# Assigning a Fixed Height to Land Cover Screen for Use in Visibility Analysis

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**Abstract:** There is little controversy over how to conduct a visibility analysis over bare terrain. However, in many areas this results in a totally unrealistic estimate of a project's visibility, and the question arises how to account for the screening effect of land cover when information about its height is not available. This paper investigates the difference between a digital model of the terrain (DTM) and canopy surface (DSM) from a 3-mile wide corridor in the state of New Hampshire, USA to evaluate the appropriateness of assigning a fixed height to land cover for the purposes of visibility analysis. The results find a 40-ft (12 m) height reasonable for forest cover, but suggest that using fixed heights for other land covers may be inappropriate.

**Keywords:** Viewshed, visibility screen

## 1 Introduction

An analysis of a proposed project's potential visibility is a critical component of every visual impact assessment (VIA). Visibility refers to the area seen from a particular viewpoint. A computer GIS or similar software is typically used to identify the area that will have potential visibility of an object in the landscape, such as a wind turbine; the area from which it is visible is called its viewshed. Essentially this analysis is a problem in geometry – given a point on a wind turbine, typically the rotor hub or the upright tip of a blade, is there a clear line of sight to an observer of a certain height located in the landscape, or is the line of sight obstructed by the terrain or land cover?

It is traditional practice to perform a visibility analysis using only ground elevation data – called terrain or topographic visibility. If the analysis parameters (e. g., ground elevation, heights of observer and of the target) are accurate, there is high confidence that views from areas without visibility will be obstructed by the terrain. However, the results excessively overestimate visibility because it does not account for the visual screening effect of land cover.

It is also traditional practice to perform a visibility analysis by assigning a fixed height to areas with forested land cover. In northern New England the practice has been to use 40 feet (12 meters) for the height of the forest canopy. While it is clear that many areas have higher forested canopies, the National Land Cover Data (NLCD) definition of forested land cover is that it must be "dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover."[1] Therefore the forest canopy can be as low as 16.4 feet, while field measurements for VIAs have often found canopies of ±60 feet. In addition, project proponents often advocate for assigning screening heights to other land cover types. To date

[1] http://www.mrlc.gov/nlcd11_leg.php

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there does not appear to have been an attempt to determine appropriate heights for the NLCD in New England.

A more appropriate approach to determining the height of screening land cover would be to use the elevation determined for the first reflective surface (DSM) from laser light detection and ranging (LiDAR) or interferometric synthetic aperture radar (IFSAR) data. The DSM approximates the elevation of the forest canopy, as well as buildings, crops, elevated highways and other cover types. The distance from the last reflected surface is used to determine terrain elevation (DTM). However, areas with free public access to these data are still quite limited. On the other hand, INTERMAP TECHNOLOGIES (2015) has made IFSAR derived DTM and DSM digital data commercially available for most of the continental US through their NEXTMap product. Conceptually, the difference between the DSM and DTM values measure the land cover's height at a particular location.

An obvious opportunity exists to use NEXTMap data to determine NLCD land cover heights. T. J. Boyle Associates (TJBA) acquired a 3-mile corridor running for approximately 180 miles through New Hampshire for use in conducting the VIA of the Northern Pass Transmission Project (NPTP). These data are repurposed here to investigate the appropriate height to assign to NLCD cover types for use in visibility analysis in northern New England.

# 2 Methods

## 2.1 Data Quality

The elevation data are available from the National Elevation Dataset (NED) at a resolution of 1/3 arc-second, which is approximately 10 meters. These data have recently been evaluated for their accuracy by comparing them to 25,000 surveyed geodetic control points. The root mean square error (RMSE) is the most common for to express vertical accuracy; for the continental US the 1/3 arc-second NED data the RMSE is 1.55 meters. A more intuitive measurement of error is proposed by the National Digital Elevation Program (NDEP), which is that 95 percent of the errors have an absolute value less than or equal to 3.02 meters (GESCH et al. 2015).

Intermap Technologies' NEXTMap data for the study area were in August, September and November 2007. The RMSE for unobstructed areas with slopes less than 10 degrees is 1.0 meters. The published linear error 95 percent confidence level is 2 meters (INTERMAP 2015, p. 53). Diminished accuracies are to be expected in areas of extreme terrain and dense vegetation.

The current NLCD database is based on 2011 Landsat satellite data. The spatial resolution is 30 meters and based on previous releases the classification accuracy for the 16 cover types described in Table 1 should be greater than 80 percent.

## 2.2 Analysis

The analysis is conducted using ArcGIS software (ESRI 2014). All data for the NPTP are projected as NAD 1983 State Plane New Hampshire FIPS 2088 Feet. The raster resolution

**Table 1:** The NLCD 2011 Land Cover Types

| Class | Classification Description |
|---|---|
| **Water** | |
| 11 | **Open Water** – areas of open water, generally with less than 25% cover of vegetation or soil. |
| 12 | **Perennial Ice/Snow** – areas characterized by a perennial cover of ice and/or snow, generally greater than 25 % of total cover. |
| **Developed** | |
| 21 | **Developed, Open Space** – areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 % of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes. |
| 22 | **Developed, Low Intensity** – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20 % to 49 % percent of total cover. These areas most commonly include single-family housing units. |
| 23 | **Developed, Medium Intensity** – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50 % to 79 % of the total cover. These areas most commonly include single-family housing units. |
| 24 | **Developed High Intensity** – highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 % to 100 % of the total cover. |
| **Barren** | |
| 31 | **Barren Land (Rock/Sand/Clay)** – areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15 % of total cover. |
| **Forest** | |
| 41 | **Deciduous Forest** – areas dominated by trees generally over 5 meters tall, and greater than 20 % of total vegetation cover. More than 75 % of the tree species shed foliage simultaneously in response to seasonal change. |
| 42 | **Evergreen Forest** – areas dominated by trees generally over 5 meters tall, and greater than 20 % of total vegetation cover. More than 75 % of the tree species maintain their leaves all year. Canopy is never without green foliage. |
| 43 | **Mixed Forest** – areas dominated by trees generally over 5 meters tall, and greater than 20 % of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 % of total tree cover. |
| **Shrubland** | |
| 52 | **Shrub/Scrub** – areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20 % of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions. |
| **Herbaceous** | |
| 71 | **Grassland/Herbaceous** – areas dominated by gramanoid or herbaceous vegetation, generally greater than 80 % of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing. |
| **Planted/Cultivated** | |
| 81 | **Pasture/Hay** – areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 % of total vegetation. |
| 82 | **Cultivated Crops** – areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 % of total vegetation. This class also includes all land being actively tilled. |
| **Wetlands** | |
| 90 | **Woody Wetlands** – areas where forest or shrubland vegetation accounts for greater than 20 % of vegetative cover and the soil or substrate is periodically saturated with or covered with water. |
| 95 | **Emergent Herbaceous Wetlands** – Areas where perennial herbaceous vegetation accounts for greater than 80 % of vegetative cover and the soil or substrate is periodically saturated with or covered with water. |

NLCD2011 Product Legend (http://www.mrlc.gov/nlcd11_leg.php).

of the DTM and DSM is 16.404 feet (i. e., 5 meters). The NLCD are projected and resampled to match the DTM and DSM resolution. This does not change the original 30 meter resolution of the NLCD, but it does make it possible to obtain 36 height estimates for every NLCD cell. All data are clipped to 1.5 miles from the NPTP centerline. The height of land cover is calculated as the difference between the DSM and DTM (i. e., height). Approximately 2 percent of the results are negative (i. e., the DSM was lower than the DTM elevation) and are deleted. These cells are not included in the analysis.

For each land cover type, ArcGIS is used to extract the cell count for each height. These values are copied to Microsoft Excel for the purposes of data management. JMP software is used to calculate the following statistics describing the height of each land cover type.

Parametric statistics assume that the data are randomly sampled from a population that has an underlying normal distribution. For the purposes of this analysis, the 5-meter posting of the NEXTMap data are assumed to create an unbiased random sample. The following parametric statistics are calculated for each NLCD land cover type.

- **Mean** ($\overline{x}$). The arithmetic average value is the sum of the data values divided by the number of data points.
- **Standard Deviation** ($s$). The standard deviation is a measure of the variation of a normal distribution. The standard deviation is expressed in the same units as the mean. A value near 0 means data points tend to be distributed very close to the mean; a high standard deviation means that the data points are more widely distributed.
- **Confidence Interval** (*CI*). The mean is based on a sample of values; a different sample is likely to result in a slightly different mean. The confidence interval reported here gives an upper and lower bound between which there is 95 percent confidence that the true value of the mean will occur.
- **Skew** ($Sk$). Skewness indicates whether a distribution is symmetrical or lopsided. A value of 0 indicates balanced symmetry. A positive value indicates that the tail of the distribution is longer on the right side; a negative value indicates that the tail is longer on the left side. There is no commonly accepted rule of thumb using skewness to test for normality. ROSE, SPINKS & CANHOTO (2015) recommend that the absolute value of skewness should be less than 2.58, and MORDKOFF (2011) recommends a value of 1.0.
- **Kurtosis** ($Ku$). Kurtosis measures whether the distribution is peaked or flat relative to the normal distribution. The kurtosis of a normal distribution is 3 – to make interpretation simpler it is often reduced by this "excess kurtosis" (i. e., 3) so 0 becomes the value describing a normal distribution. Positive values indicate a peaked distribution; negative values indicate a flat distribution. ROSE, SPINKS & CANHOTO (2015) recommend that the absolute value of kurtosis should be less than 2.58, and MORDKOFF (2011) recommends a value of 1.0.

Non-parametric make no assumptions about a population's the underlying distribution. However, it is still important that the data be randomly sampled so as to provide representative results.

- **Mode** ($Md$). The most frequent height for a particular land cover class.

- **Percentiles.** The height below which a specified percentage of cells for a particular land cover occur.
  - **Maximum**. The tallest height for a particular land cover class.
  - **90th Percentile**. Ninety percent of the cells are below this value.
  - **Upper Quartile**. The 75th percentile – three-quarters of the cells fall below this value.
  - **Median** (M). The middle height – half are above and half are below this value.
  - **Lower Quartile**. The 25th percentile – one-quarter of the cells fall below this value.
  - **10th Percentile**. Ten percent of the cells are below this value.
  - **Minimum**. The lowest height for a particular land cover class.

# 3 Results

The analysis included 55,775,839 cells covering 344,563 acres (538 square miles), which is the area within the area within 1.5 miles of the proposed NPTP in New Hampshire. Fifteen of the sixteen NLCD land cover types are represented by these data – only the Perennial Ice/Snow was not available.

Table 2 reports the parametric statistics describing the height of the NLCD land cover types; Table 3 presents the non-parametric statistics.

Approximately three-quarters of the land cover is in forest. The height distribution for each of the three forest types appears very close to normal – the skew and kurtosis values are close to zero, and the mean, mode and median are all in the 40 to 42 feet range. However, there are clearly areas of forest with 65-foot trees and other areas with 15-foot trees.

The mode – the most common height – for all other land classes is 0. For instance, even though the height for 83 percent of the open water cells is 0, the mean height for open water is 5 feet, which clearly cannot occur. An inspection of the DSM, DTM and NLCD data identifies at least a partial explanation. The resolution of the NLCD is 30 meters. Projecting and resampling these data to 5 meters to match the DSM and DTM files does not change this fundamental relationship. As a result a 30-by-30 meter cell that is classified as water may overlap onto dry land where the elevation is above water level and there is another land cover, such as trees. The reverse will also occur, where a 30-by-30 meter cell that is classified as forest overlaps a river or lake and DSM minus DTM should be zero. In other words, there is some error because of the mismatch in resolution between the NEXTMap and NLCD data. However, the proportion of the data with these types of error is expected to be modest in aggregate and the results still are expected to provide useful guidance.

In general, the non-forested land cover types are positively skewed, but not seriously so. Most also have a positive kurtosis – they are modestly peaked, though some have slightly negative kurtosis. Except for open water, none are exceptionally far from normal.

**Table 2:** Parametric Statistics Describing the Height of NLCD Land Cover Types

| Land Cover | Area (Acres) | Area (Pct) | Mean | Std. Dev. | 95 % Confidence Interval | | Skew-ness | Kurtosis |
|---|---|---|---|---|---|---|---|---|
| | | | | | Upper | Lower | | |
| Open Water | 5,129 | 0.00 | 5.042 | 15.582 | 5.075 | 5.008 | 3.902 | 17.883 |
| Developed, Open Space | 13,042 | 1.49 | 28.44 | 21.573 | 28.469 | 28.411 | 0.386 | -0.738 |
| Developed, Low Intensity | 6,808 | 3.79 | 18.557 | 16.960 | 18.589 | 18.525 | 0.938 | 0.293 |
| Developed, Medium Intensity | 2,827 | 1.98 | 12.193 | 13.767 | 12.233 | 12.153 | 1.529 | 2.322 |
| Developed, High Intensity | 684 | 0.82 | 8.257 | 10.054 | 8.316 | 8.198 | 1.777 | 3.954 |
| Barren Land | 1,223 | 0.20 | 11.432 | 16.340 | 11.504 | 11.360 | 1.759 | 2.748 |
| Deciduous Forest | 90,070 | 0.35 | 40.085 | 19.680 | 40.095 | 40.075 | 0.124 | -0.207 |
| Evergreen Forest | 57,523 | 26.14 | 41.709 | 19.505 | 41.722 | 41.697 | 0.192 | 0.020 |
| Mixed Forest | 113,435 | 16.69 | 41.182 | 18.749 | 41.191 | 41.174 | 0.021 | -0.235 |
| Shrub/Scrub | 17,126 | 32.92 | 21.180 | 18.816 | 21.202 | 21.158 | 0.909 | 0.163 |
| Grassland/ Herbaceous | 2,927 | 4.97 | 22.923 | 20.607 | 22.982 | 22.864 | 0.710 | -0.120 |
| Hay/Pasture | 7,368 | 0.85 | 9.746 | 14.797 | 9.773 | 9.719 | 1.846 | 3.035 |
| Cultivated Crops | 5,631 | 2.14 | 7.576 | 12.553 | 7.602 | 7.551 | 2.274 | 5.575 |
| Woody Wetlands | 19,246 | 1.63 | 24.173 | 19.879 | 24.195 | 24.151 | 0.661 | -0.287 |
| Emergent Herba-ceous Wetlands | 1,524 | 5.59 | 12.185 | 17.992 | 12.256 | 12.114 | 1.652 | 2.057 |

**Table 3:** Non-Parametric Statistics Describing the Height of NLCD Land Cover Types

| Land Cover | Mode | Maxi-mum | 90-pctile | Quartile | Median | Quartile | 10-pctile | Mini-mum |
|---|---|---|---|---|---|---|---|---|
| Open Water | 0 | 175 | 17 | 0 | 0 | 0 | 0 | 0 |
| Developed, Open Space | 0 | 128 | 58 | 45 | 27 | 9 | 0 | 0 |
| Developed, Low Intensity | 0 | 135 | 43 | 29 | 14 | 4 | 0 | 0 |
| Developed, Medium Intensity | 0 | 104 | 32 | 18 | 7 | 1 | 0 | 0 |
| Developed, High Intensity | 0 | 109 | 23 | 13 | 4 | 1 | 0 | 0 |
| Barren Land | 0 | 115 | 36 | 17 | 3 | 0 | 0 | 0 |
| Deciduous Forest | 42 | 152 | 65 | 54 | 40 | 26 | 13 | 0 |
| Evergreen Forest | 42 | 172 | 67 | 55 | 42 | 28 | 16 | 0 |
| Mixed Forest | 45 | 161 | 65 | 54 | 42 | 28 | 16 | 0 |
| Shrub/Scrub | 0 | 145 | 49 | 33 | 16 | 6 | 0 | 0 |
| Grassland/Herbaceous | 0 | 131 | 51 | 39 | 19 | 4 | 0 | 0 |
| Hay/Pasture | 0 | 102 | 32 | 14 | 2 | 0 | 0 | 0 |
| Cultivated Crops | 0 | 115 | 25 | 10 | 1 | 0 | 0 | 0 |
| Woody Wetlands | 0 | 141 | 53 | 38 | 21 | 7 | 0 | 0 |
| Emergent Herbaceous Wetlands | 0 | 115 | 41 | 19 | 2 | 0 | 0 | 0 |

# 4 Discussion

The primary reason for this investigation is to provide data so that a more informed decision could be made about assigning a fixed height to land cover classes for use in visibility analysis. Common practice has been to assign the deciduous, evergreen and mixed forest land cover types a fixed height of 40 feet (12 meters). This turns out to be quite close to the mean, mode and median values for forest cover in the 3-mile strip running from northern to southern New Hampshire. Should the screening height be set at this middle value, or should it be set at a lower value to be more assured that the screen is not artificially high; perhaps the lower quartile which would be about 27 feet (8 meters). On the other hand, developers might argue that the height should be increased because we know there are many taller trees in the forest. It has been TJDA's experience that the 40-foot height has worked well and it is my recommendation would be to keep it. Where it appears that important key observation points (KOPs) will be screened by higher forest cover, it is recommended that this be shown and explained with detailed cross-sections.

This leaves us with deciding what height to assign all the other land cover types. The most common (i. e., mode) height for all land cover types except forest is zero. This may seem surprising, but some reflection indicates why it is so. Many of these land cover types are composed of objects dispersed in an otherwise open environment. There can be a wide variety in object heights, but the in-between areas are often at surface level, which results in a modal value of zero. While people may focus on landscape objects, there is a lot of "negative space" present in most land cover types. For instance, the developed land cover types are defined by the amount of impervious surface present – primarily pavement and structures, which are at ground level or one to several stories high. In addition the developed cover types have some percentage of pervious area, which can be lawn or trees.

This diversity does not lend itself to being characterized by a single fixed height. One can assign high intensity development a height of a three story building, but one may have long view down open streets or across parking lots. The height of 55 percent of the cells classified as high intensity development is below eye-level (i. e., 5 feet). For medium intensity development the figure is 44 percent, for low intensity development it is 29 percent, and for developed open space it is 21 percent. Given the uncertain pattern of heights in the developed land cover types, and the large percentage of cells that are lower than eye-level, it may be reasonable to follow the current practice of not assigning a fixed to them. If developed land cover types are expected to provide a significant screening effect, then it is recommended that NEXTMap or comparable data be acquired. If the screening effect of developed land cover is only critical for a very few KOPs then it may be possible to evaluate it using cross-sections.

Following this same reasoning, it seems reasonable to continue current practice and not assign a screening height to barren land, hay or pasture, cultivated cropland, and emergent herbaceous wetlands. There are scattered landscape elements that will screen views (i. e., trees), but the median value is below eye-level.

This leaves three land cover types that fall between mature forest canopy and the cover types that are generally below eye-level.

- **Shrub/Scrub**. By definition, the shrub/scrub canopy is less than 5 meters (16 feet). While the median is 16 feet, the mean height is 21 feet, or higher than the definition allows. The height for 25 percent of the cells is below eye-level. In the northeast, areas of this type can be abandoned fields in early succession. Also recently harvested forest land appears to be classified as shrub/scrub and may include dispersed residual trees. Approximately 5 percent of the studied area is classified as scrub/shrub.

- **Grassland/Herbaceous**. The mean height is 23 feet, and the median is 19 feet. The height for 29 percent of the cells is below eye-level. This area is similar to shrub/scrub and also may be successional field or recently harvested. Approximately 1 percent of the studied area is classified as grassland/herbaceous.
- **Woody wetlands**. By definition, this cover type has trees (i. e., greater than 5 meters) or shrubs (i. e., less than 5 meters) in a wetland area. The mean height is 24 feet, and the median is 21 feet. The height for 23 percent of the cells is below eye-level. Approximately 6 percent of the studied area is classified as woody wetland.

The modal height for all three areas is 0 feet, and tree canopy in all three types can cover as little as 20 percent of the area. The practice has been not to assign a screening height to these cover types. It continues to be a safe practice for land classes that are so highly variable near eye-level to not be assigned a screening value. However, a position can be reasonably argued that a screening height of 20 feet (6 meters) be assigned to woody wetlands, and 16 feet (5 meters) be assigned to shrub/scrub and grassland/herbaceous, which appear frequently to be fields in early succession or recent timber harvests.

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