

EVALUATING METHODS TO TEST VISUAL IMPACT
FROM UTILITY TOWERS:
LBJ NATIONAL HISTORICAL PARK

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BY
JEFF BRACEWELL

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Objectives:

The objectives of this project are: (1) to apply modified techniques to measure visual detection of and perceived impact from utility towers using GIS, (2) to create a viewshed model representing number of visible utility towers from Lyndon B. Johnson National Historical Park and (3) to compare results from the former objectives with field observations as a means to evaluate the performance of these techniques.

Introduction:

The Heritage Preservation Services (HPS) defines historic landscapes as those which,

“range from thousands of acres of rural tracts to a small homestead with a front yard of less than one acre. Like historic buildings and structures, these ‘special places’ reveal aspects of our country's origins and development through their form and features and the way they were used (NPSb 2005).”

Utility towers have become as omnipresent as these ‘special places,’ and the distances between the two grow closer. Utility towers have been constructed in Grand Canyon, Yosemite, and Everglades National Parks. The incongruity between preservation and modernization came to national prominence when a utility tower overlooking “Old Faithful,” at Yellowstone Park was erected in 2004 (NPCA 2004). Groups such as Public Employees for Environmental Responsibility (PEER) have been critical of the National Park Service’s (NPS) stance on cellular towers. PEER charges the NPS with “failing to: protect the special qualities of the national parks; develop a central management plan for placing the towers; inform and solicit comments from the public; and have a clear idea of

how many cell towers exist in the national park system” (NPCA 2004). In contrast to PEER’s standpoint, reporting emergencies, and satisfying visitor demand for coverage have been prevalent arguments for the construction of cellular towers in close proximity or on park units (Kuna 2004; NPSb 2005).

NPS position on towers

From this point forward the term ‘tower’ will be used to describe the variety of utility towers in the study that serve to transmit and relay wireless data. Regarding towers, the National Park Service has been challenged to balance preservation and increasing development (Miller 2004; Kuna 2004). Section 106 of the National Historic Preservation Act (NHPA) established protocol seeking to achieve this balance by identifying historic properties that may be affected by a federal undertaking, such as licensing and permitting, and through consultation with agencies and interested parties, “avoid, minimize or mitigate any adverse effects on historic properties” (National Historical Preservation Act 1966). Additional legal obligation to evaluate and protect scenic resources exists in the National Environmental Protection Act of 1969 and the National Wild and Scenic Rivers Act (Ervin 2003). However, ambiguities within these acts allow much of its interpretation to take place on a local level often impacting historic places (Rotenstein 2004).

In February 2004, Native Americans of the United South and Eastern Tribes, Inc. (USET), and the Federal Communications Commission (FCC) announced a Memorandum of Understanding (MOU), potentially setting the tone for future NHPA modifications. This MOU was written to help guide applicants, who wish to construct

towers on USET property, with the consideration of specific religious and cultural assets (FCCb 2005). The FCC regularly reviews and revises parts of NHPA to create consistent and balanced regulations (Rotenstein 2004).

Growth in Central Texas

Texas is projected as the second fastest growing state in the U.S. (Census 2005), and much of that growth is occurring in the states central region. Lyndon B. Johnson (LBJ) National Historical Park (NHP), located north of San Antonio and west of Austin and thus, adjacent to intense growth (figure 1). Heavy regional travel creates an environment for wireless communication and the associated network towers that harbor transmission and relay devices. According to the FCC Antenna Structure Registration (ASR) a majority of the towers in this vicinity were constructed within the past ten years (FCC 2005). In 2004 a smoldering conflict surfaced between the NPS and a wireless telecom company when the company proposed to extend the height of a 181ft. tall tower



Figure 1. Lyndon B. Johnson National Historical Park, Basedata from ESRI

located less than half a mile from the Johnson Family cemetery and President Lyndon B. Johnson's burial site. The tower was not extended, but park managers realized that growth is imminent, more cellular towers will be erected and the struggle to preserve landscapes will intensify.

Visual quality

Visual quality is an important part of tourism and recreation, representing an overall desirability of an area, with intrinsic economic and societal benefits (Clay and Daniel 2000). Studies show that urban development detracts from visual quality (Anderson and Schroeder 1983) and the public generally prefers natural over man-made landscapes (Schroeder 1983; Zube 1995). Furthermore, vertical objects, such as towers have an impact on a greater spatial extent than horizontal objects (Schroeder 1983). Because the spatial extent of visual impact is widespread, scenic resources are the shared responsibility among intersecting administrative authorities and land owners (Zube 1995). The desire for natural landscapes is apparent, but comprehensive techniques for managers to measure visual quality are tenuous.

A debate over whether aesthetic quality is intrinsic or subjective has swung to the subjective account in modern philosophy (Daniel 2001). The "expert approach", one popular method to assess quality, puts the subjective task in the hand (or eye) of an expert, who, based on field observations, makes assessments and recommendations about an area's aesthetic quality. This technique has been criticized for having inadequate levels of precision, reliability and validity, ultimately proving unreliable (Daniel 2001). To this end many have sought ways to quantify landscape aesthetics, despite some scientists'

beliefs, such as Carlson (1977), that quantifying scenic beauty is neither possible nor necessary. Regardless, development conditions are such that it has become increasingly necessary that resource managers put value on aesthetic quality (Daniel 2001), and therefore accurate, quantitative models are needed to make predictive impact assessments to the viewed landscape.

In order to analyze impact to landscape, resource managers must examine the degree of impairment caused by a proposed development and show ways to; avoid, minimize and compensate for impairments (Krause 2001). One way to examine the degree of impairment from visual intruders is through visual threshold modeling (VTM). VTM has proven accurate in controlled environments, but Shang and Bishop (2000) suggest validating and expanding current findings through further experiments on extended variables and conditions, and by application of these techniques to realistic projects. Following this recommendation and given the proliferation of towers in Central Texas, the goal of the project presented here is to utilize GIS to refine and employ techniques in visual detection and viewshed modeling as a means of assessing the current visual impacts from towers on the historical landscape at LBJ NHP. An inventory of, and impact from viewed objects will help resources managers make informed decisions and strengthen negotiations to protect shared visual resources.

Visualization models

According to Ervin (2001) the ideal result of the visualization model is a balance between ‘looks like’ and ‘acts like’. Bishop (1994) describes that the ultimate goal of linking modeling to visualization is, “production of high levels of information

presentation together with high levels of interactivity showing changes of time and results of management activities.” When considering models that evaluate visual detection and impact, it is important to realize that the psychophysical sensitivity event of detection is not absolute, but rather it occurs along an S-shaped curve (figure 2) (Shang and Bishop 2000). Shang and Bishop (2000) outline the limitations in the visual modeling process as trading psychophysical sensitivity functions for thresholds in the interest of the decision-making process. GIS can help to implement these visualization models, offering an ideal tool to inventory, store, and display related data (Bishop 1994). Advancements in GIS modeling and display are helping to meet resource manager’s needs to model visual implications from complex spatial and temporal patterns in the landscape (Daniel 2001).

Study Area:

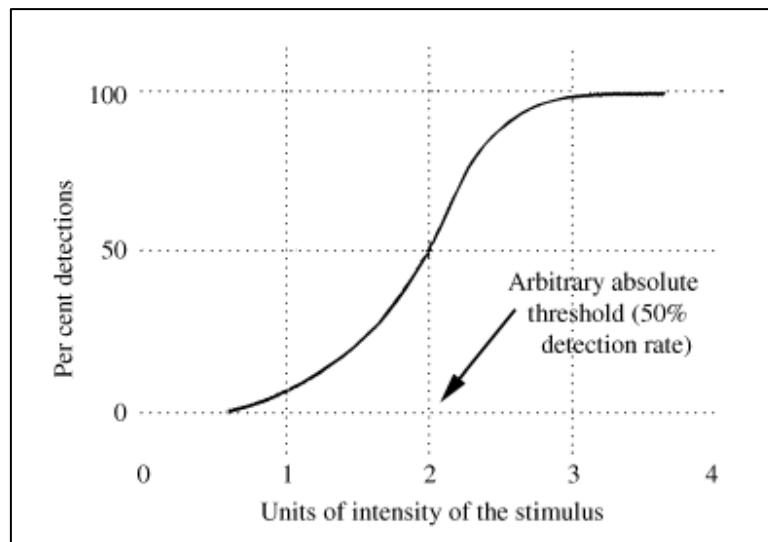


Figure 2. Threshold function (Shang and Bishop 2000)

The land surrounding LBJ NHP is typical of the Central Texas Hill Country. Located along the Pedernales River the elevations at LBJ Ranch oscillate rapidly. Landcover here is primarily a patchwork of lush riparian vegetation, cleared agricultural land, and mixed juniper/oak stands. It was both necessary and logical to limit the study area in this seemingly endless horizon of hills to a certain viewable distance from the historical area. Sparks and Kidner (n.d.) set a search radius of 20km for their zone of intrusion study of wind turbines. Also, studying visual impacts from wind turbines, Bishop (n.d.) found that between 10km and 20km, detection rates dropped from 42 percent to 7 percent under clear atmospheric conditions and summarized that the visual effects beyond 20km may be rare and depend on exceptional viewing conditions. Based on these findings and field observations the study area here was limited to 15km from the observer position (figure 3).



Figure 3. Study area – 15km from observer position, Basedata from ESRI

Data:

The primary components for this viewshed analysis included a digital elevation model (DEM), observer position, and target location. There was no conclusive information uncovered in the literature to define acceptable detail in DEM resolution for viewshed analysis. Hadrian, Bishop and Mitcheltree (1988) explain the DEM cell size should correspond with the nature of the landscape to be traversed, and that cell size can be as small as 10m or as coarse as 50m depending on the complexity of the landscape. Moller (2005) used a 20m resolution DEM resampled to 100 m for his analysis on a 6200 km² study area, justifying that computer processing demands warranted the relatively coarse data. Some suggest using a multiresolution model in which resolution coarsens with increased distance from the viewer to compensate for processing limitations (Florriani, et al. 2003). For this study the viewshed model will encompass a relatively small area, approximately 30 km², and given the complexity of the terrain, 10m DEM data is chosen. Preliminary analysis proved that processing time with a 10m DEM is acceptable. DEM data for the study site was delivered via the United States Geographical Survey's (USGS) Seamless Data Distribution system. A Global Positioning System (GPS) waypoint was recorded at the chosen observation point to be used in modeling and to re-locate the real-world position for subsequent evaluation of results. Target location data (towers) was delivered from the Federal Communications Commission (FCC) as GIS shapefiles and required limited pre-processing. FCC structures are represented with a 7-digit registration number. Some of the towers that potentially pose an impact were excluded from the FCC dataset as they did not exceed the thresholds for registration outlined in 'Code of Federal Regulations (CFR) 47 Part

17.7'. GIS data for two of these additional towers was acquired from American Towers Corporation web portal. American Tower structures are represented with a company assigned 5-digit number. One tower in the study is owned and operated by the NPS and is located within park boundaries. Data for this tower was available from LBJ NHP and is represented by an arbitrary three-digit number. Field inspection of the area indicated that all area towers are accounted for.

Methods:

The modeling methods used here strive to maintain consistency with: the goals set forth by Ervin (2001) and Bishop (1994) towards the production of accurate and repeatable methods that effectively represent changes in time and management activities.

Visual detection

A visual detection threshold occurs at a point where an object is visible but not identifiable, while a recognition threshold occurs at the point where enough information about the object is transmitted to allow recognition by the observer (Magill 1990). Visual size, contrast, object shape and landscape background all play roles in detection and recognition thresholds (Shang and Bishop 2000; Bishop 1997). In this study, visual detection alone is considered, because it is believed that an object need not be recognized to have an impact. Shang and Bishop (2000) used results from survey responses about perceptions towards man-made objects in the landscape in an effort to determine visual detection thresholds and a medium visual impact threshold (MVIT), defined as a measure of impact as high or low based on a majority consensus by subjects. The study was

carried out in a controlled environment, using projected computer generated images with modified visual attributes of size, contrast, object type, and landscape type to represent various viewed object-landscape relationships (Shang and Bishop 2000). Results indicated that contrast-weighted visual size is a key indicator of detection and recognition. However, the MVIT model was not able to accurately describe the impact relationships between viewers and objects (Shang and Bishop 2000). Because of the MVIT shortfall, the study presented here takes the cautious approach of considering a towers visual impact as relative to other towers in the study area. As a result, a tower with a larger visual size correspondingly has a larger impact. Based on detection rates by subjects Shang and Bishop (2000) developed a best-fit model to predict visual detection using contrast weighted visual size described by the following equation:

$$S = M * (\arctan(1/d)*60)^2$$

Where:

S: Angular dimension to the target
M: Cross-sectional size of the target
D: The distance to the target

Some of the towers in the study area are free-standing and create a cross-sectional triangular shape that converges at the towers peak, while other towers are guyed and more uniform in cross-sectional size from base to peak (figure 4). Ideally, the cross-

sectional size of each target would be measured, but given access and time constraints a standard 2 meter width is used for each tower considered in the model. An opportunity for error also exists in the visual size equation, as arctan is based on a right angle which is not likely formed in the real-world, given the complexity of the terrain. It is believed that any inaccuracies between actual cross-sectional size vs. 2m cross-sectional size and/or in the visual size equation will not significantly influence results.

Visual size is weighted by contrast as a percentage where: contrast equals the difference between object and background divided by 256 (Shang and Bishop 2000). Testing slides of transmission towers Shang and Bishop (2000) found that object-background contrast varied between 7 and 26 percent; with contrast most frequently occurring at 13 percent. When considering contrast weighted visual size, uninformed detection occurs for 50 percent of the public with an object-background contrast of 13 percent at 24 minutes of arc² (Shang and Bishop 2000). For this study, a tower should



Figure 4. Left - Free standing tower, Right - Guyed Tower

become detectable for most observers when:

$$\text{minutes of arc}^2 * 0.13 > 24 \text{ (Shang and Bishop 2000).}$$

Given the undulating landscape, object background varies from above horizon to below horizon. This study does not account for the difference in contrast that exists between the object backgrounds.

Research suggests that other factors affecting target visibility are vegetation and terrain (Schroeder 1987). If a portion of the view to a target is blocked by vegetation or terrain that part of the target should be eliminated from the visual size equation. No methods were uncovered in the literature to measure the blocked / viewed portion of a target. The following calculations were developed for this study using *modified slope* to solve for the height of the unviewed portion of target.

If target is above observer:

$$e_{ob} - e_o / d_{ob} * d_t = h_{ao}$$
$$h_{ao} - (e_t - e_o) = h_{uv}$$

If target is below observer:

$$e_o - e_{ob} / d_{ob} * d_t = h_{bo}$$
$$(e_o - e_t) - h_{bo} = h_{uv}$$

where:

e_{ob}	Elevation of obstruction
e_o	Elevation of observer (+2m for viewer offset)
d_{ob}	Distance to obstruction
d_t	Distance to target
h_{ao}	Height of unviewed portion of target above observer
h_{bo}	Height of unviewed portion of target below observer
e_t	Elevation of target
h_{uv}	Height of unviewed portion of tower

Viewer position was based on field observation using the following desired criteria: sufficient elevation so that local horizon would not completely block targets, little or no vegetation blocking targets (this was especially important because the DEM is based on a vegetation free surface), and a position that would represent an area that the touring public would likely encounter. These criteria were met at a position on the northern portion of the LBJ Ranch (figure 5).



Figure 5. Observation Point

Visual detection and perceived impact

GIS has been employed in a considerable amount of viewshed modeling and visual impact studies (Hadrian, Bishop and Mitcheltree 1988; Bishop and Hulse 1994; Moller 2005; Bishop n.d.) and is trusted as a capable tool for this study. All GIS related processes were performed using ArcGIS Desktop 9.1 and the 3D Analyst extension. The

following steps outline the basic procedures used here to determine visual detection and impact using GIS: (1) create a viewshed model, (2) establish lines of sight (LOS), (3) apply visual size equations and (4) generate results. A viewshed analysis is run originating at the observer position in order to assess intervisibility with tower bases. A portion of a tower is unseen if a tower base is not visible, and that unseen portion should not be included in the visual size equation. Distances and elevations along a LOS profile are needed to determine the viewed portion of a tower. 'EZ-Profiler', a script by Min-Lang Huang extracts elevations at prescribed distances from an observer along a LOS. In this study 'EZ-Profiler' was used to extract elevation points every 10m from observer position based on the 10m resolution of the DEM. Visual inspection of the viewshed model, when overlaid with extracted elevation points, indicates the point (xyz) of the obstruction (figure 6). The viewed portion of the target can now be calculated using *modified slope*. The viewed portion of all towers is entered into contrast weighted visual size equations with results representing the theorized visual impact.



Figure 6. Extracting elevation points

Number of visible utility towers

The result of a viewshed map is binary in the sense that each grid cell or location is either visible or not. Viewshed can be interpreted as view of an area from a single point or, in reverse, as the locations from which an object can be seen (Ervin 2003). The results here will be based on the assumption that intervisibility exists between the towers and an observer.

The ‘viewshed’ command is initiated using a 10 meter DEM as the *input raster* and allowing for the earth’s curvature and refractivity. All 12 towers in the study area are included as *input points* (figure 7). Control parameters were added to reflect height at the observer and target positions plus a maximum search radius, based on upper limits for visibility.

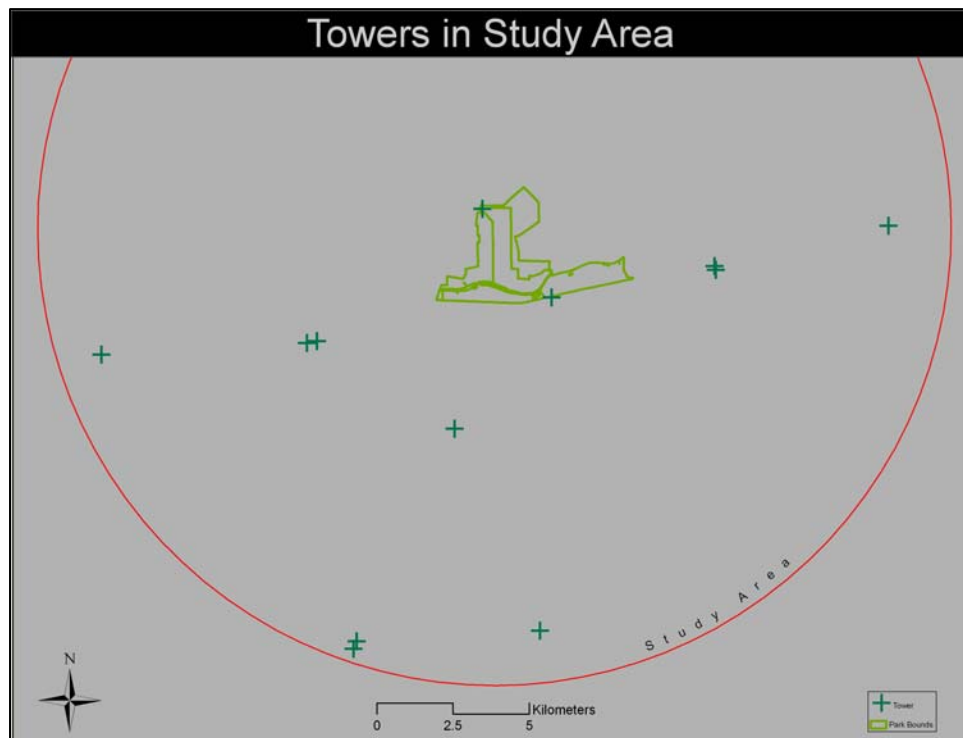


Figure 7. All towers in study area

Viewshed control parameters:

- OFFSETA - offsets the point from the base elevation (Tower height in meters)
- OFFSETB - offsets each raster cell for viewer height (2 meters)
- RADIUS2 – sets maximum search radius from input points (15km)

The result of the analysis is a grid with a value (0-12) assigned to each cell representing number of towers visible from that location.

The final outputs presented in this report are a graduated symbols map to represent the level of impact from each tower in the study area based on contrast weighted visual size, and a classed viewshed map indicating number of towers visible from the study area.

Results:

Results were field verified by the author on April 4, 2006 at approximately 5p CST. Visibility, as reported by the National Weather Service on Weather Underground (www.wunderground.com) in nearby Fredericksburg, Texas was 10 miles under clear skies. Based on the viewshed model visibility was partially blocked to two of the twelve towers considered for this study (table 1). In both cases the towers were at distances too great to field verify if these findings were valid. The study area used in this project was considered valid, as no towers outside the study area were visible.

<i>FCC Reg #</i>	<i>Tower Ht.</i>	<i>Unviewed Ht.</i>	<i>Viewed Ht.</i>
1046995	67.70	9.79	57.91
1208849	90.40	5.38	85.02

Table 1. Towers with obstructed intervisibility and corrected heights

Visual detection threshold

In calculation results only tower 100 met the 24 minutes of arc² visibility threshold (table 2). Despairingly, field observation revealed that all of the towers except for 1208848 were detectable. Perhaps contrast was incorrectly represented or viewer visual sensitivity was considerably different from viewers in previous studies. It is also speculated that a significant inaccuracy may lie between real-world observation and photographed scenes, which these calculations are based on. Photos attached in appendix 1 were taken at the same time field observations were made, but visual acuity in the photos does not accurately represent what was viewed in the field. In general towers were more visible in field observation than their photographed counterparts. This observance suggests that the 24 minutes of arc² threshold should be smaller to represent more viewed towers.

<i>Reg. #</i>	<i>Structure Ht.</i>	<i>Dist. To Target</i>	<i>Min. of Arc2</i>	<i>Contrast 13%</i>	<i>Detectable at 13%</i>	<i>Detectable by Obs.</i>	<i>Obs. Class</i>	<i>Jenks Class</i>
FCC								
1012207	131	13173.59	17.84	2.32	No	Yes	1	1
1046995	57.91	14551.11	6.46	0.84	No	Yes	1	1
1208848	128	14531.15	14.33	1.86	No	No	0	1
1208849	85.02	7397.83	36.72	4.77	No	Yes	3	3
1209887	348	11407.4	63.21	8.22	No	Yes	4	3
1212953	93	7511.06	38.96	5.07	No	Yes	3	2
1215535	79.2	5807.6	55.5	7.22	No	Yes	2	3
1234148	76.2	11643.29	13.29	1.73	No	Yes	1	1
1238215	151.2	5502.56	118.03	15.34	No	Yes	4	4
American Tower								
92085	54.86	7210.37	24.94	3.24	No	Yes	2	2
92086	55.17	2931.99	151.69	19.72	No	Yes	3	4
NPS								
100	91.44	760.52	3736.72	485.77	Yes	Yes	5	5

Table 2. Summary of tower visual sizes

Visual Impact

During field observation it was difficult to distinguish slight differences in visual size therefore towers were grouped into five natural classes by apparent size. Likewise, Jenks Natural Breaks classification, which classes data by natural groupings, was used to classify the measured visual sizes into five groups. Overall, measurements for visual size corresponded well with field observations, with only minor discrepancies (figure 8). These inconsistencies could be attributable to inaccurate cross-sectional size or error in tower height reported to, or by the data sources. Generally, as measured visual size increased so did visibility and impact. One glaring inaccuracy in the visual impact results occurred with tower 92086. This tower was ranked second most visible by visual size

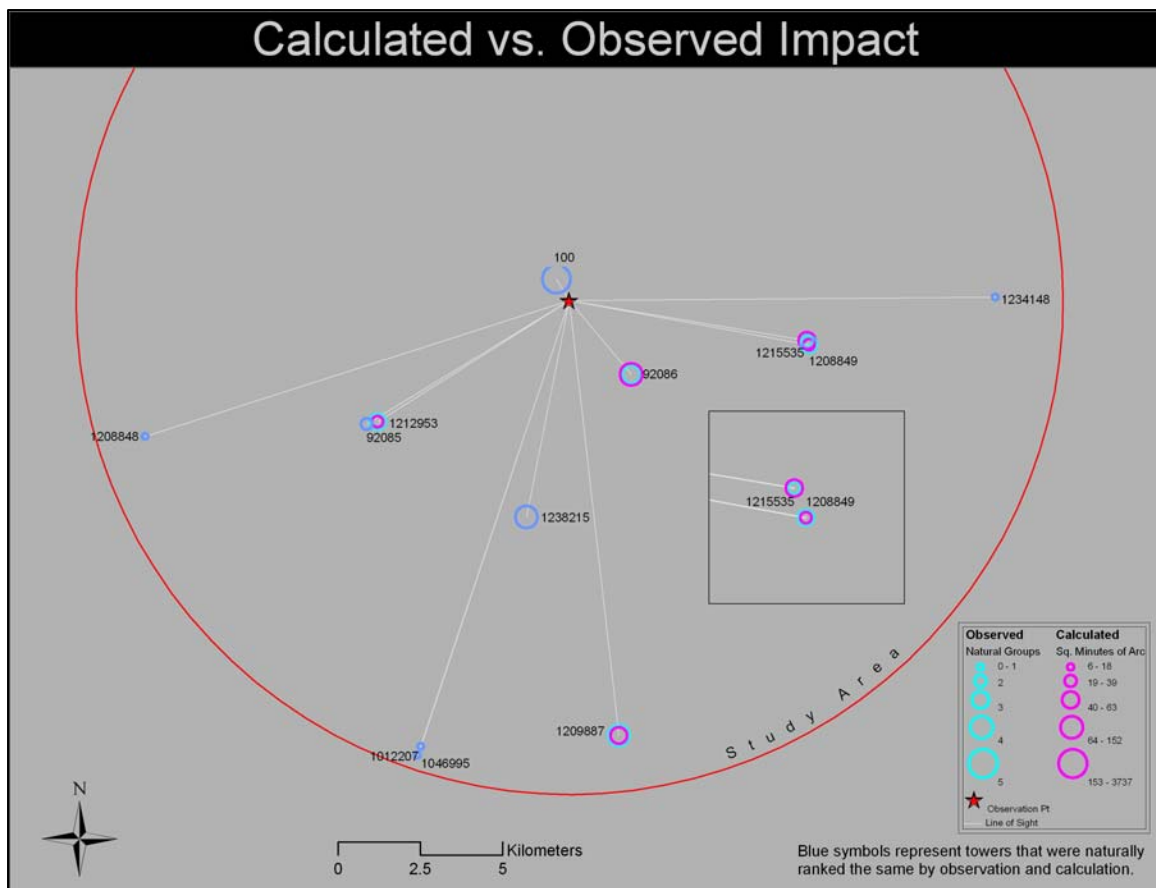


Figure 8. Graduated Symbols representing and comparing impact

calculations, but field evaluation indicated it as much less visible. This disagreement was most likely due to the object-background contrast. In most cases the object was contrast with sky (above horizon), but in the case of tower 92086 the background was almost entirely below horizon, or land. The results presented in this section are limited to one observation point perspective the intention being to test methods for visual detection thresholds and perceived impact. In the case of LBJ NHP the experience of a visitor is not limited to just one survey point, but rather entire park districts.

Viewshed Model

This viewshed model represents number of towers visible from any given place in the study area. Vegetation, which could potentially block intervisibility with a tower, is not accounted for. As expected, the most intense concentration of visible towers is from within the park boundary, as this was the center of the study area (figure 9). This result certainly corresponds with field observations, as eleven towers were visible from the observation point. Interestingly, a band of visibility to multiple towers exists along the Highway 290 corridor (figure 9). The pattern is likely the result of heavy tower placement along thoroughfares to provide wireless communication for travelers.

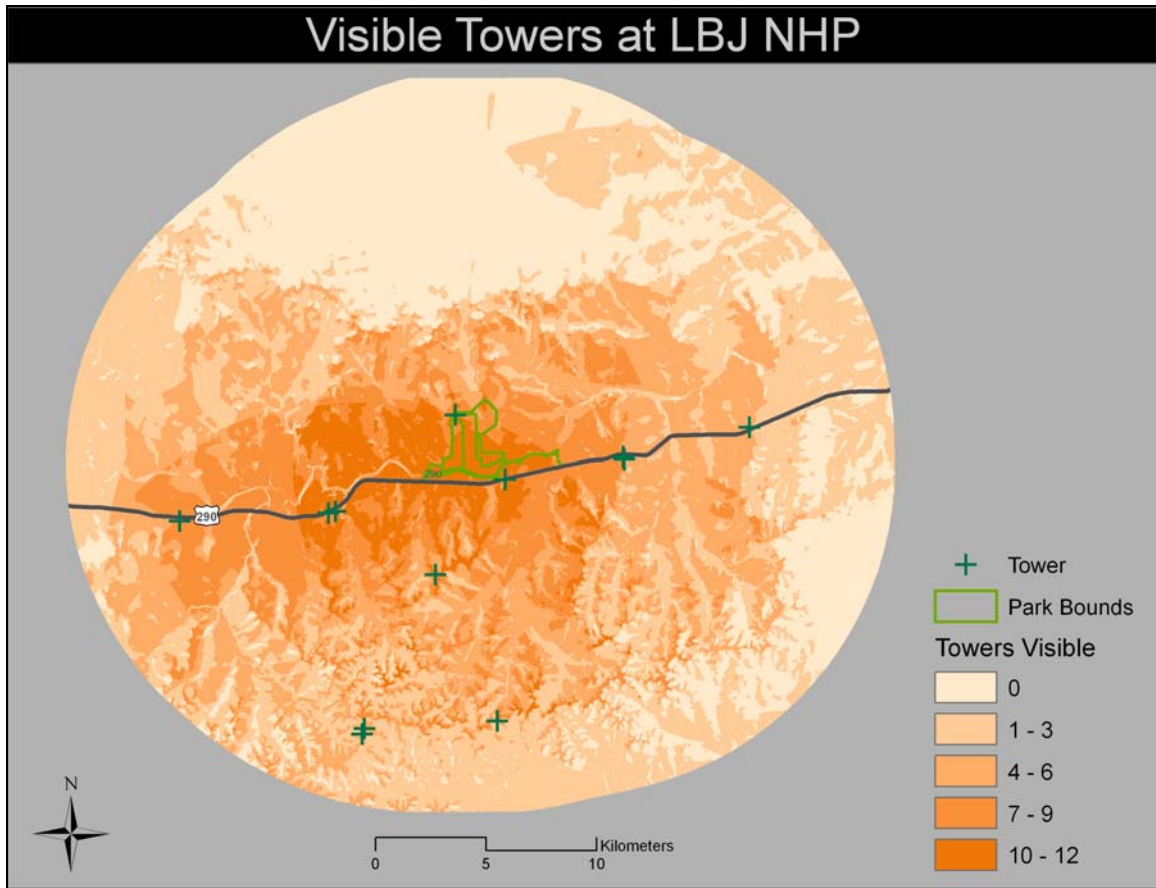


Figure 9. Viewshed representing number of visible towers

This model does a good job of giving an overview of impact, but the person interpreting its results for practical applications should be aware of its limitations. Operator choice dictates many of the variables guiding the output of a viewshed model. Additional viewer controls, like azimuth and vertical angle, can be used to control field of view and imitate real-world obstacles such as trees or buildings. Other user choices like setting observer position from linear features can be help to assess the viewshed characteristics from roads or hiking trails. A seemingly infinite number of classification and visualization schemes are available in ArcMap and ArcScene. Representations can range from simplistic, “can or can’t see” models, to animation. Ultimately, the viewshed model

and subsequent representation should be tailored per specific purpose and audience, with the audience mindful of what is or is not considered in the model.

Discussion

Techniques to determine visual detection thresholds and visual impact were tested here with varying degrees of success. Some techniques were not validated by evaluation, but this fact should not dispel their potential value. The major weaknesses in this project are thought to be (1) that field verification came from a single observer, (2) that visual contrast was applied uniformly, and (3) that breadth of cross-sectional size was not measured for individual towers. For future studies accurate measurements of contrast and size should be followed by a field level survey with a sufficient number of subjects to create a suitable sample size. Reference to Shang and Bishop (2000) will provide a strong foundation for survey form. Appropriate statistical techniques can then be used to quantitatively compare responses to calculated measurements.

If only half of a tower is visible from a viewer location then only that half should be accounted for in visual size calculations. The technique introduced here to calculate viewed portion of a target will need to be further tested in conjunction with visual size calculations to verify its accuracy.

As a visualization tool, it is recommended to use visual size calculations in conjunction with 'from target' designed viewshed models, like the one described in this report, to limit the search radius to a maximum visible distance. Results could then be buffered at distances within the viewshed of a target to represent zones of relative impact. Visualization techniques such as the former will make interpretation and reporting of

impact from visual intruders more robust and meaningful. However to have confidence in these products resource managers must be aware the results are only as valuable as the inputs.

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Appendix



*Photo presented at 30% zoom to fit entire tower in field of view, all other towers presented at 100% zoom.
Tower number is shown in bottom left of photos*







92086



R to L 1208849, 1215535

