuss the effect of distance on the actual visibility of the towers.

Hull and Bishop (1988) examined the relationship of distance to scenic impact for 500-kV lattice towers at distances of 100 m to 5 km (328 ft to 3.1 mi) in three landscape types. The study compared observers' ratings of scenic beauty with and without the towers in view, using a 10-point rating scale. Similarly to Bishop et al.'s 1985 study, results indicated that scenic

impact decreased as the distance to the towers increased, and that the rate of change varied by landscape type.

In Jones and Jones' field-based study examining the visibility of transmission facilities in closed forest, open forest, and grassland settings in the Pacific Northwest, high-voltage electric transmission towers were found to be visible for longer distances than the BLM's 15-mi (24-km) background distance zone, at least in the Pacific Northwest, with cleared ROWs in forested areas shown to be visible as far as 40 mi (64 km) (Jones and Jones 1976). Jones and Jones recommended that visual impact analyses for transmission analyses use distances ranging from 1.4 to 8.2 mi (2.3 to 13.2 km), depending on the tower size and landscape setting for transmission facilities not requiring cleared ROWs. Far larger areas of analysis were recommended for transmission facilities with cleared ROWs, ranging from 1.5 mi (2.4 km) for an 80-ft (24-m) ROW to 24.3 mi (39.1 km) for a 640-ft (195-m) ROW. These distances were projections based on limited observations of transmissions facilities primarily in forested and mountainous landscapes, unlike most BLM-administered lands. The study described here seeks to use the methodology employed by Sullivan et al. (2012) for the wind energy visual contrast threshold distance analysis to derive recommended areas of visual impact analysis for selected transmission facility types in non-forested landscapes typical of BLM-administered lands in the western United States.

3 Methodology

The methodology used for the study is very similar to that employed for Sullivan et al.'s study of wind turbine visibility in western landscapes conducted for BLM in 2011 to 2012 (Sullivan et al. 2012). The methodology for this study employed:

1. Field-based observations of different electric transmission facilities in different landscape settings from distances ranging from 0.1 mi (0.2 km) to beyond 17 mi, (27 km), during which the visual characteristics of the facilities were recorded, photographs of the facilities taken, and the visibility of the facilities was rated; and
2. Geospatial analyses that measured the maximum limits of visibility of the transmission facilities, correlated the changes in visibility ratings of the facilities with changes in the viewing distance under a variety of lighting and atmospheric conditions, and determined at which distances various facility components became visible.

The on-site fieldwork for this study was conducted in four fieldwork exercises totaling 16 days; most observations were conducted in April, June, July, and August of 2013, with additional brief observations conducted in January 2013. The January 2013 fieldwork primarily consisted of determining the maximum limits of visibility of a 500-kV lattice tower facility and testing the data collection forms. The remainder of the fieldwork consisted of recording sources of visual contrast for the facilities, rating the visibility of the facilities, and determining the maximum limits of facility visibility. Fieldwork participants included three Argonne National Laboratory (Argonne) employees, with two employees per trip. The backgrounds of the participants varied, including a landscape architect, an archaeologist, and a graduate student in ecology. Each observation was made by two observers.

Eleven transmission facilities were observed in the course of the study. Table 1 is a summary of 10 of the facilities. An additional four observations (2% of the total number of observations) were made of an unidentified 230-kV H-frame line in Southern Idaho. The facility was identified in the geographical information system (GIS) and on aerial photos, but could not be accessed to verify materials construction.

Table 1. Transmission Facilities Observed in the Study						
Facility Name^a	Power Rating	Number of Circuits	Tower Type	Location	Number of Observations	Percentage of All Observations
Midpoint-Summer Lake	500 kV	Single	Galvanized Lattice	Southern Idaho	113	49%
Marketplace-Adelanto	500 kV	Single	Galvanized Lattice	Southern California	16	7%
McCullough-Victorville	500 kV	Single	Galvanized Lattice	Southern California	7	3%
Antelope	500 kV	Single	Galvanized Monopole	Southern California	22	9%
North Las Vegas	500 kV	Single	Galvanized Monopole	Southern Nevada	25	11%
Bighorn	230 kV	Double	Galvanized Monopole	Southern California	11	5%
American Falls – Atomic City	230 kV	Single	Corten H-Frame	Southern Idaho	10	4%
Pocatello	230 kV	Single	Wooden H-Frame	Southern Idaho	18	8%
Glenn’s Ferry	230 kV	Single	Corten H-Frame	Southern Idaho	8	3%
Mountain Home	230 kV	Single	Corten H-Frame	Southern Idaho	4	2%

^a By convention, transmission lines are named by combining the names of the substations at either end of the transmission line. This convention is not always followed, however, and names for the 230-kV lines could not be determined. In this report, the names of the lines are either those that are publicly available, or they are constructed names using a substation the line, for example: “Antelope 500-kV line,” or a nearby town, for example, “Pocatello 230-kV line.”

During the three contrast threshold distance assessment field trips in April, June, and July–August of 2013, a total of 232 daytime observations were made from 123 locations (referred to as study observation points [SOPs]).

The towers for all facilities in the study either had surface treatments that reduced reflectivity, or had weathered sufficiently that the surfaces did not produce glinting or glare.

Figures 1 through 4 show examples of each type of transmission tower observed in the study.

For each observation, single-frame photographs were taken of the transmission facility at a variety of focal lengths. For many locations, panoramic sequences were also taken. Data recorded included descriptions of the location of the viewpoint; weather, general lighting, and



Figure 1. Midpoint-Summer Lake 500-kV Lattice Transmission Tower



Figure 2. North Las Vegas 500-kV Monopole Transmission Tower



Figure 3. Mountain Home 230-kV H-frame Transmission Tower



Figure 4. Bighorn 230-kV Monopole Transmission Tower

visibility conditions; and the backdrop content and color. In addition, observers collected information about the solar azimuth and elevation, the shading and/or sunlight on the towers, and the overall lighting angle, as seen from the viewer's position.

Visibility assessments for the facilities were also made for each observation in order to assess the effects of distance and atmospheric variables on the visibility and visual contrast levels of the observed transmission facilities. The visibility assessments consist of numeric ratings on a scale of 1 to 6, scored on the visibility of a transmission facility within its landscape setting and for the weather and lighting conditions at the time of the observation. The visibility rating is a judgment made by the observer by comparing the transmission facility in view with language described on a Visibility Rating Form that accounts for the visual characteristics of the transmission facility appropriate to each rating level. Photographs were not used for visibility ratings; the ratings were conducted through naked-eye observations of the facilities in the field. The study included a total of 464 individual ratings of facility visibility.

The rating scale is loosely based on the BLM's Visual Resource Management VRM system (BLM 1984), specifically, the Visual Contrast Rating (BLM 1986a), which is used to predict the visual contrast of a proposed project with the surrounding natural landscape. The Visibility Rating Form was customized for use with existing, rather than proposed, facilities. The form also included several open-ended questions soliciting information from the observer to justify, explain, and/or expand upon the numeric visibility rating. The visibility ratings and instructions used by the observers to rate visibility are reproduced in Table 2.

Visibility ratings of "1" or "2" would generally correspond to very low levels of visual contrast in the framework of the Visual Contrast Rating; ratings of "3" or "4" would correspond

Table 2. Visibility Rating Form Instructions Used To Rate Visibility of Transmission Facilities	
Visibility Rating	Description
Visibility Level 1: <i>Visible only after extended, close viewing; otherwise invisible.</i>	An object/phenomenon that is near the extreme limit of visibility. It could not be seen by a person who was not aware of it in advance and looking for it. Even under those circumstances, the object can only be seen after looking at it closely for an extended period of time.
Visibility Level 2: <i>Visible when scanning in general direction of study subject; otherwise likely to be missed by casual observer.</i>	An object/phenomenon that is very small and/or faint, but when the observer is scanning the horizon or looking more closely at an area can be detected without extended viewing. It could sometimes be noticed by a casual observer; however, most people would not notice it without some active looking.
Visibility Level 3: <i>Visible after brief glance in general direction of study subject and unlikely to be missed by casual observer.</i>	An object/phenomenon that can be easily detected after a brief look and would be visible to most casual observers, but without sufficient size or contrast to compete with major landscape elements.
Visibility Level 4: <i>Plainly visible, could not be missed by casual observer, but does not strongly attract visual attention, or dominate view because of apparent size, for views in general direction of study subject.</i>	An object/phenomenon that is obvious and with sufficient size or contrast to compete with other landscape elements, but with insufficient visual contrast to strongly attract visual attention and insufficient size to occupy most of the observer's visual field.
Visibility Level 5: <i>Strongly attracts visual attention of views in general direction of study subject. Attention may be drawn by strong contrast in form, line, color, or texture, luminance, or motion.</i>	An object/phenomenon that is not of large size, but that contrasts with the surrounding landscape elements so strongly that it is a major focus of visual attention, drawing viewer attention immediately and tending to hold viewer attention. In addition to strong contrasts in form, line, color, and texture, bright light sources (such as lighting and reflections) and moving objects associated with the study subject may contribute substantially to drawing viewer attention. The visual prominence of the study subject interferes noticeably with views of nearby landscape elements.
Visibility Level 6: <i>Dominates view because study subject fills most of visual field for views in its general direction. Strong contrasts in form, line, color, texture, luminance, or motion may contribute to view dominance.</i>	An object/phenomenon with strong visual contrasts that is of such large size that it occupies most of the visual field, and views of it cannot be avoided except by turning the head more than 45 degrees from a direct view of the object. The object/phenomenon is the major focus of visual attention, and its large apparent size is a major factor in its view dominance. In addition to size, contrasts in form, line, color, and texture, bright light sources and moving objects associated with the study subject may contribute substantially to drawing viewer attention. The visual prominence of the study subject detracts noticeably from views of other landscape elements.

to low to moderate levels of visual contrast; and ratings of “5” or “6” would correspond to high levels of visual contrast. There is not necessarily a direct correspondence between the visibility ratings and conformance with VRM class management objectives. This is because the language

used to define visibility is not identical to that used to describe conformance with VRM class management objectives in the visual contrast rating process.

New observers were trained in the field, with a brief discussion of the purpose of the form. For the first few ratings a user performed, ratings and the rationales for assigning a rating were discussed in order to ensure that the instructions were clear. Raters, however, were not told that their ratings were high or low, correct or incorrect, or otherwise coached or instructed about how to conduct visibility ratings.

Each observer completed a separate Visibility Rating Form for each observation, rating the visibility and answering the questions for each form independently without consulting the other observers. Observers could discuss their ratings after observations, but they were not allowed to change the ratings once the form was completed. Observers were asked to review the visibility rating instructions for every observation.

Upon completion of each trip, information from the data forms was entered into a searchable database developed for the study. The location of each observation was identified and matched to the corresponding SOP. Notes also were entered to provide an electronic copy of the field notes. Photographs were selected from various focal lengths and added to each record. The data were also exported to a KMZ file for use in Google Earth. The database provides a means to search data from each of the three main field trips and to make comparisons across the trips and locations.

Using the database, a GIS program, and other software tools, several types of calculations were made to enhance or correct the data collected in the field. These included the following:

1. **Distance:** This value was calculated using a GIS program. Because transmission lines are linear features that may be at any angle with respect to the observer's line of sight, the

distance from the observer of the transmission as a whole varies. For this reason, reference towers were identified for the purpose of distance measurements, photography, and visibility assessments. The observers centered their views on the selected reference tower when assessing visibility; the facility photographs were also centered on the reference tower, and distance to the facility was measured as a straight line toward the reference tower. In order to reduce the variance in the distance measurements, most views of transmission facilities were made perpendicular to the lines or nearly so, but for various reasons, this was not always possible. Visibility assessments were made for the transmission facility as a whole, not just the reference tower and its immediate vicinity. Thus, in some cases, observers turned their heads to take in the whole visible line, and therefore might be looking at sections of the line that were at significantly different distances than the reference tower.

2. **Solar Azimuth:** The solar azimuth was determined by inputting the date, time, and location for the observation into a web-based application provided by the National Oceanic and Atmospheric Administration (NOAA) (<http://www.esrl.noaa.gov/gmd/grad/solcalc/>).
3. **Bearing:** This value was calculated using the GIS. The bearing represents the direction in which the observation was made, that is, the direction of the reference tower.
4. **Lighting angle:** The lighting angle for each observation was calculated to indicate what the lighting conditions would have been for the transmission facility on the basis of the geometry of the sun and the location of the reference tower. This calculation was derived from the values for the solar azimuth and the bearing.

5. **Average Visibility Rating:** The average visibility rating (AVR) was calculated by averaging the ratings from the two viewers for each observation. The database querying capability was used to extract subsets of the observations for analysis.

Study Limitations

A field study of this nature has numerous limitations, which must be considered when interpreting any results. Generally, they can be classified as:

1. Limitations related to the facilities themselves;
2. The inherent complexity of the factors involved in visibility of objects in real landscape settings;
3. Limitations related to the study methodology; and
4. The inherent variability in ratings between observers because of their differing perceptions of the facilities and other landscape elements.

First, while there is nothing unusual about the transmission facilities that were selected for the study, they represent a very small sample of the many transmission facilities that exist in the West. There are many variations in tower size and details, and the number and location of conductors (relative to the tower structure). As noted, there are also variations in the materials used and their coatings that affect reflectivity. Because weathering dulls the reflectivity metal surfaces of towers and conductors, newer facilities might cause greater visual contrast than the facilities observed in this study. Also, in some cases, one or more additional transmission facilities were located in close proximity to the facility that was the focus of the observation. While observers consciously tried to ignore the other facilities, the other facilities may have affected the visibility rating for the observed facility, especially at longer distances, where it might be hard to distinguish one facility from another.

Second, distance is only one of many factors that affect perceived visual contrast of an object in a landscape setting. As noted in Section 1, numerous factors may reduce or increase the visibility of an object in the landscape, and there are complex interactions among the factors. Because transmission line visibility depends so heavily on the contrast of the towers and conductors with the visual backdrop, it is likely that different landscape types would result in visibility ratings that would differ from those observed here, even if other situational variables could be controlled.

Third, there are factors relating to the methodology used that might affect the results. The visibility ratings are not quantitative measurements but are based on professional judgments, using particular language that may have introduced inaccuracies into the ratings. Although much of the other data collected about the observations were more factual or quantitative in nature, some items involved judgments (e.g., contrast between the transmission facilities and background) which may have varied slightly from individual to individual. Although the observations were made on many different days, it is possible that the full range of possible viewing conditions was not represented in the observations. Because of the large number of observation points and the long distances between them, some locations had more observations than others, and not all points had observations made at the same times of day. The ratings at some observation points were undoubtedly affected by surrounding landscape elements in the foreground and middle ground viewing distances that were unique to the viewpoint and could distort the distance/contrast relationship. Finally, the observations involved only two observers, clearly less than optimal, but necessitated by practical limitations.

Aside from the 500-kV lattice poles, the number of observations for each facility type was relatively small, which could affect the reliability of the ratings.

There are also limitations attributable to the observers themselves. Despite an effort to make the visibility rating language relatively simple, objective, and focused more on visibility and contrast issues than on emotional reactions to what was seen, the language may have been interpreted slightly differently by the different observers, and even if it had not been, would still yield visibility ratings that vary somewhat between individuals. By the end of the study, the observers had made hundreds of observations, and their visibility assessments may have changed because of the repeated exposure. Finally, although all of the observers had “normal” vision, visual acuity did vary slightly between the observers, although this generally seemed only to affect observations at very long distances, generally near the limits of visibility.

These limitations are important and must be considered when interpreting the results presented below and when attempting to generalize the results or apply them to different landscape settings or facility types. Nonetheless, the results are based on a significant number of observations using a consistent approach to the individual ratings. There was good agreement between the individual ratings, likely a result, in part, of the relatively simple and straightforward rating approach and descriptions of the visibility levels.

4 Results

Phase 1: Sources of Visual Contrast and Maximum Visibility Distance Analysis

Sources of Visual Contrast

Transmission Towers

At all observation distances, the transmission towers were the major source of visual contrast. The height of the towers and their upright forms create strong vertical line contrasts that

may be visible at long distances, especially in treeless landscapes, and particularly when the towers are placed on elevated landforms that make them silhouetted against the sky, often referred to as “skylining.” In this study, beyond a distance of 7 mi (11 km), only the towers were ever visible.

Lattice Members

At shorter distances, the individual lattice members of lattice towers became visible, and at the shortest distances were plainly visible, especially when silhouetted against a uniform bright sky backdrop. The complex rectilinear geometry of the lattice work contributed substantially to visual contrast at short distances. The farthest distance at which individual lattice members were visible was 7 mi (11 km), though typically they were visible only at substantially shorter distances.

Conductors

At shorter distances, the individual conductors (cables) became visible, and, similarly to the lattice members, at the shortest distances were plainly visible, especially when silhouetted against a uniform bright sky backdrop. They rarely contributed strongly to visual contrast; however, in certain lighting situations, they became conspicuous, as shown in Figure 5. The farthest distance at which individual conductors were visible was 7 mi (11 km), though typically they were visible only at substantially shorter distances.



Figure 5. In Certain Lighting Situations, Conductors Can Add Substantially to Visual Contrast of Transmission Facilities

Glass Insulators

Several types of insulators are available for use in transmission facilities. If translucent glass insulators are used, in certain lighting conditions they may refract light strongly, such that they appear very bright and can constitute strong sources of visual contrast especially at distances of less than a few miles. This effect is shown in Figure 6. The farthest distance at which translucent glass insulators were visible was almost 5 mi (8 km), though typically they were visible only at substantially shorter distances.

Maximum Visibility Distance Analysis

In this study, the maximum distance at which a transmission facility was visible to the unaided eye was approximately 17.2 mi (27.7 km). In this observation, lattice transmission towers for a 500-kV line were visible on the western slope of a ridge 1.25 mi (2.0 km) east of



Figure 6. Translucent Glass Insulators Can Be Strong Sources of Visual Contrast

U.S. 95 in the Eldorado Valley near Henderson, Nevada, from a viewpoint 17.2 mi (27.7 km) north of the line on East Horizon Pkwy/Gas Line Road, in an undeveloped area south of Henderson, Nevada. The observation was made on January 30, 2013, at 10:00 a.m. under sunny conditions. The observation location was obtained using global positioning system (GPS) devices. The line location and identity were confirmed using a GIS, remotely sensed imagery, Google Earth software, and commercially available transmission infrastructure geospatial data.

For this observation, only the towers were visible, skylined on the distant ridge. The towers were judged to be near the limit of visibility. They appeared tiny and would not likely be visible to a casual observer; however, in this case, the observers were scanning the landscape closely and specifically looking for transmission facilities. At this distance, only a very short vertical line contrast was visible for each tower, and thus the towers were not recognizable as transmission towers per se. The observers judged that the facility might have been visible at slightly greater distances than 17.2 mi (27.7 km); however, the circumstances precluded

observation from greater distances. In total, 500-kV lattice towers were observed beyond 10 mi (16 km) in 16 separate observations. While appearing very small at these long distances, as will be discussed below, for a number of observations beyond 10 mi (16 km), the facilities were judged to be plainly visible after only a brief glance in the direction of the facility.

Facilities using 500-kV monopole towers were observed up to 11.1 mi (17.9 km) and may have been visible from greater distances. Topography and access restrictions not only prevented skylined views that may have resulted in greater visibility distances, but they also prevented visibility assessments from greater distances. In total, 500-kV monopole towers were observed beyond 10 mi (16 km) in two separate observations. They were judged not likely to be visible to casual observers beyond 8 mi (13 km).

Facilities using 230-kV H-frame towers were observed up to 8.0 mi (12.9 km) and may have been visible from greater distances; however, they were judged to be near the limit of visibility at 8.0 mi (12.9 km). In total, 230-kV H-frame towers were observed beyond 5 mi (8 km) in nine separate observations. They were judged not likely to be visible to casual observers beyond 3.5 mi (5.6 km).

Facilities using 230-kV monopole towers were observed up to 3.5 mi (5.6 km) and definitely would have been visible from greater distances; topography and access restrictions not only prevented skylined views that may have resulted in greater visibility distances, but they also prevented visibility assessments from greater distances. They were judged likely to be visible to casual observers at the maximum observed distance of 2.5 mi (4.0 km).

Phase 2: Facility Visibility Rating

The visibility rating portion of this study utilized a combination of field-based observations of the various transmission facilities and geospatial analyses to determine the approximate distances at which the visual contrasts associated with the transmission facilities reach levels that have significance for conducting VIAs. The facilities were observed under a variety of lighting and atmospheric conditions in order to determine, to the extent possible, what effect these variables might have on visibility ratings and threshold distances. At each observation point, basic information about the observation point, the weather, lighting conditions, and other situational variables was recorded. The facilities were photographed, and a visibility assessment was conducted by each observer independently, based not on photographs but on the view of the facility from the field at the time of the observation.

Visibility Rating Trends

500-kV Lattice Tower Facilities

Figure 7 is a graph of the relationship between distance and AVR for the Midpoint-Summer Lake 500-kV lattice tower transmission facility observations. As was the case for all transmission tower types, AVRs varied for a given distance but clearly decreased as the distance from the SOP to the facility increased.

Figure 7 shows a high degree of variability in the AVRs for a given distance, but with AVRs reaching “5” (major attractant of visual attention) at distances up to 3 mi (5 km) and reaching “3” (easily visible after a brief glance) at distances of up to 10 mi (16 km). As discussed above, 500-kV lattice tower facilities were visible up to 17 mi (27 km) (not shown in Figure 7).

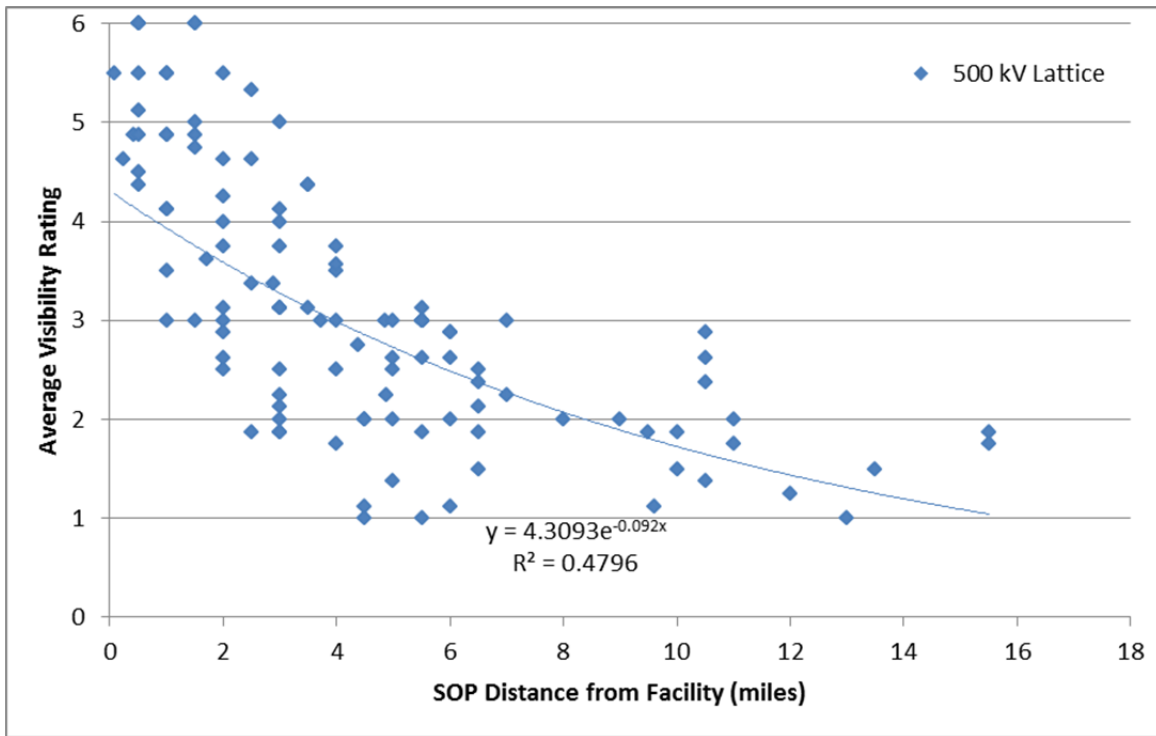


Figure 7. Average Visibility Ratings by Distance for Primary 500-kV Lattice Tower Transmission Facility

Beyond 11 mi (18 km), however, they were judged to be too small and faint to be noticed by most casual observers.

Using the data collected for lighting direction and contrast with the backdrop, analyses were run to try to ascertain whether frontlighting or backlighting of the facilities or the backdrop (sky or ground) significantly affected the AVR. Both visibility factors would likely affect the contrast of the facility with the backdrop. Because frontlighting (and to a lesser extent sidelighting) would make the tower lattice members appear brighter, it might be expected that frontlit/sidelit lattice towers would be less visible against a sky backdrop, but more visible against ground backdrops, which are almost always darker than the sky. Conversely, it might be expected that backlit (silhouetted) towers would be more visible against sky backdrops, and less visible against ground backdrops. The study data show little difference in AVR for frontlit

towers against sky or ground backdrops (as shown in Figure 8); frontlit towers against sky backdrops actually rated slightly more visible (on average) than those against ground backdrops. A more significant difference between backlit towers against sky and ground backdrops is shown in Figure 9, but only at shorter distances.

A possible explanation for the similarity in ratings for frontlit lattice towers against sky and ground backdrops may be that, in general, the sky is so much brighter than the towers (even when the towers are frontlit) that the towers always appear silhouetted against the sky, thus appearing similar to backlit towers, that is, higher contrast against a sky backdrop. In both cases, AVR varies more widely against ground backdrops than sky backdrops; this may be a result of

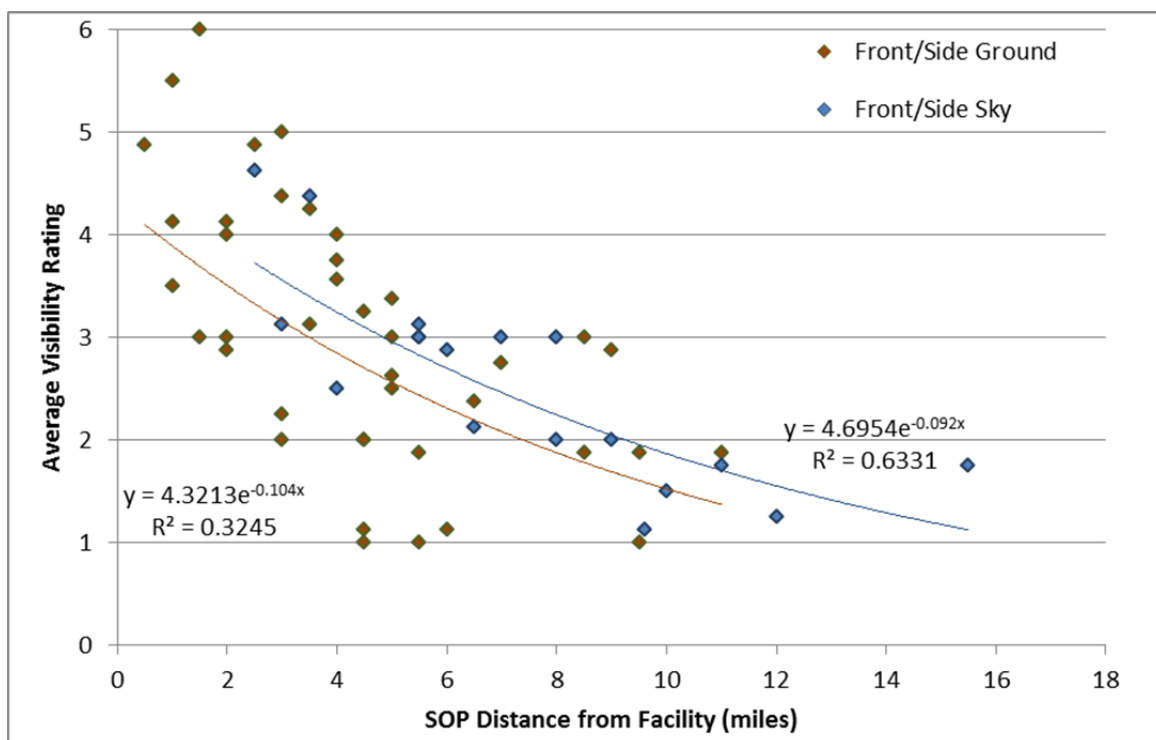


Figure 8. Average Visibility Ratings for Front- and Side-lit 500-kV Lattice Towers as a Function of Distance and Backdrop Type

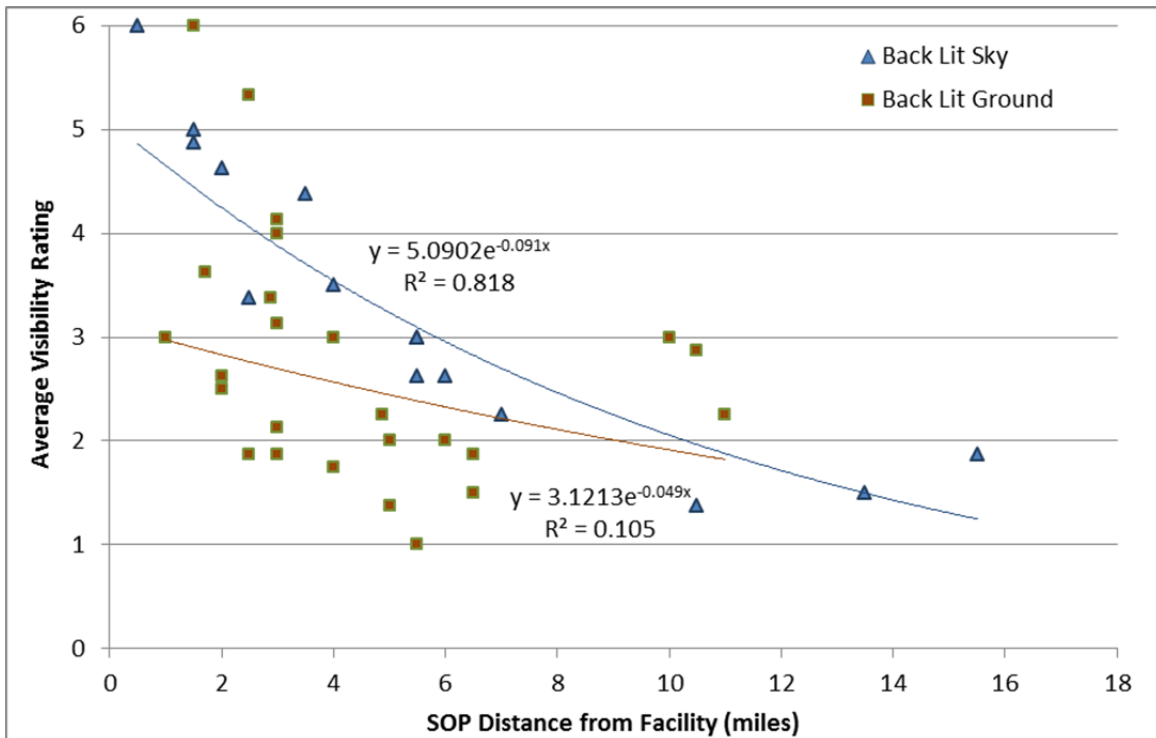


Figure 9. Average Visibility Ratings for Backlit 500-kV Lattice Towers as a Function of Distance and Backdrop Type

the inherent greater variability (due to color and texture contrast) of ground backdrops relative to sky backdrops.

Plotting 500-kV lattice tower facility AVRs against backdrop contrast rating (a high/medium/low judgment by one of the observers) as a function of distance suggests that a more general assessment of tower/backdrop contrast level correlates better with AVRs than lighting angle and specific backdrop type, as shown in Figure 10. As would be expected, Figure 10 shows that contrast ratings are generally higher as the distance between the observer and the facility decreases, but even at shorter distances, low contrast is associated with low AVRs. It is also interesting to note that AVRs for observations rated as having low contrast between the towers and background rarely exceeded “3”; that is, they were easily

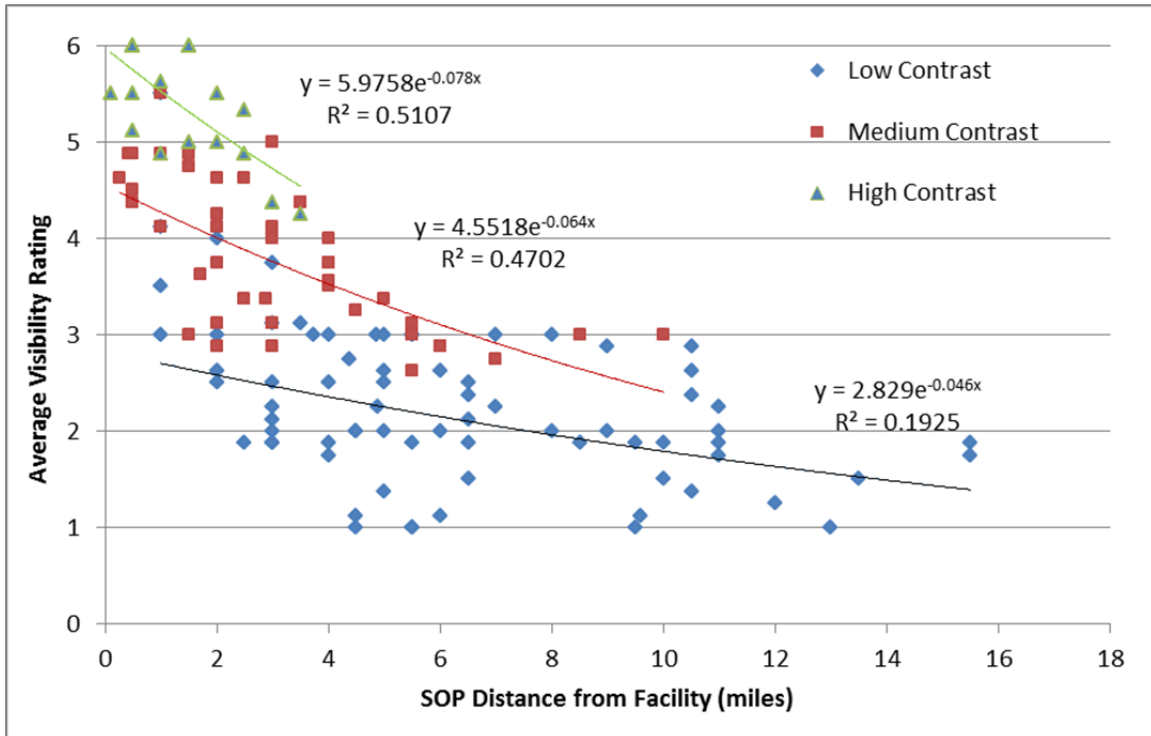


Figure 10. Average Visibility Ratings for 500-kV Lattice Towers as a Function of Distance and Rated Contrast between Towers and the Backdrop

visible but were relatively minor sources of visual contrast, and, in many cases, would not have been noticeable to casual observers ($AVR \leq 2$). Anecdotally, the observers noted that in many cases where lattice towers were viewed against darker and varied ground backdrops, they could be difficult to see even at distances as short as 2 mi (3 km).

Finally, the AVRs for the observations of the Midpoint-Summer Lake 500-kV lattice tower line in Idaho were compared with the AVRs for the observations of the Marketplace-Adelanto and McCullough-Victorville 500-kV lattice tower lines in California (Figure 11). The AVRs are generally consistent, but with slightly higher AVRs for the California lines, which may be attributable to the uniformly sunny conditions during the California observations, while a substantial number of the Idaho observations were made under cloudy conditions, which would sometimes decrease the contrast and the associated AVRs.

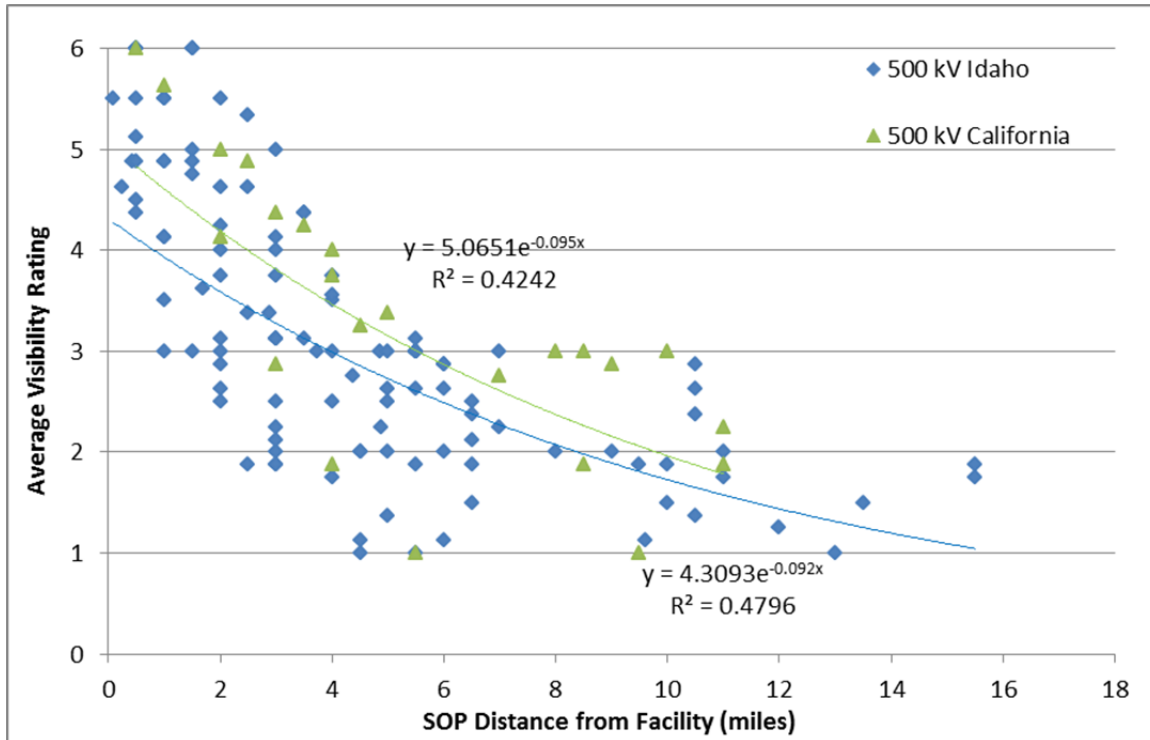


Figure 11. Average Visibility Ratings for Idaho and California 500-kV Lattice Towers as a Function of Distance

500-kV Monopole Facility

The relationship between distance and AVR for observations of the two 500-kV monopole transmission facilities is graphed in Figure 12 and compared with that for all 500-kV lattice tower facilities.

Figure 12 shows AVRs for the 500-kV monopole facilities reaching “5” (major attractant of visual attention) at distances up to 2.5 mi (4.0 km), which is only slightly less than the values for 500-kV lattice tower facilities at that distance, but reaching “3” (easily visible after a brief glance) at distances of only up to approximately 5 mi (8 km), which is considerably less than for lattice tower facilities. Thus the visibility/distance curve for the 500-kV monopole facilities is somewhat steeper than that for the 500-kV lattice tower facilities. However, because both

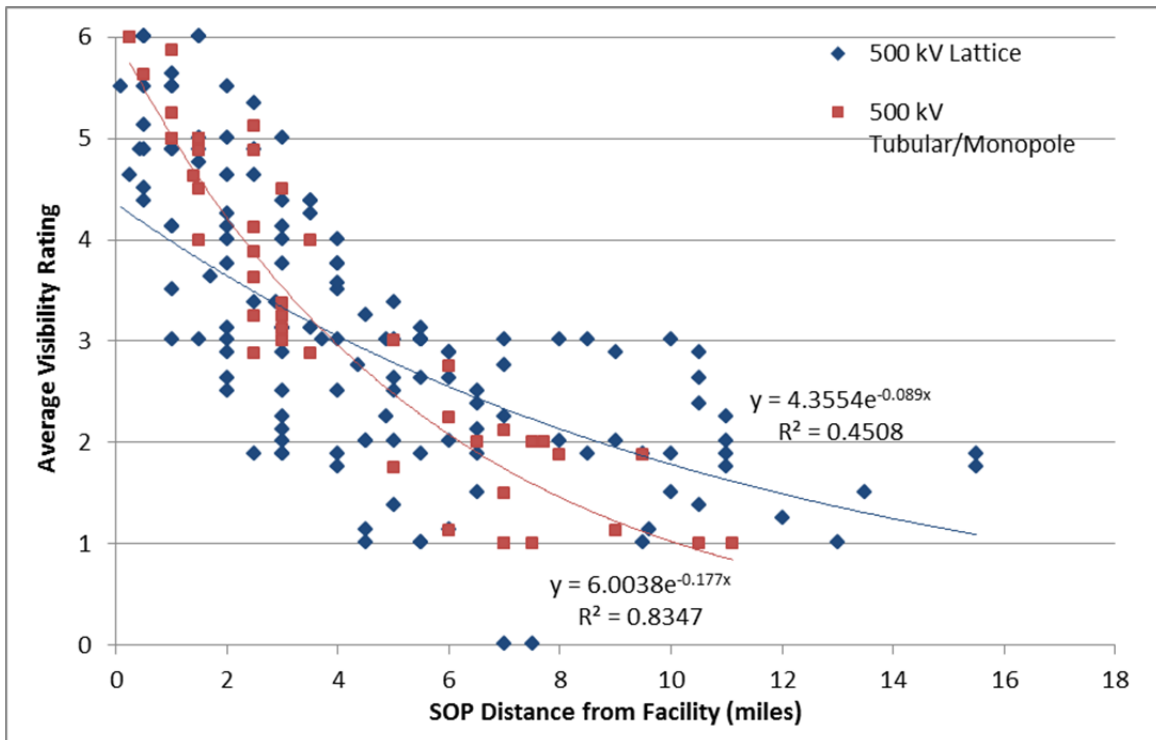


Figure 12. Average Visibility Ratings for 500-kV Monopole Facilities and for 500-kV Lattice Tower Facilities as a Function of Distance

500-kV monopole facilities are on the outskirts of urban areas with more visually cluttered backdrops, it cannot be assumed that this relationship would be observed for other lines. The 500-kV monopole facilities maximum visibility distance for this study was 11 mi (18 km).

230-kV H-Frame Tower Facilities

Figure 13 is a graph of the relationship between distance and AVR for 230-kV H-frame tower transmission facility observations. The AVR reaches a “5” (major attractant of visual attention) only at distances up to 1.5 mi (2.4 km). The AVR reaches a “3” (easily visible to casual observers) at distances up to 3.5 mi (5.6 km). Beyond this distance, the facilities were judged unlikely to be noticed by casual observers, and, even when skylined, were nearing the

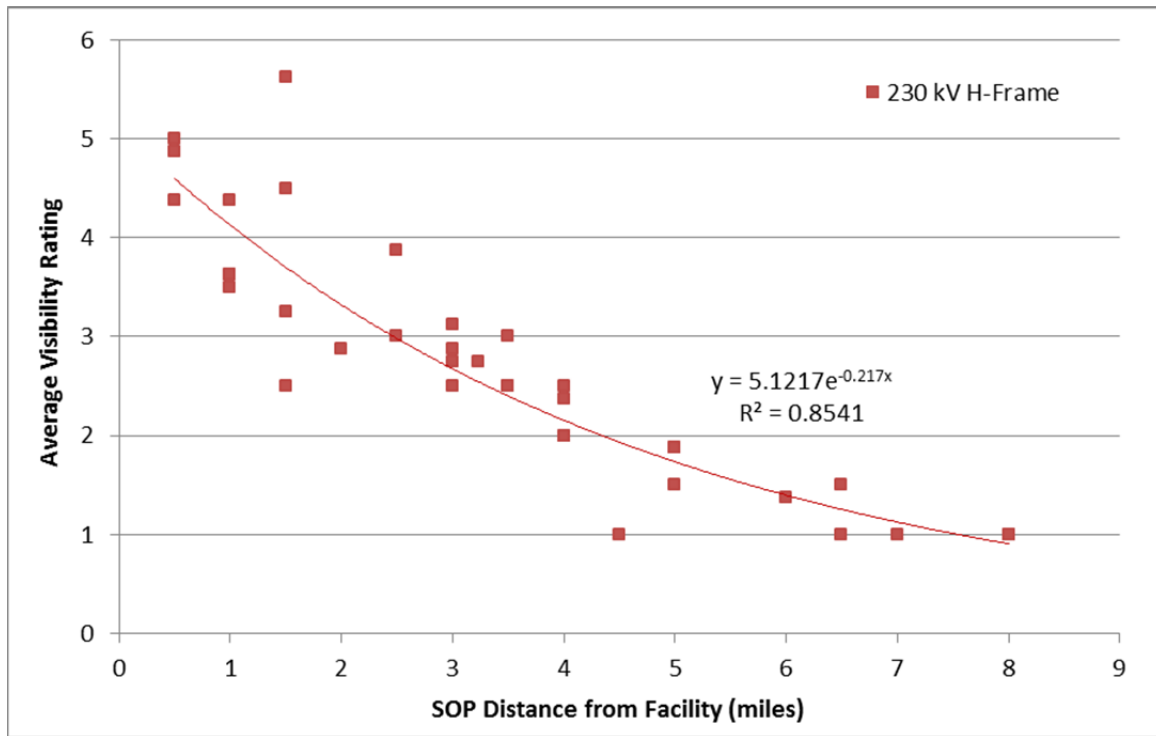


Figure 13. Average Visibility Ratings by Distance for all 230-kV H-frame Tower Transmission Facilities

limit of visibility at distances beyond 6.5 mi (10.5 km). The maximum visibility distance of 8 mi (13 km) is less than half that for 500-kV lattice tower facilities.

Figure 14 shows a comparison of AVRs for 500-kV lattice tower and 230-kV H-frame tower facilities. As might be expected, the much larger and taller lattice towers are visible at longer distances than the H-frame towers; however, the study data suggest that AVRs for the two tower types may converge at very short distances.

230-kV Monopole Facility

Figure 15 is a graph of the relationship between distance and AVR for the 230-kV monopole transmission facility observations. The AVR reaches a “5” (major attractant of visual attention) at a distance of 1 mi (1.6 km). The AVR reaches a “3” (easily visible to casual

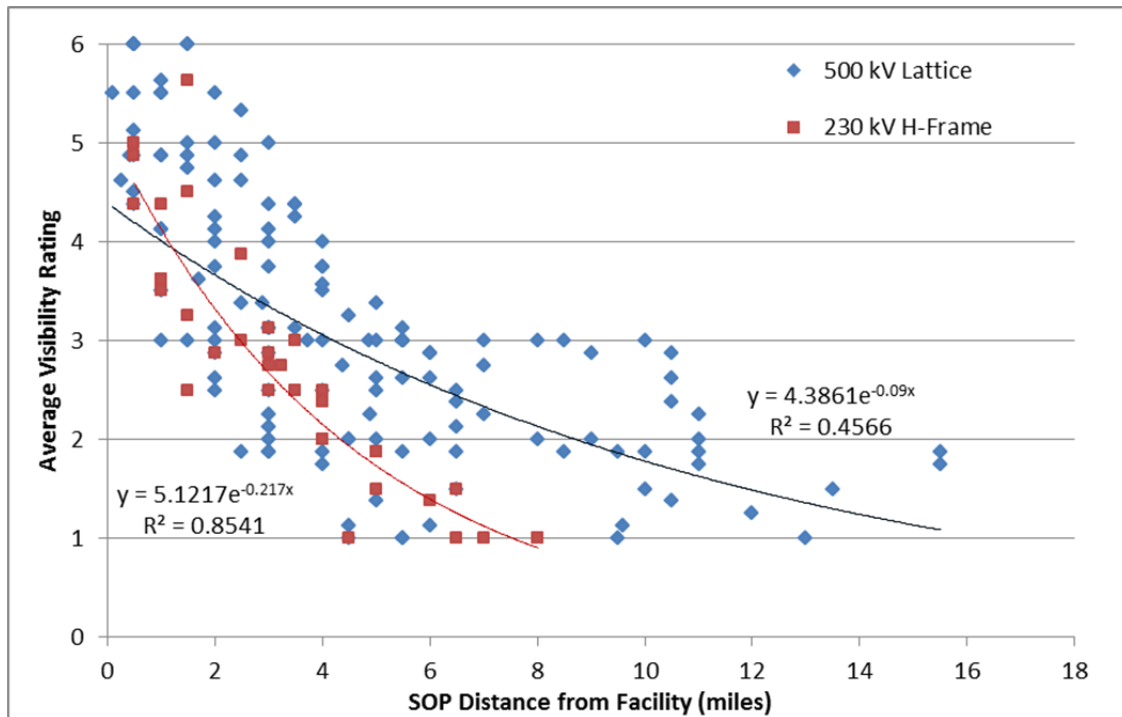


Figure 14. Average Visibility Ratings for 500-kV Lattice Tower Facilities and for 230-kV H-frame Tower Facilities as a Function of Distance

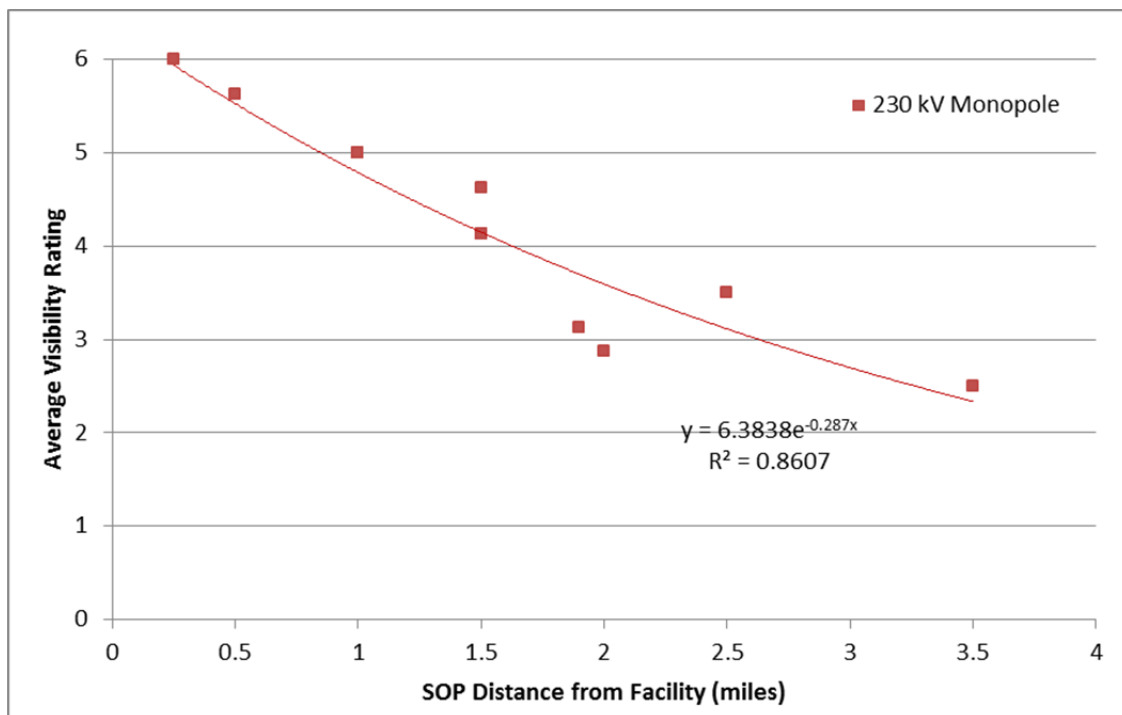


Figure 15. Average Visibility Ratings for a 230-kV Monopole Facility as a Function of Distance

observers) at distances of about 2.5 mi (4.0 km). However, views were limited to ground backdrops, there are very few data points, and the view was cut off beyond 3.5 mi (5.6 km) because of topography and access restrictions, so caution must be used in interpreting the data.

5 Discussion

Visual Contrast Distance Thresholds

This study sought to identify visual contrast distance thresholds appropriate for visual impact analyses and for the siting of selected transmission facilities to avoid or minimize potential visual impacts to visually sensitive landscapes. Given this purpose, the following contrast thresholds are proposed:

1. **Limit of visibility:** This contrast distance threshold determines the outer limit of visual effects associated with visual contrast from wind farms under normal circumstances. In this study, the corresponding average visibility rating (see Table 2) is “1.” This rating can be summarized as describing a facility that is at the extreme limit of visibility.
2. **Limit of scanning visibility:** This distance threshold determines the distance at which a facility might be missed by casual observers but is easily visible when scanning or actively looking closely at the landscape. In this study, the corresponding average visibility rating is “2.”
3. **Limit of casual visibility:** This distance threshold determines the distance at which a facility would likely be easily visible to anyone looking briefly in the general direction of the facility, without foreknowledge or active looking. In this study, the corresponding average visibility rating is “3,” summarized as describing a facility that would be

noticeable to a casual observer. At this level of visibility, contrasts are usually low, but may rise to a moderate level, depending on circumstances and landscape context.

4. **Limit of visual preeminence:** This distance threshold determines the distance at which a facility becomes a major focus of visual attention, tending to attract and hold visual attention because of strong contrast in form, line, texture, color, or motion. In this study, the corresponding average visibility rating is “5.” At this level of visibility, contrasts are generally at a high level, although the transmission facility may not be visually dominant over major landforms such as mountains.

The authors suggest that *at a minimum*, the distance away from the project that should be analyzed for potential visual impacts in a VIA for a transmission facility (the area of impact analysis) should correspond to the limit of casual visibility, and a more conservative distance would be the limit of scanning visibility. The rationale for identifying the limit of casual visibility as the minimum distance for a VIA is that at this distance, a transmission facility of a given type is likely to be easily seen by people, and therefore will definitely cause some kind of visual impact for most viewers, though it may be small.

A rationale for selecting the more conservative threshold as the basis for impact analyses is that scanning or looking closely at the landscape is a common activity, especially in areas that are visually sensitive, or have high scenic quality, or both; for example, at scenic overlooks or along scenic and historic trails. It may be appropriate to analyze and describe potential visual contrasts that might be encountered, even if they cause very small impacts and might not be seen by casual viewers. Figure 16 shows the relationship between the proposed limits of impact analysis and the visual contrast threshold distances.

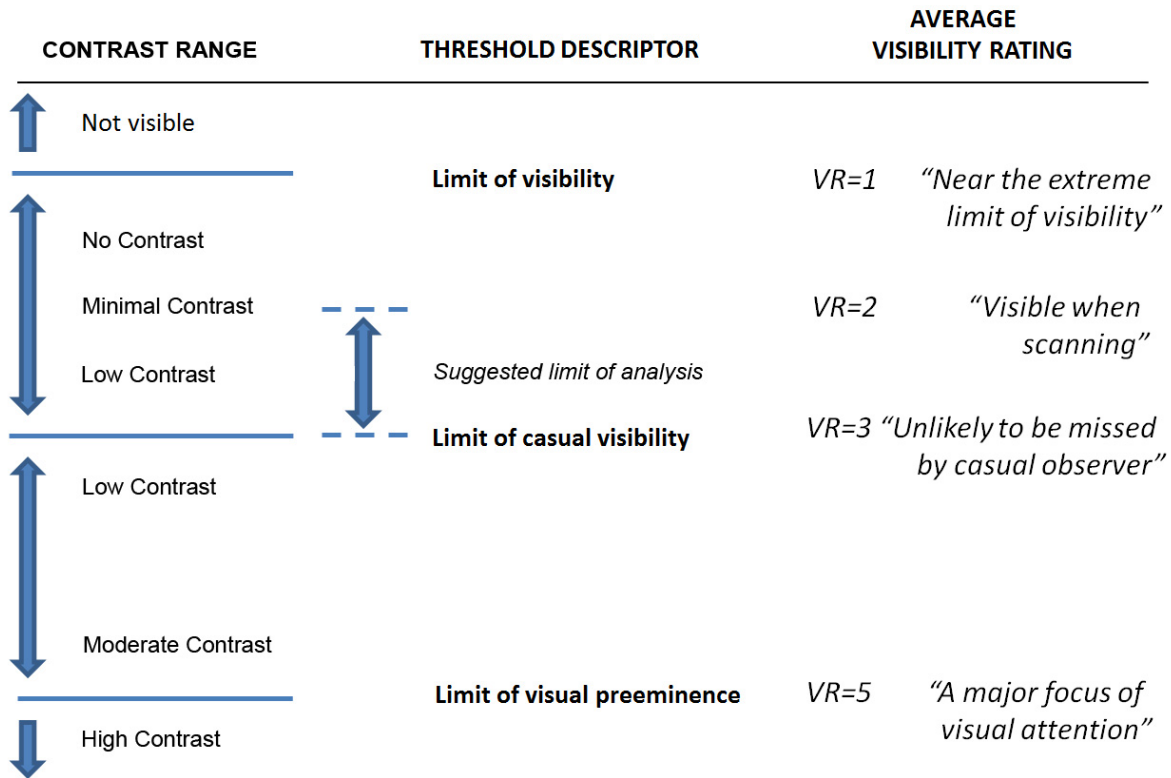


Figure 16. Proposed Contrast Thresholds for VIAs (VR = Visibility Rating)

A review of the visibility ratings for each rating level provides data needed to develop threshold distances that may be appropriate for transmission facilities in settings similar to those observed in this study. Because of limitations of the data collected, visual contrast distance thresholds and appropriate areas of impact analysis are proposed only for 500-kV lattice tower facilities and for 230-kV H-frame tower facilities.

Proposed Contrast Threshold Distances for 500-kV Lattice Tower Facilities

The farthest distance that a 500-kV lattice tower facility received an AVR of “3” (the limit of casual visibility) in this study was 10 mi (16 km), which the authors recommend should be the *minimum* distance from the project that should be included in a VIA, for similar projects in a similar landscape setting; that is, generally devoid of screening vegetation and with good air

quality and low humidity typical of non-urban western landscapes. In this study, the facilities that received this rating and those just slightly above and below this rating at similar distances were either skylined or visible against relatively light-colored ground backdrops in sunny conditions, conditions relatively favorable for visibility and appropriate for a VIA.

A more conservative distance for a VIA would be the limit of casual visibility (an AVR of “2”). In this study, the farthest distance a facility received an AVR of “2” was 11 mi (18 km), which is relatively close to the 10 mi (16 km) limit of casual visibility; however, an observation of a facility at 15.5 mi (25 km) received an AVR of “1.875.” Thus it might be reasonable to extend the limit somewhat to 12 to 13 mi (19 to 21 km) to assure that all facilities likely to be visible are included.

The farthest distance at which a 500-kV lattice tower facility received an AVR of “5” (limit of visual preeminence) was 3 mi (5 km). Thus at about this distance, a 500-kV facility may become a major focus of visual attention, and hence is likely to be a major source of visual contrast.

Proposed Contrast Threshold Distances for 230 kV H-frame Facilities

The farthest distance that a 230-kV H-frame facility received an AVR of “3” (the limit of casual visibility) in this study was 3.5 mi (5.6 km), which the authors recommend should be the *minimum* distance from the project that should be included in a VIA, for similar projects in a similar landscape setting; that is, generally devoid of screening vegetation and with good air quality and low humidity typical of non-urban western landscapes.

A more conservative distance for a VIA would be the limit of casual visibility (an AVR of “2”). In this study, the farthest distance a 230-kV H-frame facility received an AVR of “2”

was 4 mi (6 km). However, an observation of a facility at 5 mi (8 km) received an AVR of “1.875.” Thus it might be reasonable to extend the limit somewhat to 4 to 5 mi (6 to 8 km) to assure that all facilities likely to be visible are included.

The farthest distance at which a 230-kV H-frame facility received an AVR of “5” (limit of visual preeminence) was 1.5 mi (2.4 km). Thus at about this distance, a 230-kV facility may become a major focus of visual attention, and hence is likely to be a major source of visual contrast.

Visibility of Transmission Facilities in Photographs vs. Field Settings

As noted above, visibility ratings were conducted in the field without the use of photographs. At every location, however, high-resolution photographs of the transmission facilities were taken at a variety of focal lengths, using a Nikon digital camera. Facility photos can be obtained by contacting the lead author at *sullivan@anl.gov*. The photographs were not digitally manipulated or enhanced in any way after being taken. Some of the photos are blurred, largely because of high winds at the time the photographs were taken, and many were taken in less than optimal lighting and atmospheric conditions. Some slight image degradation undoubtedly occurred as a result of the jpeg compression used to convert the files to a manageable size; however, the image resolution is still high.

In the authors’ judgment, based on the many observations for this study and the Wind Visual Impact Threshold Distance study (Sullivan et al. 2012), and on comparison of the corresponding photographs with the narrative records from the observations, the photographs consistently under-represent the degree of visibility observed in the field. While true to some degree for all of the photographs, this is particularly true for photographs of the facilities taken

from longer distances. This is not simply an issue of viewing the photographs from the wrong viewing distance, a common and important problem when viewing visual impact simulations (Benson 2005). The photos are less sharp and show less contrast than was observed in the field. Scottish Natural Heritage (2006) suggests that the camera's inability to replicate the full contrast range visible to the human eye is a "key limitation of photographs in replicating the human experience."

The under-representation of visibility in the photographs generated from the study is important to consider when viewing the photos from the study; the authors strongly suggest consulting the narrative record for each observation to get a better understanding of what was actually observed in the field. It is likely that photographs taken under better conditions, with better equipment, and by more skilled photographers would be less subject to the problem of under-representing visibility with respect to sharpness and contrast (to a degree); however, no still photograph can capture the full human visual experience.

Future Research Needs

Conducting field research of this nature involves many compromises in order to reap the benefits of observing facilities in real landscape settings. Control over important variables is lost, and the results are affected by multiple situational variables that may have complex interactions that cloud correct interpretation of the results and make extension of the results to other situations difficult.

The study presented here examined several transmission facilities believed to be typical of facilities that exist or are under construction in the western United States at this time; however, there are many different designs and sizes of transmission towers, and only four

designs were examined here. Given the large differences in visibility and contrast thresholds observed in this study between the various design/size combinations, there is no doubt that other tower designs of different sizes would have different limits to visibility and contrast threshold distances. Studies are needed to identify visibility limits and contrast threshold distances for other tower designs and sizes.

Also, the choice of locations for the study immediately precluded other locations that may have attributes that would be important to consider in an ideal situation. For example, studies examining visibility and contrast thresholds in other regions with different landscape types and air quality are needed, because it is likely that visibility in the typically less open landscapes and relatively hazy skies of the non-Western regions of the United States is lower than in western landscapes. Finally, the use of professionals, rather than members of the public, to make judgments about contrasts and visibility also involves difficult trade-offs.

Potential studies that would validate, build upon, or improve upon the study presented here include the following:

- Studies that use more observers to conduct visibility ratings and include more observations;
- Studies that use members of the public to conduct visibility ratings;
- Studies involving larger or smaller transmission towers using different designs and in different settings, including different regions of the country;
- Studies that address specific visibility factors in a more controlled way, such as through the use of digitally manipulated photos to adjust tower size, spacing, contrast with the background, and so forth; and

- Studies that include assessment of impacts to specific sensitive visual resource areas, such as national parks, wilderness areas, or national scenic or historic trails.

Acknowledgments

Funding support for the work described in this paper was provided by the Department of the Interior Bureau of Land Management (BLM). The authors wish to thank the BLM and the individuals within BLM who made the success of these efforts possible, especially Sherry Lahti and Walt George (BLM Wyoming).

6 References

Benson, J.F., 2005, "The Visualization of Windfarms," pp 184–192 in *Visualization in Landscape and Environmental Planning*, I.D. Bishop and E. Lange (editors), Taylor & Francis, New York.

Bishop I.D., et al., 1985, "Visual Simulation and Assessment of Electricity Transmission Towers,' *Landscape Australia* 7:191–199.

Bishop, I.D., and D.R. Miller, 2007, "Visual Assessment of Off-shore Wind Turbines: The Influence of Distance, Contrast, Movement and Social Variables," *Renewable Energy* 32:814–831.

BLM (Bureau of Land Management), 1984, *Visual Resource Management*, BLM Manual Handbook 8400, Release 8-24, U.S. Department of the Interior, Washington, D.C.

BLM, 1986a, *Visual Resource Contrast Rating*, BLM Manual Handbook 8431-1, Release 8-30, U.S. Department of the Interior, Washington, D.C.

BLM, 1986b, *Visual Resource Inventory*, BLM Manual Handbook 8410-1, Release 8-28, U.S. Department of the Interior, Washington, D.C.

BLM, 2013, *Best Management Practices for Reducing Visual Impacts of Renewable Energy Facilities on BLM-Administered Lands*, Bureau of Land Management, Cheyenne, Wyoming. 342 pp, April.

DOE and DOI (U.S. Department of Energy and U.S. Department of the Interior), 2008, *Programmatic Environmental Impact Statement, Designation of Energy Corridors on Federal Land in the 11 Western States*, DOE/EIS-0386, Final, Nov. Available at <http://corridoreis.anl.gov/>.

Furby, L., et al., 1988, "Public Perceptions of Electric Power Transmission Lines," *Journal of Environmental Psychology* 8:19–43.

Glicksman, R.L., 2013, "Energy Transmission Across Wild and Scenic Rivers: Balancing Increased Access to Nontraditional Power Sources with Environmental Protection Policies," *Public Land and Resources Law Review* 34 Rev. 1:1–47.

Hull, R.B., and I. Bishop, 1988, “Scenic Impacts of Electricity Transmission Towers: The Influence of Landscape Type and Observer Distance,” *Journal of Environmental Management* 27:182–195.

Jones and Jones, 1976, *Measuring the Visibility of High Voltage Transmission Lines in the Pacific Northwest*, Final Report to the Bonneville Power Administration, U.S. Department of the Interior, Nov.

Scottish Natural Heritage, 2006, *Visual Representations of Windfarms. Good Practice Guidance*, prepared by Horner and Maclellan and Envision, March 29. Available at <http://www.snh.org.uk/pdfs/publications/heritagemanagement/Visual%20Representation%20of%20windfarms%20-%20excerpt.pdf>. Accessed Nov. 3, 2011.

Shang, H., and I.D. Bishop, 2000, “Visual Thresholds for Detection, Recognition, and Visual Impact in Landscape Settings,” *Journal of Environmental Psychology* 20:25–140.

Sullivan, R., et al., 2012, “Wind Turbine Visibility and Visual Impact Threshold Distances in Western Landscapes,” in *Proceedings, National Association of Environmental Professionals, 37th Annual Conference*, May 21–24, 2012, Portland, Ore. Available at <http://visualimpact.anl.gov/windvitd/docs/WindVITD.pdf>. Accessed Dec. 5, 2013.

University of Newcastle, 2002, *Visual Assessment of Windfarms Best Practice*. Scottish Natural Heritage Commissioned Report F01AA303A. Available at http://www.snh.org.uk/pdfs/publications/commissioned_reports/f01aa303a.pdf. Accessed June 3, 2011.