

Viewshed Creation: From Digital Terrain Model to Digital Surface Model

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Abstract

Intervisibility studies are limited by the dearth of Digital Surface Model (DSM) elevation data. Most publically available DEMs are Digital Terrain Models (DTM). This paper explores the use of ArcGIS to create DSMs from DTM data. The USGS National Elevation Dataset will be enhanced by extracting vegetation information and man-made structures from the National Land Cover Database (NLCD), Landfire, and National Biomass and Carbon Dataset (NBCD) viewsheds. The resulting composite DSM will be compared with in-situ observations, LIDAR, and IFSAR DSM viewsheds.

Results from a flat area in the Rio Grande Valley of Texas show that correct modeling of vegetation is critical to viewshed generation. The 30 meter national land cover and vegetation data sets perform poorly in urban and agricultural areas where crop types change rapidly and tree lines along roads contribute significantly to masking intervisibility. Results from more rolling terrain in Maine suggest greater utility for using the 30 meter data to create DSMs. In both areas LIDAR and IFSAR DSMs significantly outperformed the DSMs created from NED, and a 1 meter LIDAR DSM significantly outperformed a 3 meter version, justifying the much higher storage requirements.

Introduction

Viewsheds or intervisibility studies identify the cells in an input raster that can be seen from one or more observation points. They are used in a wide array of applications, such as security, military, commercial, land use planning, and a plethora of others. Viewsheds are usually created with using DEM (digital elevation model) datasets as the input elevation dataset. Most publically available DEMs are of the bare earth, or a digital terrain model (DTM).

Vegetation and man-made structures hamper intervisibility studies. A DTM does not factor these types of obstructions into account and the resulting viewshed can be flawed. To overcome this a digital surface model (DSM) can be used during the viewshed creation. However, there is a dearth of DSM data available.

The most common DEM in the US is the National Elevation Dataset (NED) created by the United States Geological Service (Gesch, 2007 and Gesch and others, 2002). The NED is a DTM and comes in resolutions of 1", 1/3" and 1/9", which are usually considered equivalent to 30, 10, and 3 meter resolution. The NED is derived from a number of sources including digital line graphic products, digitized topographic maps, photogrammetry, and LIDAR. The accuracy

of the NED depends on the source used to create it. Though it should be noted that all DEM data contain errors and has varying degrees of uncertainty (Fisher and Tate, 2006).

Because the most publically available DEM data are DTMs, accurate modeling of viewsheds for anything that requires line of site is problematic. Using DTM data in an area that has significant vegetation will yield inaccurate results. Figure 1 shows a viewshed performed on a site in the Rio Grande Valley (RGV), Texas using 1" NED, (left). The sensor was nearly 80 meters off the ground, with 360 degree visibility, and a target height of 1.5 meters. Based on the results the sensor can observe essentially all the surrounding areas. The picture below the map shows the areas indicated by the red angle. Due to vegetation and man-made structures, very few targets 1.5 meters high would be visible. On the right is a viewshed performed at a Maine site using 1/3" NED. The sensor was 1.5 meters high and a target height of 1.5 meters. The results show that while the topographic features were more correctly modeled, there is vegetation that would further restrict the area visible. This picture was taken during leaf-off season and the difference would be more pronounced during leaf-on season.

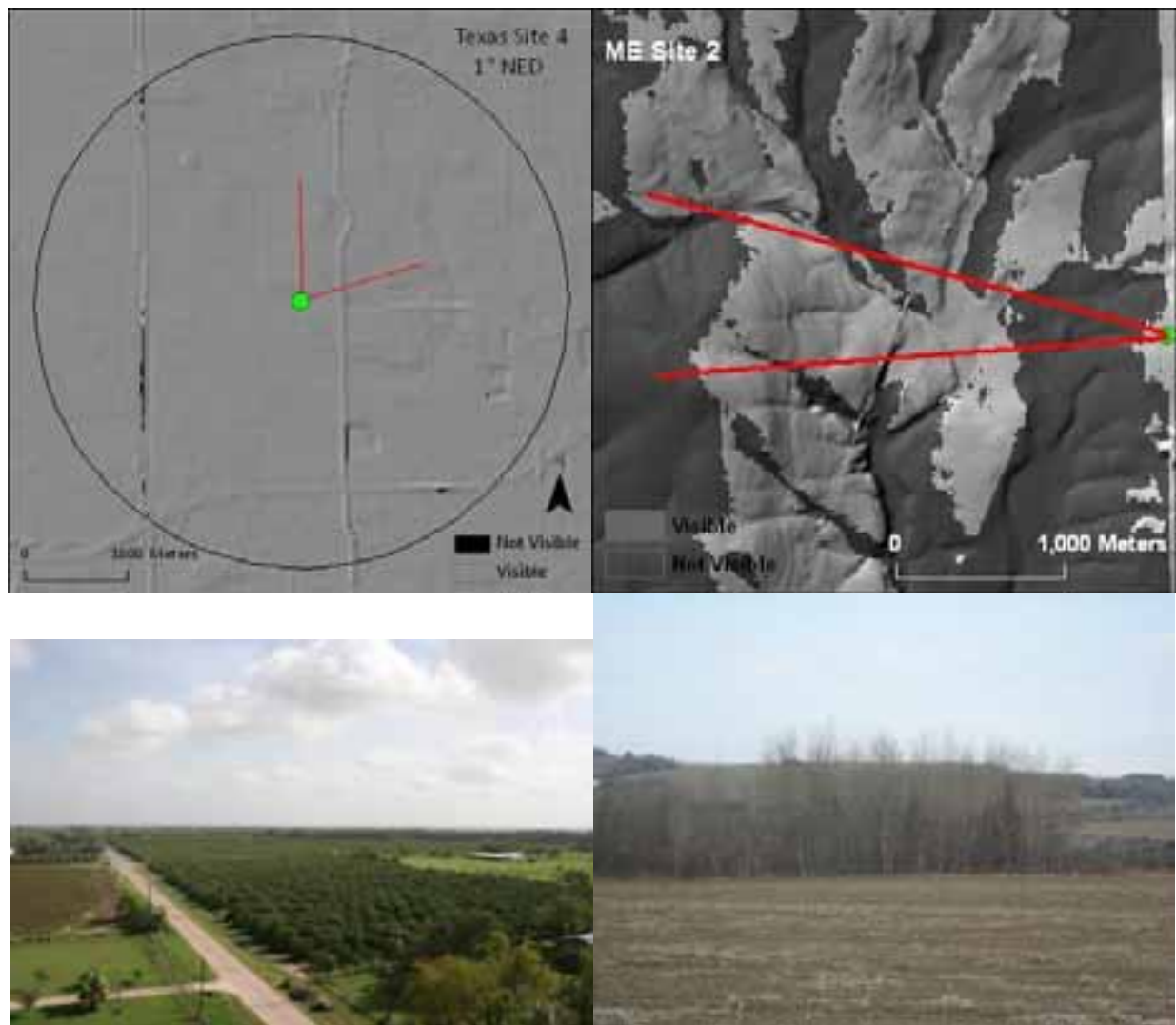


Figure 1. Views from RGV Site 4 and Maine Site 2. NED DTM compared to field photograph.

Guth theorized that by combining traditional DTM datasets with available vegetation information it would make it possible to create a composite DSM that may be more accurate in viewshed creation (Guth 2009). The three most common sources of vegetation data for the U.S. are the National Land Cover Dataset (NLCD), the Landfire dataset, and the National Bio-Carbon Dataset (NBCD). All three datasets have information concerning the location of vegetation; two of them have man-made structure information and, with the exception of the NLCD, have average height information.

This project aims to overcome the limitations of DTM based viewsheds by creating DSM DEMs through combining readily available DTM data with ancillary data sources. To corroborate the results, LIDAR point clouds (available for the RGV sites), IFSAR five meter DSM (available for two sites in Maine), and the Shuttle Radar Topography Mission (SRTM) (USGS 2004 and 2006) DSM were used to create additional viewsheds. In-situ observation will be used to further corroborate the results of the DTM and DSM viewsheds. The resulting DSM will not be free of error (Fisher, 2006), but may yield a more accurate viewshed as reflected in reality.

Study Areas

The study areas were chosen to represent different environments that any area may represent, to include an urban location, crop lands, forested area, and suburbs. The RGV sites encompass 86.1 square kilometers and the Maine study areas encompass 94.6 square kilometers.

The first study areas were in the RGV, Texas ((97° 49'W, 26 ° 4'N) in the areas of La Feria and Santa Maria (Table 1).

Table 1. Summary of RGV study areas based on NLCD 2001 and 1/9" NED.

Site	Mean Slope	Area	Crops/Pasture	Developed	Woodland/Forest	Scrub/Barren Land
RGV1	1.42°	22.6 sq km	70.65%	12.97%	8.50%	4.82%
RGV2	1.00°	17.6 sq km	81.96%	9.05%	2.96%	4.34%
RGV3	1.17°	24.6 sq km	53.36%	36.20%	3.55%	2.46%
RGV3	0.89°	21.2 sq km	74.39%	18.56%	2.60%	4.45%

The second study areas were in Northern Aroostook County, Maine (67° 51'W, 46° 34'N) between Fort Fairfield and Mars Hill (Table 2).

Table 2. Summary of Maine study areas based on NLCD 2001 and 1/3" NED.

Site	Mean Slope	Area	Crops/Pasture	Developed	Woodland/Forest	Scrub/Barren Land
ME1	3.32°	4.5 sq km	26.65%	29.85%	10.79%	11.53%
ME2	3.70°	25 sq km	64.04%	4.77%	15.05%	9.00%
ME3	4.81°	39.9 sq km	43.58%	9.29%	45.74%	9.00%
ME4	3.89°	25 sq km	34.40%	4.00%	58.42%	2.10%

The RGV study area is very flat; intervisibility studies usually indicate near complete visibility for any given site. The Aroostook County, ME study areas have rolling hills and a large number of forested areas that can detrimentally affect visibility, (Figure 2).

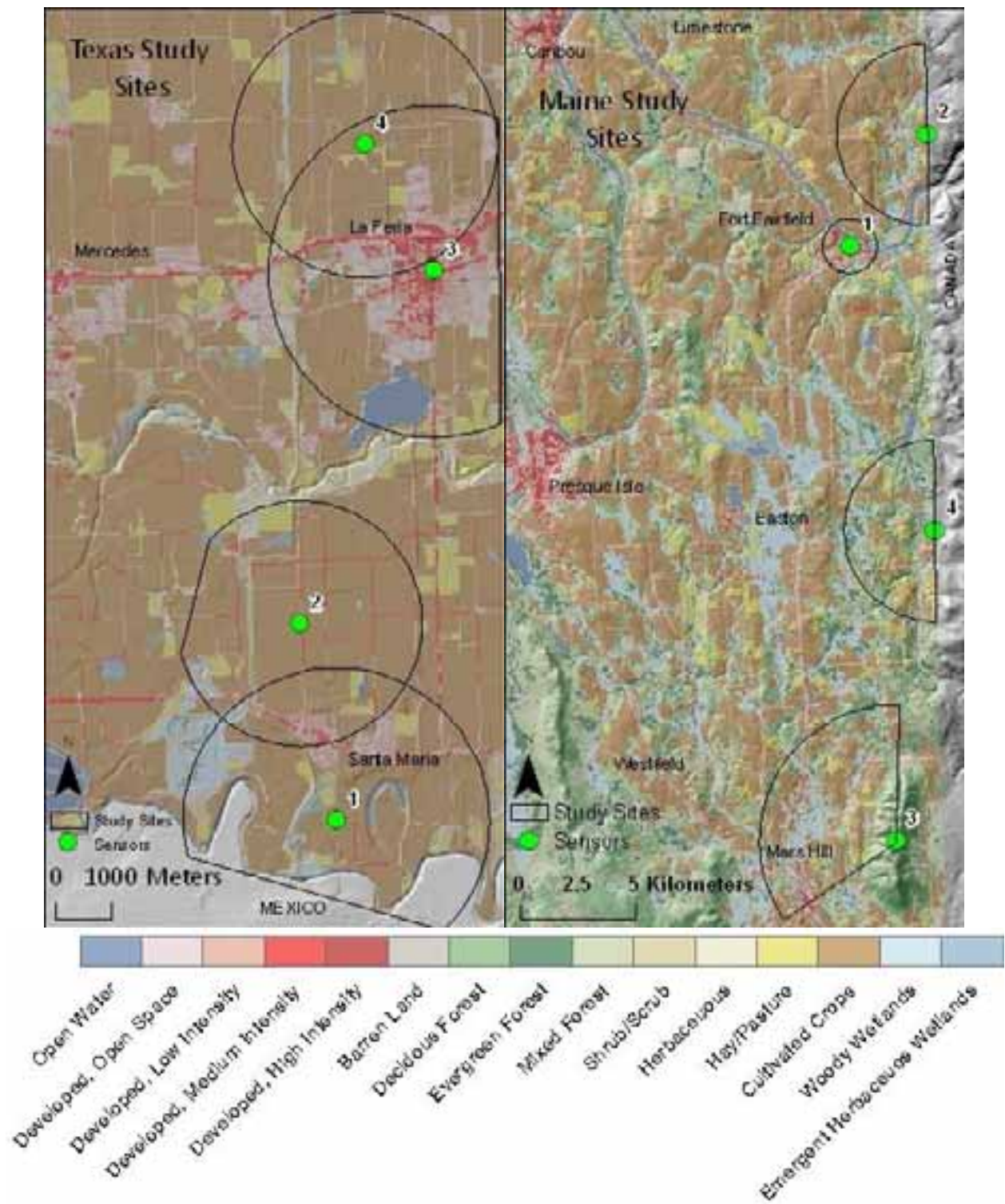


Figure 2. Study areas for RGV, Texas and Aroostook County, Maine. NLCD and NED 1/3".

Data

NED and DEM

The United States Geological Service has created the NED from the best available elevation data; some areas have 1/3" and 1/9" data available in addition to national 1" coverage. Additionally, the NED is updated every two months and is public domain (USGS). These qualities make the NED one of the most commonly available DTM source.

The study used the NED supplied by the USDA Natural Resource Conservation Service (NRCS) Geospatial Data Gateway web site, which the USDA re-projects to NAD 1983 UTM projection. This data is regularly synchronized with USGS's update schedule, ie every two months. Both study areas had NED data available though in different resolutions and derived from different data sources. The RGV sites had both a high accuracy NED derived from LIDAR at the 1", 1/3" and 1/9" resolution and an older version of the NED at 1" and 1/3" derived from "unknown" data. The LIDAR derived data was made available in 2008 and the "unknown" was dated 2005. Some of the surrounding counties from the RGV sites have not had their NED updated to LIDAR based data. These counties were derived from digital line graphic (DLG) files which suggest that the older NED in the RGV sites was also derived from DLGs; however, the metadata for the area in question stated "unknown". The NED data available for the Maine sites was derived from DLG files in 2005 and was available in 1" and 1/3" resolutions. (See appendix B for metadata and download dates of DEM sources).

The Texas Natural Resources Information Systems (TNRIS) supplied the LIDAR point clouds for the RGV sites. The data was collected with a ground sample distance of 0.7 meters in 2007 and made available in 2009. The data has a vertical accuracy of ± 18 cm. (Sanborn Mapping Company, Inc). The LIDAR data was in classified LAS format, both DSM and DTM data could be extracted. Applied Imagery's software, Quick Terrain Modeler was used to extract the DSM data from the point cloud with a resolution of one meter.

The study used the Shuttle Radar Topography Mission (SRTM) version 2.0 for the RGV sites and version 1.0 for the Maine sites. The data was obtained from the Global Land Cover Facility at the University of Maryland. The data was limited to 1" resolution and is canopy based (USGS 2004; 2006).

IntraMap supplied IFSAR DTM and DSM data for the Maine sites (Hensley 2007). The IFSAR data had a resolution of five meters and covered two of the study areas. It was collected in 2007 and published in 2008. The vertical accuracy is recorded as 1 meter RMSE in flat unobstructed areas (IntraMap 2008).

Vegetation Mapping Projects

The NLCD 2001 (Fry and others 2004) database is a landcover dataset that records 29 different categories of landuse. These include evergreen trees, and developed low intensity landcover. The NLCD dataset does not include height information.

The NBCD data is based on the SRTM, NED, Landfire and NLCD-2001. The purpose of the NBCD is to produce an estimate of basal area-weighted canopy height, above ground live dry biomass and standing carbon stock for the conterminous United States for the year 2000 (Woods Hole Research Center). Its resolution is limited to 30 meters and has weighted canopy height that can be directly added to existing elevation DEM to create a viable composite DTM.

The Landfire dataset is a five-year wildfire, ecosystem and wildland fuel dataset and is based on the NLCD with a effective resolution of 30 meters. The vegetation data has approximate height information. This study uses the Existing Vegetation Height (EVH) dataset to obtain vegetation height, calculating the EVH height by “the average height weighted by species cover” (U.S. Geological Survey).

All three datasets are based from Landsat imagery and therefore the resolution is fixed at 30 meters which approximates 1” resolution NED. The Landfire dataset notes that the dataset “should not be used at the individual pixel level or on small groups of pixels” (U.S. Geological Survey). The same could be argued for the other datasets as well. However, using no vegetation data probably will yield incorrect results and using some vegetation data will hopefully result in better results. The question is whether the available data helps.

The study used the best data available but there exists several gaps of time between when the datasets were collected and processed. The LIDAR data was collected between 2005 to 2007; whereas the NLCD, Landfire and NBCD were produced earlier this decade. The IFSAR data was collected in 2007 and the NAIP imagery used in the in-situ observations was collected in 2007 for the Maine sites and 2008 for the RGV sites.

Methodology

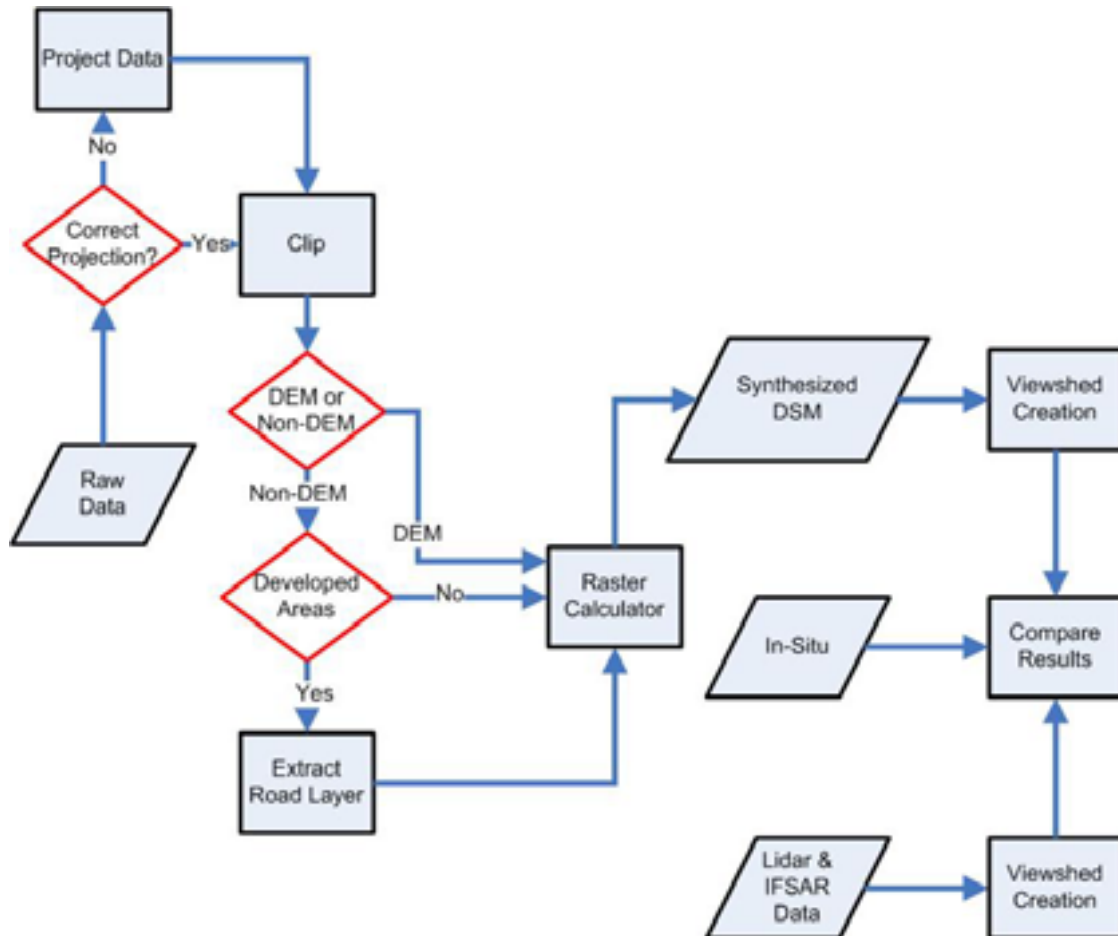


Figure 3. Overview of methodology used to create and compare viewsheds.

All primary datasets: the NED, LIDAR, SRTM, NAIP imagery, and ancillary elevation datasets were converted to NAD 83 UTM from their original projections. Table 3 shows the different datasets, their original projection, and any conversion errors to NAD 83.

Table 3. Original projections of data and resulting datum conversion errors as per European Petroleum Survey Group (EPSG) Geodesy Parameters Version 7.5 database.

Dataset	Original Projection	Transformation Error
Landfire	NAD 1983 Albers	None
NLCD	NAD 1983 US Contiguous Albers Equal Area Conic USGS	None
NBCD	NAD 1983 US Contiguous Albers Equal Area Conic USGS	None
SRTM 1"	WGS 1984	1 meter
NED 1", 1/3", 1/9"	NAD 1983 UTM14N/UTM19N (USDA)	None
LIDAR	NAD 1983 StatePlane Texas South FIPS 4205 Feet	None
IFSAR DTM and DSM 5 Meter	NAD 1983 UTM 19N (IntraMap)	None

Once the study re-projected the data, the NBCD data could be directly added to the elevation datasets. The NBCD raster data had approximate heights for vegetation and no man-made features. The Landfire and NLCD datasets were reclassified and the man-made features were taken into account before adding to the elevation data.

The Landfire and the NLCD datasets both had areas classified as low, medium, and high intensity developed areas. These designations corresponded with roads and concentrations of man-made structures. Neither dataset differentiated between structures and road features. The quickest method to address this would be to classify all developed areas as zero meters in height, but this models the city areas incorrectly. To overcome this difficulty the study added e911 roads dataset (Maine) and the Stratmap street layers (RGV) to the study areas. These vector datasets were then buffered to the correct width as per NAIP comparison, converted to a raster then integrated with the reclassified vegetation layers as zero height. Street locations were then identified in the Landfire and NLCD datasets by proximity and visual inspection. The identified road features were extracted from the datasets and then added with the buffered street dataset. This enabled more correct modeling of road and man-made structures in relation to vegetation features.

The NLCD and Existing Vegetation Heights (EVH) Landfire dataset do not have vegetation height information in the raster values. The EVH dataset has different classifications of vegetation and their approximate height range, i.e. 1-2 meters. The NLCD has different types of landcover with no height information.

Both the NLCD and the Landfire datasets had to be reclassified to ensure the raster value referred to height information. In the case of the Landfire dataset, the greater of the heights in a given range was used for the new value. In cases where the height was $> x$ meters, the height was multiplied by 1.5 and rounded up, (i.e. $x = \text{round}(1.5x)$). The NLCD did not have approximate heights, only types of landcover. Based on the information in the Landfire database and on the author's observation, the different types of landcover were given an arbitrary height

(see appendix one). All forested regions were given the dominant height in the Landfire dataset for the given area.

Reclassified data was multiplied with the road data. All road data were given a value of zero and other areas a value of one. This changed the vegetation height to zero where road features were and maintained developed areas, creating a more realistic height index. This reclassified data was then added to the existing NED to create a composite DEM of the area that was used in viewshed creation.

The study then calculated the viewshed with a target height of 1.5 meters to approximate viewing humans and vehicles. The target height was measured from the surface of the viewshed being created. It would have been more accurate to measure the height from the DTM in each study but limitations of the software prevented this. Each viewshed was calculated at the same resolution to maintain equitable comparisons. The smallest resolution data was the LIDAR DSM with one meter, which was originally used as the viewshed resolution. To ensure that only within the boundaries of the delineated study areas were considered each viewshed was converted to a vector data, clipped to the buffer of the sensor, and then converted back to a raster. This allowed the author to ensure the viewshed was calculated against the same area for each dataset and to facilitate the easier collection of in-situ data. This process of calculations took a prohibitively long time and the computer would often crash during the process. A compromise of three meters was used as the viewshed resolution, (see appendix D for the ArcModel of this process).

Comparative viewsheds were performed at one meter and three meter to assess the possible loss of accuracy. It was noted that the primary difference between the two resolutions was that the one meter viewsheds extenuated the height of the vegetation and structures to create more non-visible areas and crops/orchards had a speckling of visible areas, see figure 4 and table 4.

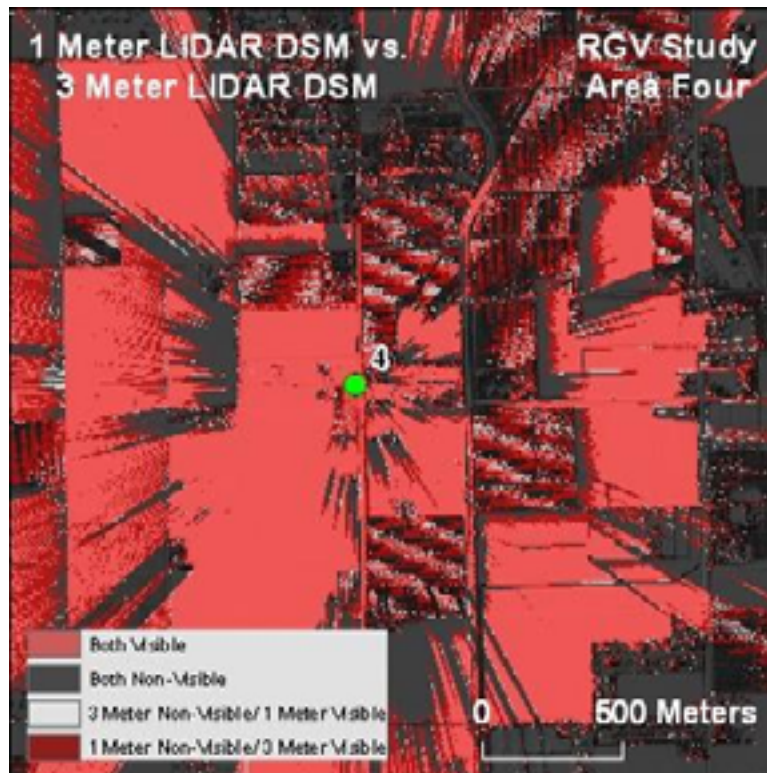


Figure 4. Comparison of three meter LIDAR DSM viewshed against one meter LIDAR DSM overlaid with LIDAR DSM hillshade.

Table 4. Percentage differences between one meter LIDAR DSM viewshed and three meter LIDAR DSM viewshed. These percentages are not comparable with percentages, (shown later in paper), since they were performed as bounding boxes and were not limited to the defined study area.

LIDAR DSM Viewshed	RGV1	RGV2	RGV3	RGV4
1 Meter				
Visible	18.39%	43.35%	6.95%	19.99%
Non-Visible	81.61%	56.65%	93.05%	80.01%
3 Meter				
Visible	30.19%	63.92%	16.15%	69.28%
Non-Visible	69.81%	36.08%	83.85%	30.72%

The LIDAR point cloud was manipulated with Applied Imagery's Quick Terrain Modeler to extract a DSM DEM from the first returns. The LIDAR data was collected with a ground sample distance of 0.7 meters, the DSM DEM was created with a resolution of one meter. Without access to the point cloud obtaining a DSM at the desired resolution would have been difficult. While performing a mosaic of the LIDAR data there were slivers in the data. In order to average out these slivers, the study used the following calculation in the raster calculator:

Con(IsNull([LIDAR_DEM.img]), FOCALMEAN ([LIDAR_ DEM.img], RECTANGLE , 3 , 3 , data),[LIDAR_ DEM.img]) .

In-Situ Observations

In both areas the study recorded and compared in-situ observations with the other viewsheds. The in-situ observation spotter utilized the latest available NAIP imagery and sketched what areas were visible, (figure 5). This information was then digitized into a GIS and compared with the composite viewsheds and the DSM DEM viewsheds. The in-situ observer collected data for Texas during August (leaf-on) and the Maine sites in February and March (leaf-off season).



Figure 5. Examples of the author collecting in-situ (RGV) observation and the finished product of the observation (Maine).

Results

RGV Sites

Figure 6 shows the RGV site's visible pixels for each viewshed. Data is shown with the type of DEM used, for the composite DEM a plus (+) symbol is used to tie the NED and ancillary elevation data together. Both the NEDs that were LIDAR derived and "unknown" were computed; LIDAR have the designation of "L", i.e. 1" (L) to differentiate them from the NED that was derived from "unknown".

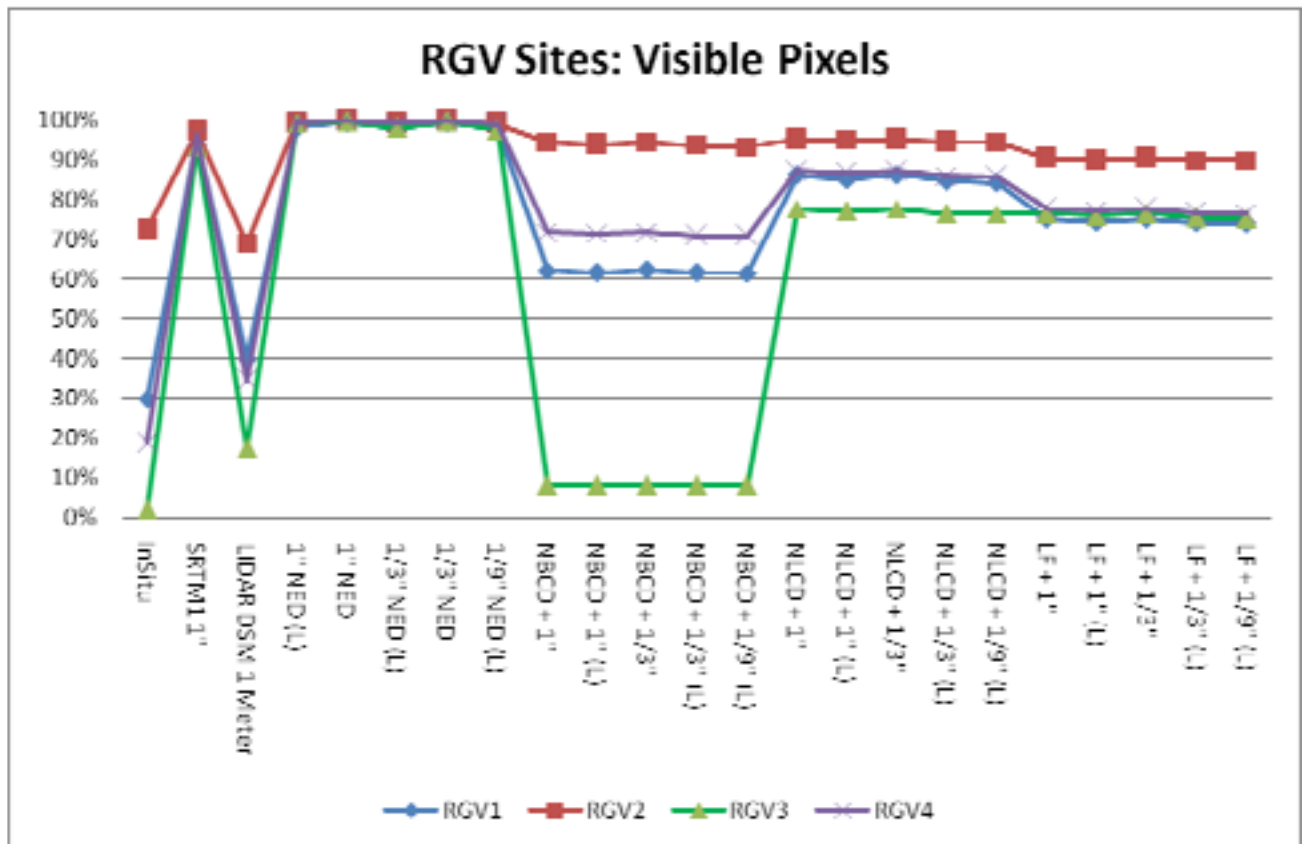


Figure 6. Visible percentage of viewsheds for RGV, Texas sites.

There is not much difference between the DTM NED viewsheds that were derived from LIDAR vs Unknown data, (see table 5 below). These differences were reflected in all the composite DEMs created. It does not matter whether the composite DEM was created from the 1/9" or 1" elevation data, or whether the data was derived from highly accurate LIDAR data or not; the differences between them is minimal. Vegetation data is much more important than the underlying DEM data. This is likely because the mean slope of the RGV sites is 1.1° degrees, i.e. flat. For the RGV sites topography appears to have very little impact on computed intervisibility. For flat areas it is imperative that the best vegetation data be acquired.

Table 5. Percent of visible pixels from RGV sensors with NED DTMs used for viewshed.

DTM Viewsheds	RGV1	RGV2	RGV3	RGV4
1" NED (L)	98.14%	99.46%	99.15%	99.72%
1" NED	99.44%	99.97%	99.67%	100.00%
1/3" NED (L)	97.82%	99.08%	98.06%	99.12%
1/3" NED	99.47%	99.98%	99.65%	100.00%
1/9" NED (L)	97.54%	98.97%	97.62%	99.06%

The most closely aligned viewsheds are Insitu and LIDAR DSM. This is further evidenced by the four examples shown below in figure 7 and table 6. The in-situ data is displayed as a transparent red for visible and transparent for non-visible while the DEM viewshed is shown as black non-visible and white visible. This allows four combinations of colors to indicate whether both compared datasets are visible, non-visible, visible/non-visible, and non-visible/visible.

Some irregularities with the LIDAR data appear, including telephone lines and tall antenna arrays. Visible in study two: the tower in the northeast part of the study area and the jagged non visible lines that run NW to SE and N to S. The sharp edges of the in-situ observations may not conform with reality, but without creating a fuzzy viewshed this is difficult to display.

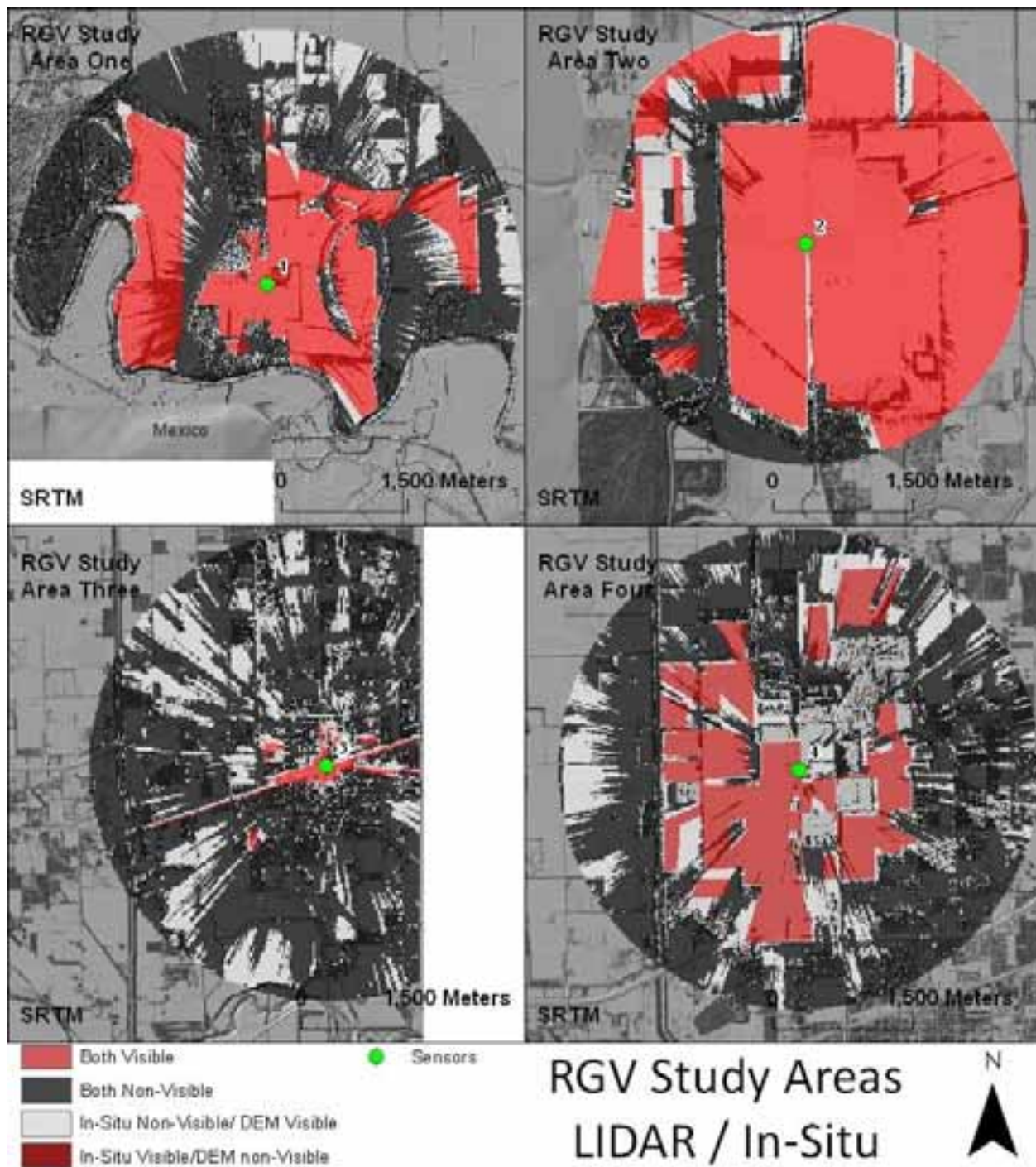


Figure 7. Texas study areas LIDAR DSM 1 meter compared to In-situ observation, overlaid LIDAR DSM.

Table 6. Percent visible for RGV sites compared between LIDAR DSM and in-situ observation.

	RGV1	RGV2	RGV3	RGV4
InSitu	29.64%	72.58%	1.92%	18.88%
LIDAR DSM 1 Meter	39.80%	68.85%	17.42%	34.52%

The results of the SRTM viewshed indicated much of the area was visible. Figure 7 shows the difference between the in-situ and SRTM. When the target was lowered to zero meters extreme amounts of artifacts were present in the viewshed. Guth has shown that the SRTM over-smoothes areas of high topography and has too much noise in flat areas. Together these limitations combine to lower the effective resolution of the SRTM to at least 2" rather than 1" (Guth 2006). For this study the SRTM data is too coarse to be used in a large scale viewshed; in the hillshade to the right of the viewshed map the noise in the SRTM becomes visible. Guth further cautioned users that would utilize the vegetation data because of its inconsistent height characteristics as shown in figure 8. (Guth 2009) (See figure 39 in appendix C for a figure depicting additional differences).

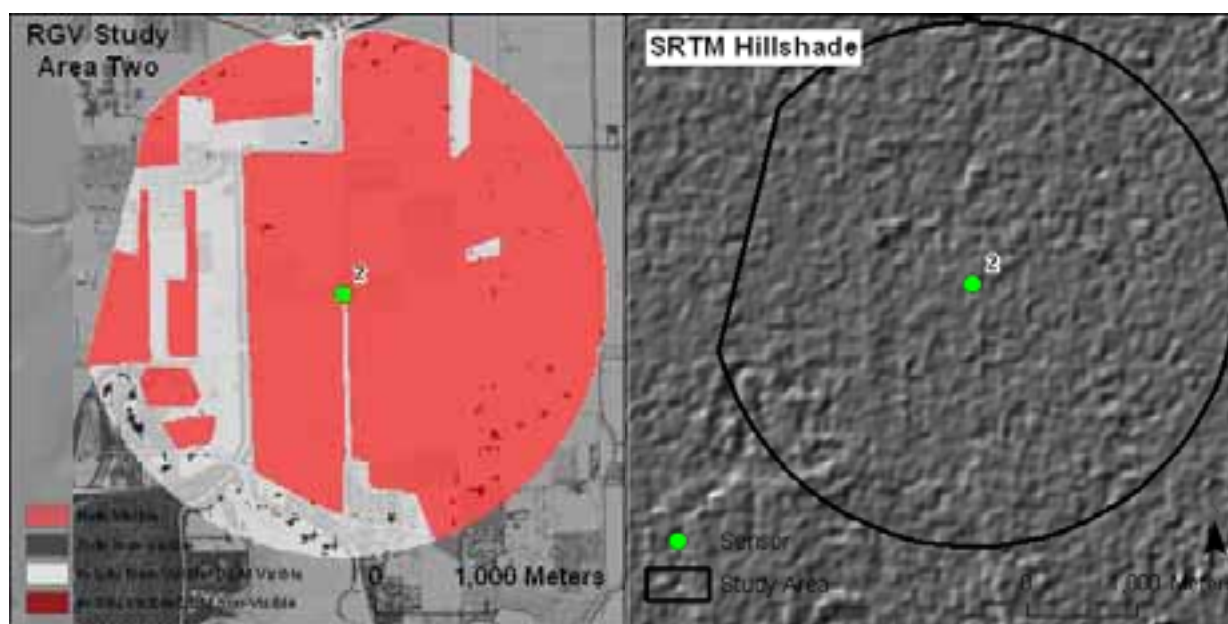


Figure 8. SRTM compared to In-Situ observation for RGV site two and SRTM hillshade of the area.

The NBCD data also appeared to correspond closely at RGV study site three. When comparing the NBCD data, several areas of man-made structures are incorrectly given a vegetation height, resulting in a false positive. Figure 9 shows a comparison between NLCD developed areas and NBCD vegetation information. Figure 10 shows a comparison between NBCD data and NAIP imagery that indicate some vegetation in the area with significant man-made structures.

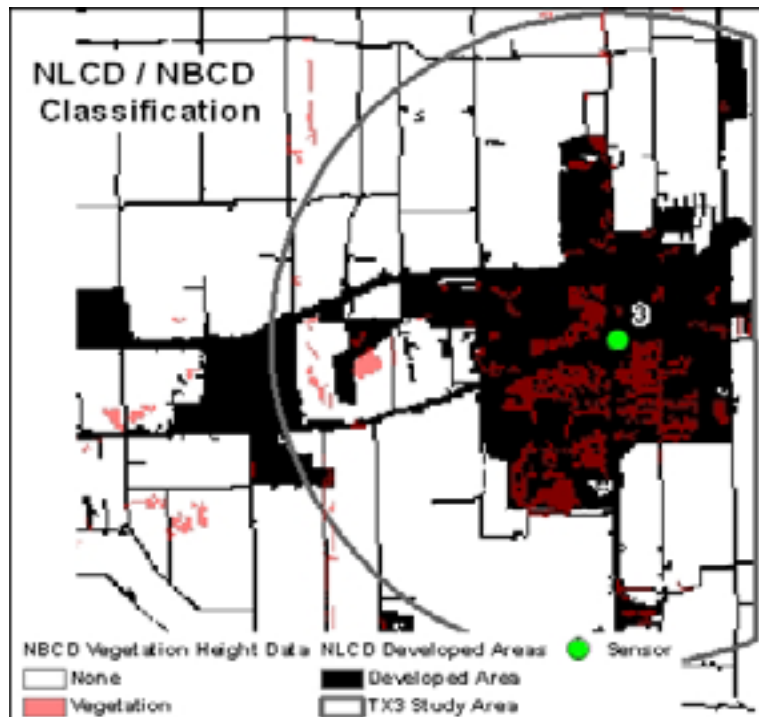


Figure 9. Comparison for RGV site three between NLCD developed areas and NBCD height information. The two datasets show different types of landcover in the study site.

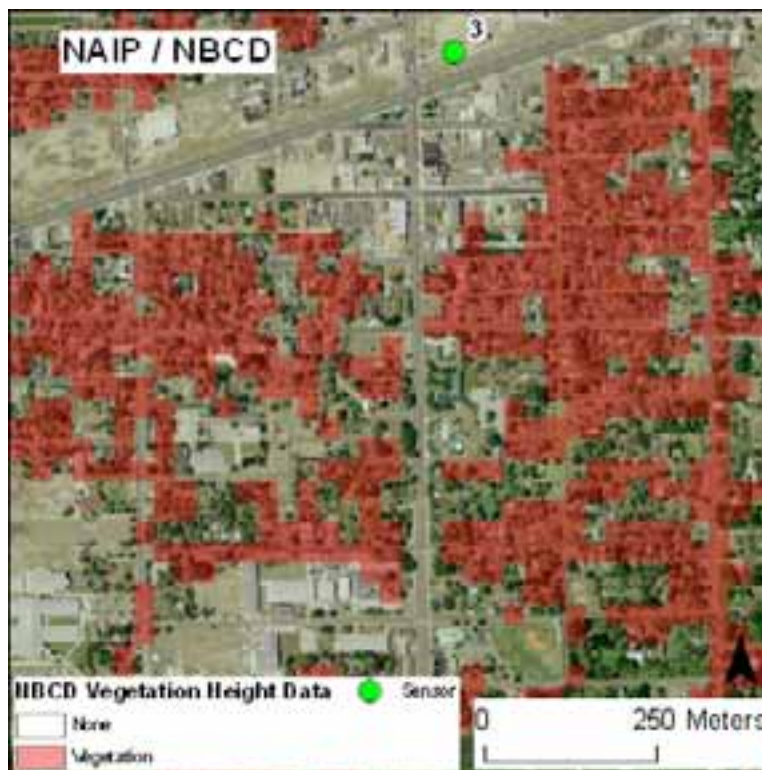


Figure 10. NBCD vegetation data overlaid on 2008 NAIP imagery.

The NLCD, Landfire and NBCD data composite viewshed results show some improvement over the NED, but for most applications they would be unacceptable. The NLCD, NBCD, and Landfire composite DSMs are fairly easy to create, but they yield unsuitable results for most areas. (Refer to appendix C for all comparisons between all the RGV study sites and the in-situ observations).

Maine Sites

Figure 11 shows the visible pixels for the Maine study sites, using the same format as the RGV graph. It does not use the “L” designation because no LIDAR derived DEM information was available. For sites one and two IFSAR data was available; this data is at the right end of the graph to avoid confusion.

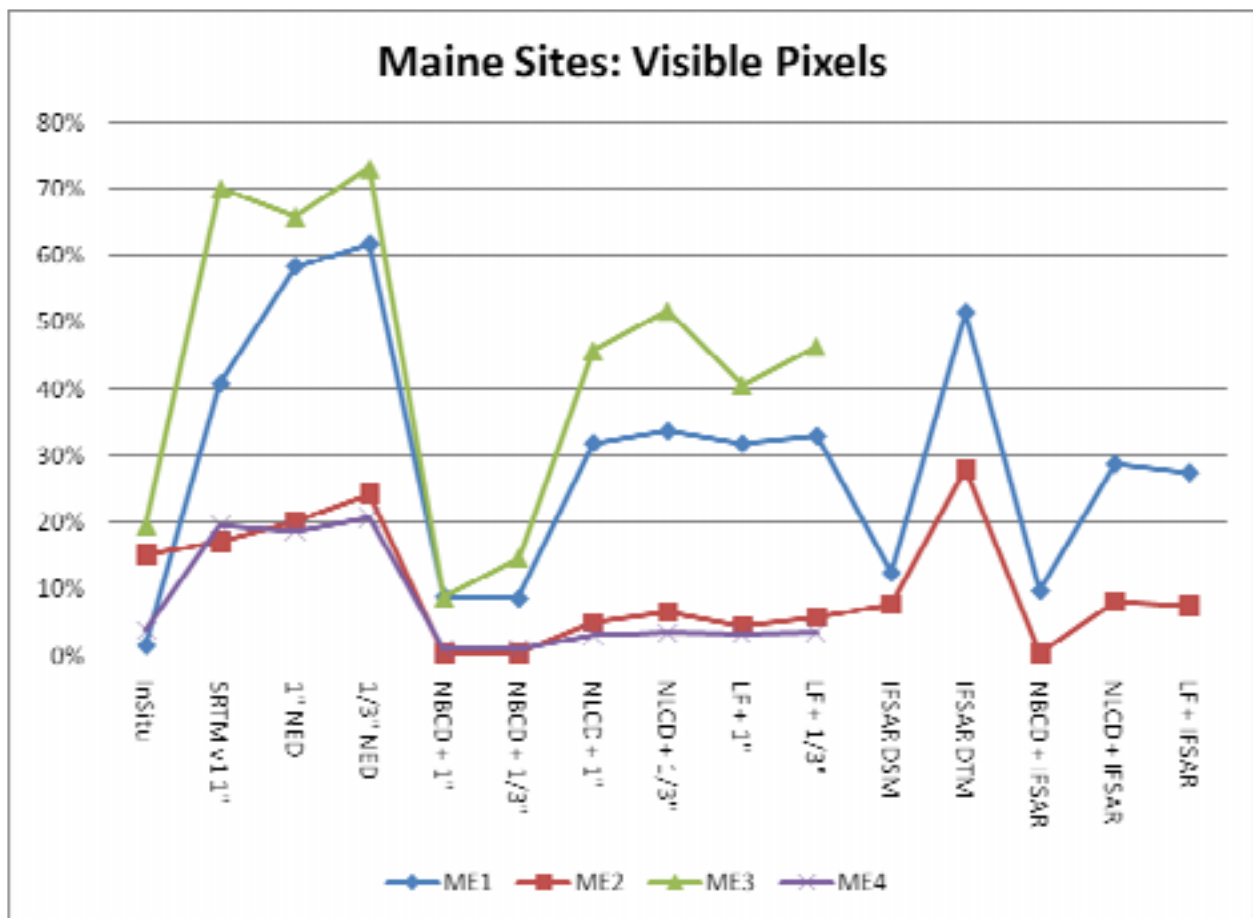


Figure 11. Visible percentage of viewsheds for Aroostook County, Maine sites.

The NED data had similar results for each of the study sites; site three represented the most disparity between the viewsheds with the NED 1/3" having 7.24% more visible area than the NED 1". Site three is the largest study area for Maine and the differences between the DTM are that much more exacerbated. The parallels between the NED viewshed data is carried over to the composite DEMs with the exception of site four. At site four half of the study area is blocked by trees to the north and the topography precludes viewing to the south-west, figure 12 displays

the immediate area around the site four's sensor. Site four composite viewshed results are in appendix C.

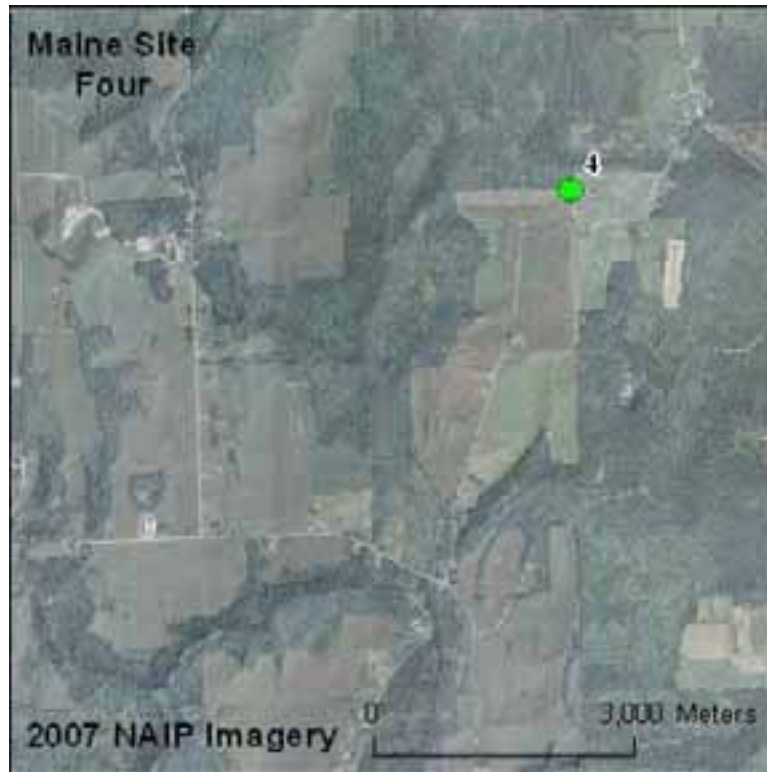


Figure 12. Maine site four overlaid 2007 NAIP imagery of the area.

The IFSAR DTM viewshed data was 10.27% less visible than the 1/3" NED viewshed at site one and 3.88% more visible at site two. The differences between the DTM data viewsheds is shown in table 7. Site one is located on the corner of an intersection and the underlying topography has been modified by the man-made structures. Unless the dataset can model structures, it will be incorrect, (see figure 13).

Table 7. Percent of visible pixels for Maine sensors when viewshed computed against DTM DEMs.

DTM Viewshed	ME1	ME2	ME3	ME4
1" NED	58.47%	20.19%	65.93%	18.69%
1/3" NED	61.82%	24.13%	73.17%	20.76%
IFSAR DTM	51.55%	28.01%	N/A	N/A

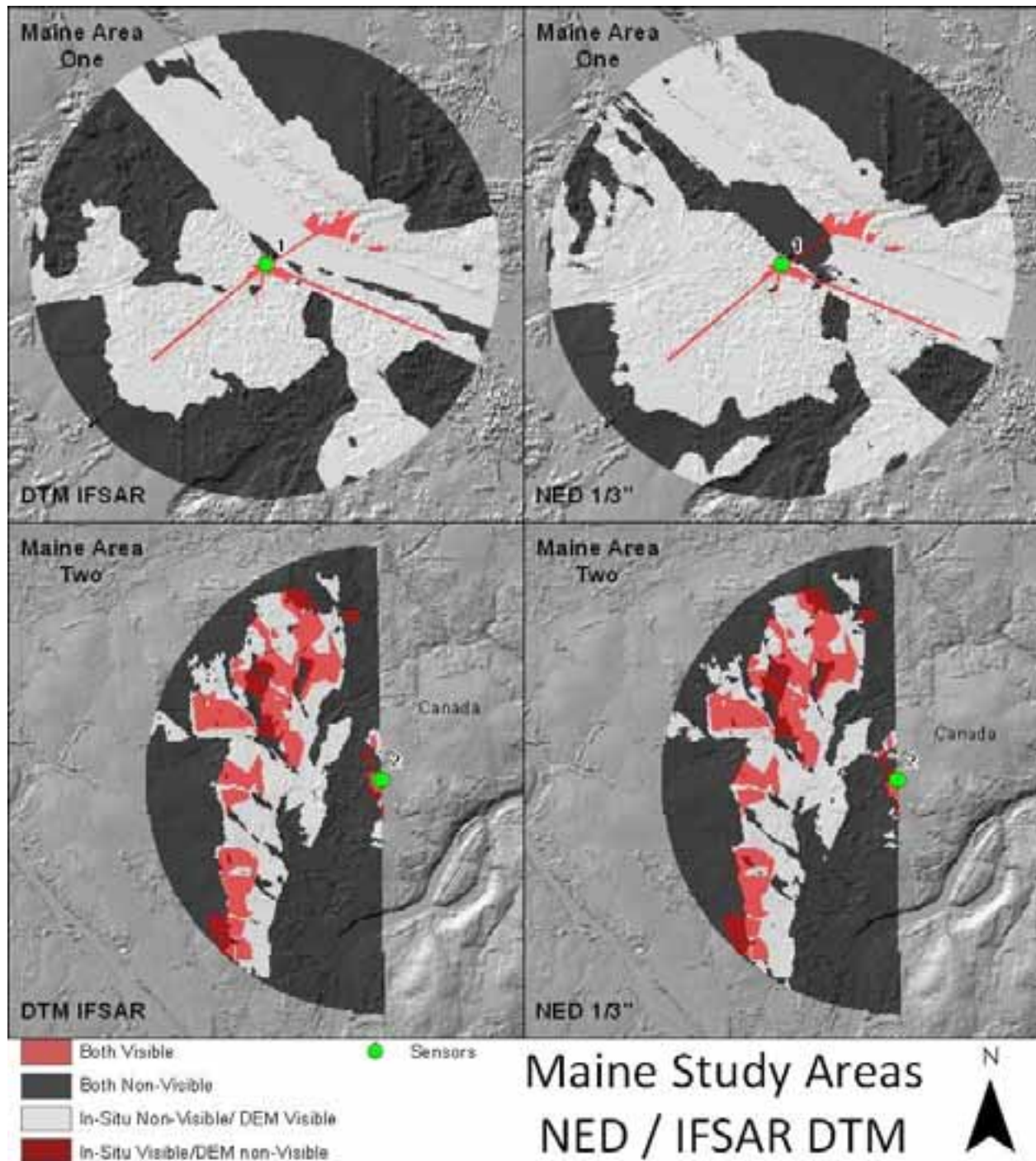


Figure 13. Maine study site one and two, DTM viewsheds compared to in-situ observation, overlaid on IFSAR DSM hillshade.

The IFSAR DSM provides a closer match to the in-situ observations for sites one and two than the other DTMs and composite DSM DEMs. Site two primarily has vegetation and topography obstructions that do not have noticeable influence on the IFSAR DSM viewshed. However, site one's major obstructions are man-made. The vertical and horizontal accuracy of the IFSAR DSM (2 meters horizontal, 1 meter vertical in areas of unobstructed flat ground) does contribute

a greater degree of negative correlation to the in-situ data. There is only a 45% convergence between the IFSAR DSM and in-situ observation at site one. Figure 14. This is in contrast to the 66% coverage the LIDAR DSM viewshed has against the in-situ data at RGV study site three. The LIDAR DSM data appeared to model the clean lines of man-made structures better than the IFSAR DSM.

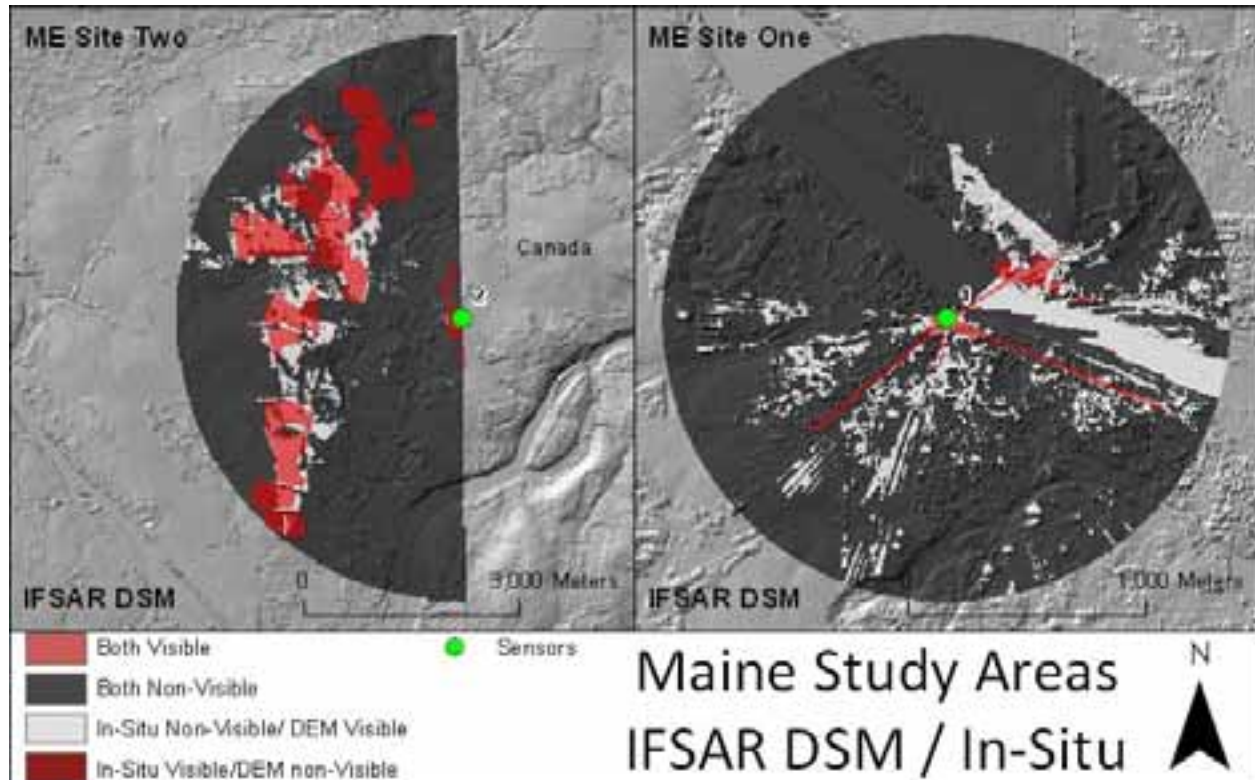


Figure 14. Maine study areas IFSAR DSM 5 meter compared in-situ observation, overlaid IFSAR DSM.

The SRTM had the same problems exhibited in the RGV Sites, the flat areas had too much radar noise and the steep areas were over-smoothed. For the Maine sites, this resulted in the SRTM being unable to adequately model the vegetation or structures in the study areas. Site two appears to match the in-situ data but their positive visibility only overlays one another 21%, see figure 15. (See figure 40 in appendix C for SRTM comparative viewsheds).

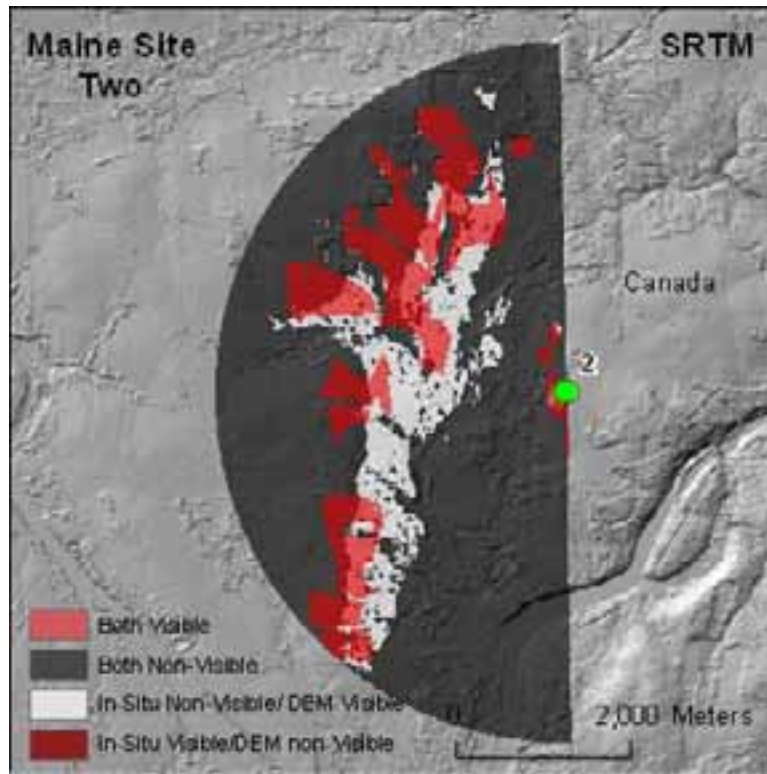


Figure 15. Maine study site two. SRTM 1" viewshed compared to in-situ observation, overlaid on IFSAR DSM hillshade.

According to the graph the NBCD data appears to positively correlate with the in-situ results for Maine sites one and three. The RGV sites the NBCD data is intermingled with the structures in the town, which appears to create the situation for a false positive. This is repeated with site three when a closer examination shows that the NBCD + 1/3" DTM viewshed yields almost the exact opposite of the in-situ data, see figure 16. Appendix C shows the other Maine study sites.

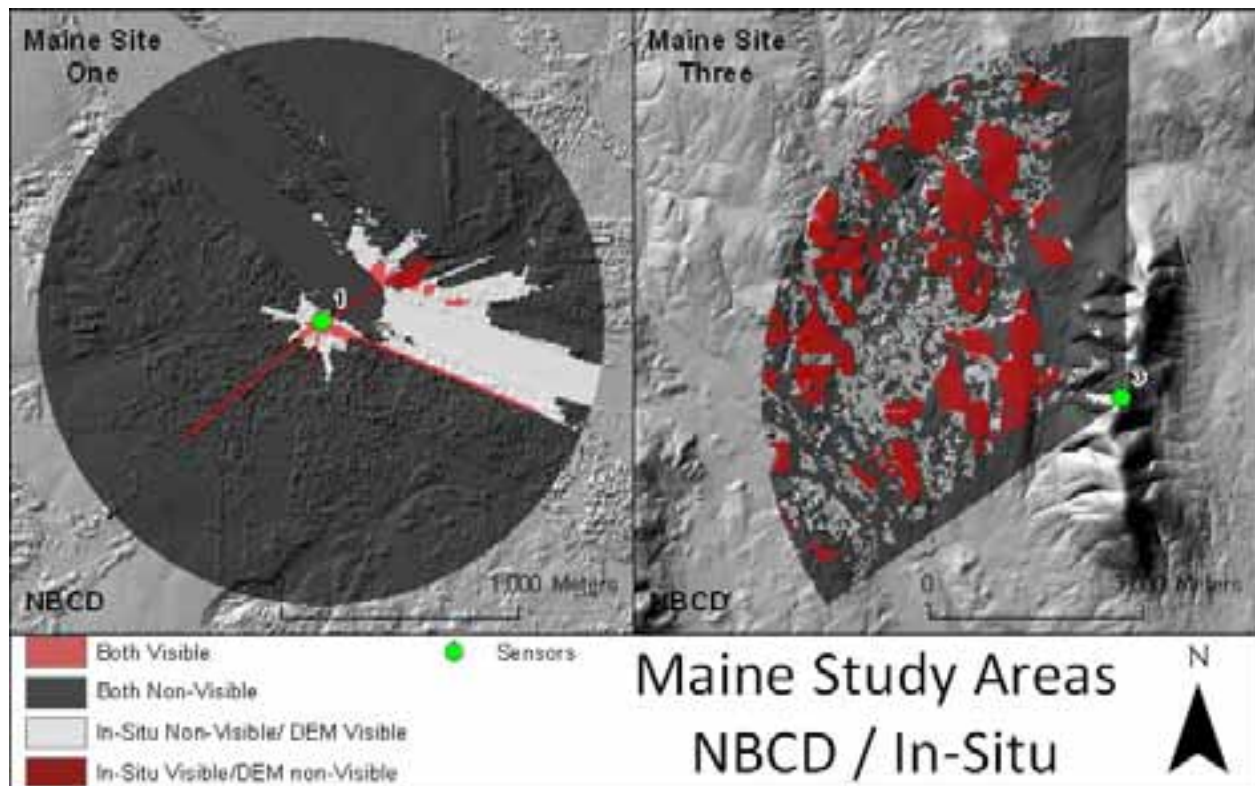


Figure 16. Maine study site one and two. SRTM 1" viewshed compared to in -situ observation, overlaid on IFSAR DSM hillshade on the left and the NED on the right.

Findings With RGV and Maine

Both urban areas (site three RGV and site one ME) were modeled best by the IFSAR and LIDAR DSM data with the LIDAR being the better of the two. None of the three ancillary datasets used (NBCD, NLCD, and Landfire) did a good job of modeling the complexities of an urban environment. The NBCD data ignores all urban data and the other two datasets have blocks of urban data set aside in large parcels designating them as low, medium, and high intensity. This makes it difficult to correctly model structures and streets as shown in figure 17. This problem can be overcome by using either IFSAR or LIDAR DSM data. If not available, local users would need to obtain or create a local dataset containing building footprints, extrude them, and add them to the composite DSM.

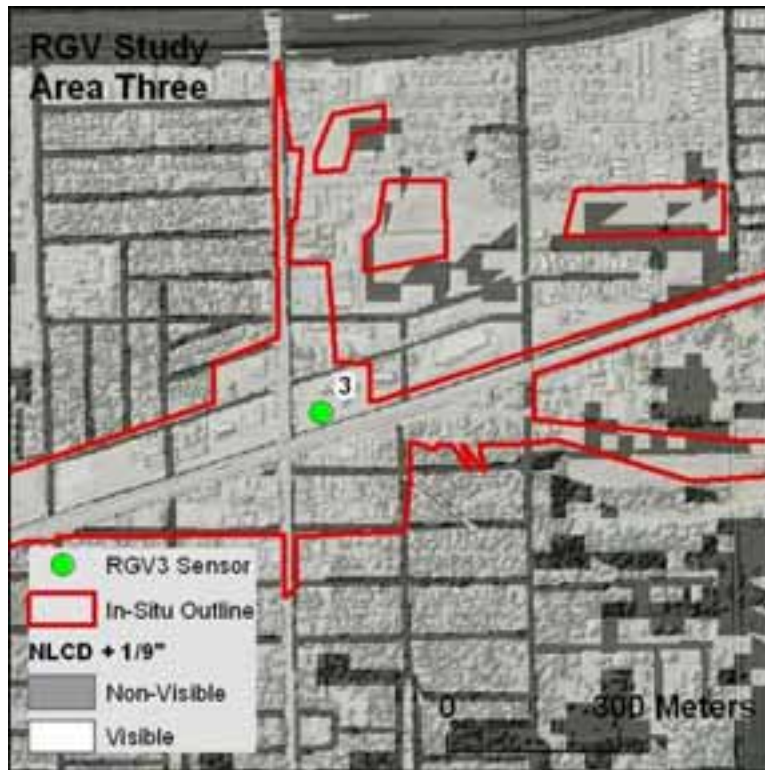


Figure 17. RGV Study Site Three. NLCD + 1/9" composite DSM compared to in-situ observation, overlaid LIDAR DSM.

The vegetation data found in the NLCD, NBCD and Landfire datasets was inadequate at the large scale where the viewsheds were performed. Figure 18 displays Landfire data for RGV sites one and four overlaid by LIDAR DSM. The transparent arrows indicate areas classified as cultivated crops when in fact they were either orchards or standing trees. These omissions become more apparent when viewsheds were computed against the data. Other Landfire products have reported shortcomings when used on a local scale since the dataset is intended to be used at a national scale. In order to use the Landfire dataset for large scale viewsheds, further refinement of the data should be carried out by local users (Scott 2008). This will improve accuracy.

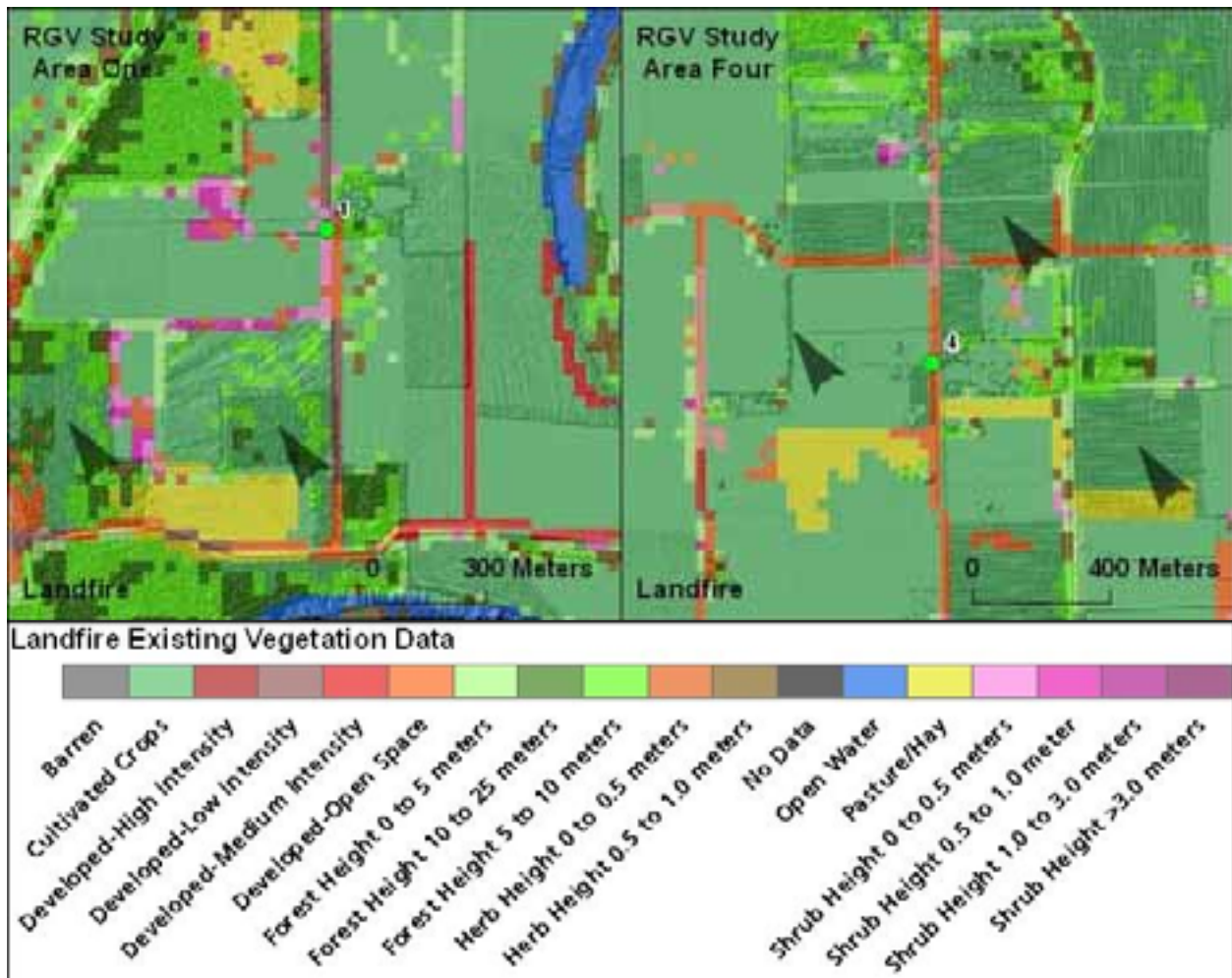


Figure 18. Landfire classification overlaid on LIDAR DSM hillshade. Transparent arrows indicate areas that appear to have the incorrect classification.

The other two vegetation datasets, NLCD and NBCD have more generalized data which misses much of the detailed vegetation. Figure 19 shows the same two areas as above but with height data for the NBCD and category information for the NLCD.

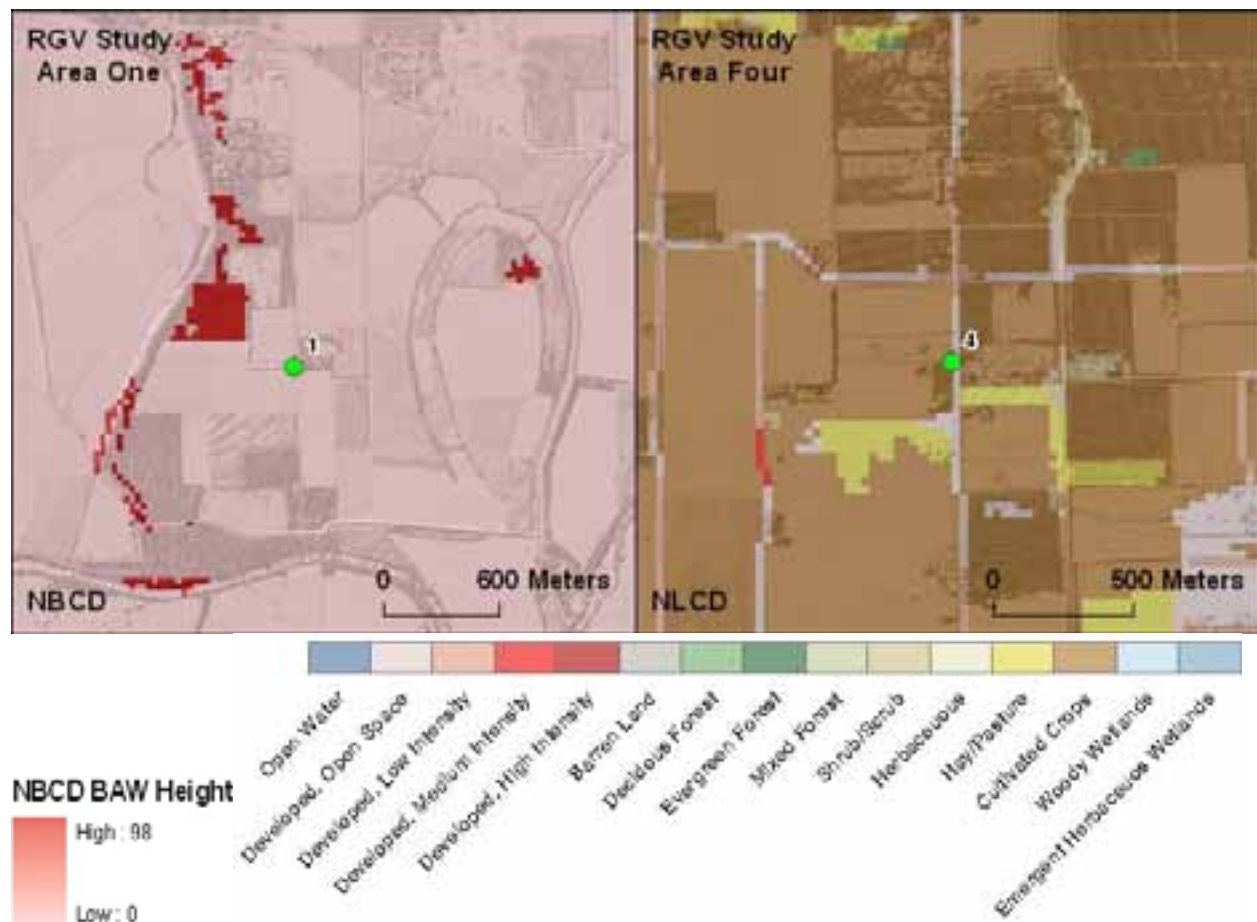


Figure 19. RGV sites one and four showing NBCD and NLCD data overlaid on LIDAR DSM data.

Discussion

This study used a subjective in-situ process to collect visibility measures; which depended on the ability of the observer to identify terrain and sketch it on a map. This was dependent on the experience of the collector, the tools used and the time of year (leaf-on or leaf-off). Besides direct comparison with LIDAR and IFSAR DSM data there was no way to determine how accurate the in-situ collections were.

Swanson (2003) collected in-situ data while comparing the differences between viewshed software and the ability of different DEM resolutions to accurately compute intervisibility. He used a total surveying station at each observer point and had a target mounted in a vehicle that would traverse specific azimuths. When line of site was obscured distance measurements were taken and recorded (Swanson 2003).

Because of the large area covered by each study site Swanson's method may be impractical to duplicate. With time, and at least two people, this study's in-situ data could implement spot visibility checks at key locations to further validate the findings. However, depending on how often the vegetation and man-made structures change any in-situ data could become outdated very quickly.

To overcome this problem and to more accurately model intervisibility with DEM data that does not change to reflect environment changes, Fisher, and others proposed a fuzzy approach to viewshed creation (Fisher 1996; Anilela and others 2002). They argued that instead of simple visible/not visible classification, a viewshed should have several gradients of possible visibility. (Fisher 2009). While fuzzy viewsheds can add more realism to a viewshed they are not easy to produce and require specialized software and weights for the fuzzy creation that have not been standardized.

During the course of collecting in-situ data for this study the author was able to see through the vegetation at some sites. Traditional intervisibility studies are unable to model this ability; fuzzy viewsheds can more correctly model this phenomena. By taking into consideration distance, slope, and density of the vegetation, the viewshed can show those areas that have a higher probability to be seen when the in-situ observation is performed.

Conclusion

The results for the RGV sites indicate topography had very little effect on the viewsheds while the Maine sites indicated that both good topography and vegetation data were needed. The sites in the RGV had a range of slope from 0° to 20.5° (those areas greater than 8° were along man-made canals and the Rio Grande River), whereas the range of slope for Maine sites was from 0° to 43.1°. Based on these results, in flat areas the correct modeling of vegetation is the most important factor in obtaining an accurate viewshed. In steeper areas both vegetation and topography are important to obtain accurate viewsheds. Whenever significant vegetation exists,

which hampers the sensor from seeing the target, DTMs are not sufficient to obtain an accurate result.

Existing national vegetation data, the NLCD, NBCD, and Landfire datasets, coupled with DTM data to form a composite DSM, performed poorly in both urban and in agricultural areas where crops types change rapidly and tree lines along roads contribute significantly to masking intervisibility. However, these composite DSMs yielded better results than using only DTM data.

IFSAR DSM, LIDAR DSM and in-situ observation outperformed the DTMs and composite DSMs, and a 1 meter LIDAR DSM significantly outperformed a 3 meter version, justifying the much higher storage requirements. In-situ observations can yield promising results but are labor intensive, and are prone to error, which increases as the study areas cover more ground. A benefit of collecting an in-situ viewshed is leaf-off and leaf-on visibility conditions may be more accurately modeled than otherwise possible with DEMs.

Appendix A

Table 8. NLCD reclassification criteria used to extract elevation data from dataset.
NLCD Reclassification

Type	Meters
Pasture & Barren	0
Deciduous Forest	10
Evergreen Forest	10
Mixed Forest	10
Scrub cover & Scrub Trees & Orchards	5
Cultivated Crops	1
Woody Wetlands	10
Emergent Herbaceous Wetlands	1
Developed Areas	15

Set Maine forests to 25 to conform with greater amounts of trees reported as 10-25 meters by Landfire dataset.

Table 9. Landfire reclassification criteria used to extract elevation data from dataset.
LandFire Reclassification

Type	Meters
Open Water	0
Developed-Open Space	0
Developed	15
Barren, Pature/Hay, Cultivated Crops	0
Herb Height 0 to 0.5 meters	1
Herb Height 0.5 to 1.0 meters	1
Herb Height >1.0 meter	2
Shrub Height 0 to 0.5 meters	1
Shrub Height 0.5 to 1.0 meter	1
Shrub Height 1.0 to 3.0 meters	3
Shrub Height >3.0 meters	5
Forest Height 0 to 5 meters	5
Forest Height 5 to 10 meters	10
Forest Height 10 to 25 meters	25
Forest Height 25 to 50 meters	50
Forest Height >50 meters	75

NBCD Reclassification

None needed

Appendix B

NED metadata (Note: The Cameron County NED was obtained for both “unknown” and LIDAR derived NED. The download dates and information is recorded below).

Cameron County NED 1/9”

Downloaded 04/1/2010

Originator: USDA/NRCS - National Cartography & Geospatial Center

Publication Date: 2000-Present

Source Scale Denominator: 3 meter

Process Date: 201003

Grid Coordinate System Name: Universal Transverse Mercator

UTM Zone Number: 14

Horizontal Datum Name: North American Datum of 1983 (NAD83)

Ellipsoid Name: GRS1980

Cameron County NED 1/3”

Downloaded 04/1/2010

Originator: USDA/NRCS - National Cartography & Geospatial Center

Publication Date: 2000-Present

Source Scale Denominator: 10 meter

Process Date: 201003

Grid Coordinate System Name: Universal Transverse Mercator

UTM Zone Number: 14

Horizontal Datum Name: North American Datum of 1983 (NAD83)

Ellipsoid Name: GRS1980

Cameron County NED 1/3”

Downloaded 10/29/2009

Originator: USDA/NRCS - National Cartography & Geospatial Center

Publication Date: 2000-Present

Source Scale Denominator: 10 meter

Process Date: 200905

Grid Coordinate System Name: Universal Transverse Mercator

UTM Zone Number: 14

Horizontal Datum Name: North American Datum of 1983 (NAD83)

Ellipsoid Name: GRS1980

Cameron County NED 1”

Downloaded 04/1/2010

Originator: USDA/NRCS - National Cartography & Geospatial Center

Publication Date: 2000-Present

Source Scale Denominator: 30 meter

Process Date: 201003

Grid Coordinate System Name: Universal Transverse Mercator
UTM Zone Number: 14
Horizontal Datum Name: North American Datum of 1983 (NAD83)
Ellipsoid Name: GRS1980

Cameron County NED 1"

Downloaded 10/29/2009
Originator: USDA/NRCS - National Cartography & Geospatial Center
Publication Date: 2000-Present
Source Scale Denominator: 30 meter
Process Date: 200905
Grid Coordinate System Name: Universal Transverse Mercator
UTM Zone Number: 14
Horizontal Datum Name: North American Datum of 1983 (NAD83)
Ellipsoid Name: GRS1980

Aroostook County NED 1/3"

Downloaded 10/20/2009
Originator: USDA/NRCS - National Cartography & Geospatial Center
Publication Date: 2000-Present
Source Scale Denominator: 10 meter
Process Date: 200905
Grid Coordinate System Name: Universal Transverse Mercator
UTM Zone Number: 19
Horizontal Datum Name: North American Datum of 1983 (NAD83)
Ellipsoid Name: GRS1980

Aroostook County NED 1"

Downloaded 10/20/2009
Originator: USDA/NRCS - National Cartography & Geospatial Center
Publication Date: 2000-Present
Source Scale Denominator: 30 meter
Process Date: 200905
Grid Coordinate System Name: Universal Transverse Mercator
UTM Zone Number: 19
Horizontal Datum Name: North American Datum of 1983 (NAD83)
Ellipsoid Name: GRS1980

Appendix C

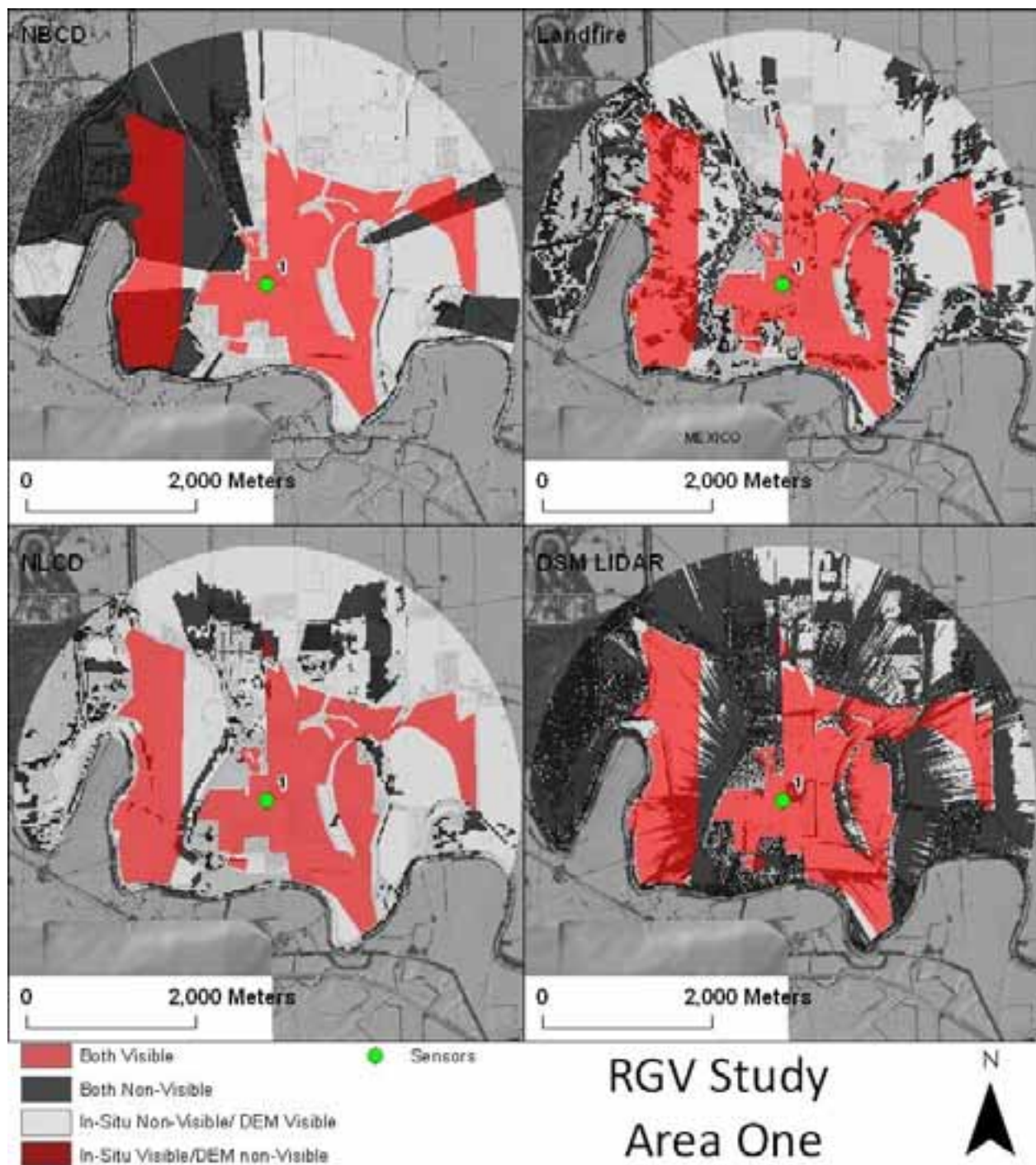
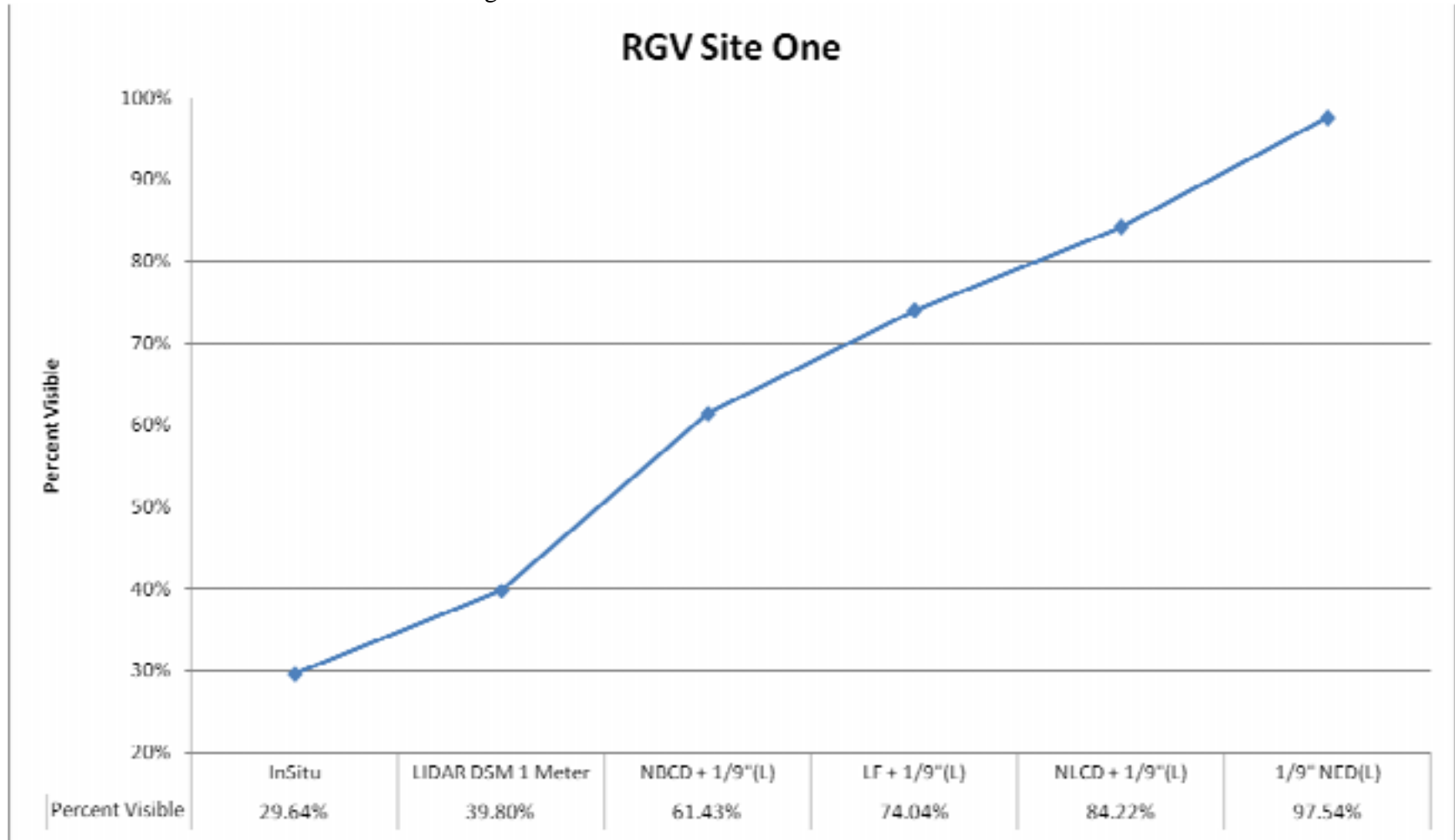


Figure 20. Maine study area 1 with NBCD, Landfire, and NLCD composite DSM viewsheds. Also DSM LIDAR viewshed. Overlaid LIDAR DSM.

Table 10. Percent visible at RGV site 1 using different DEM data.



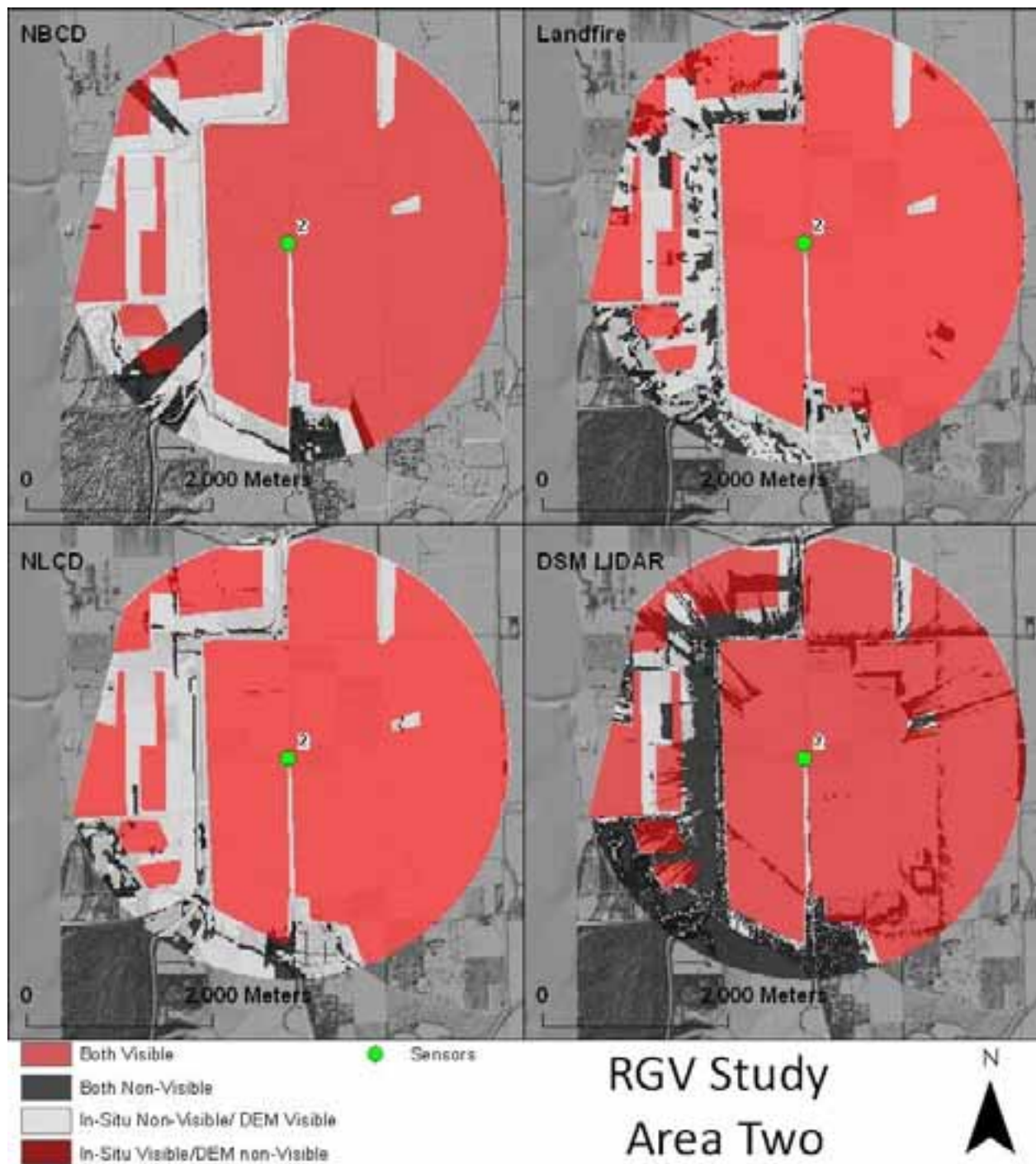
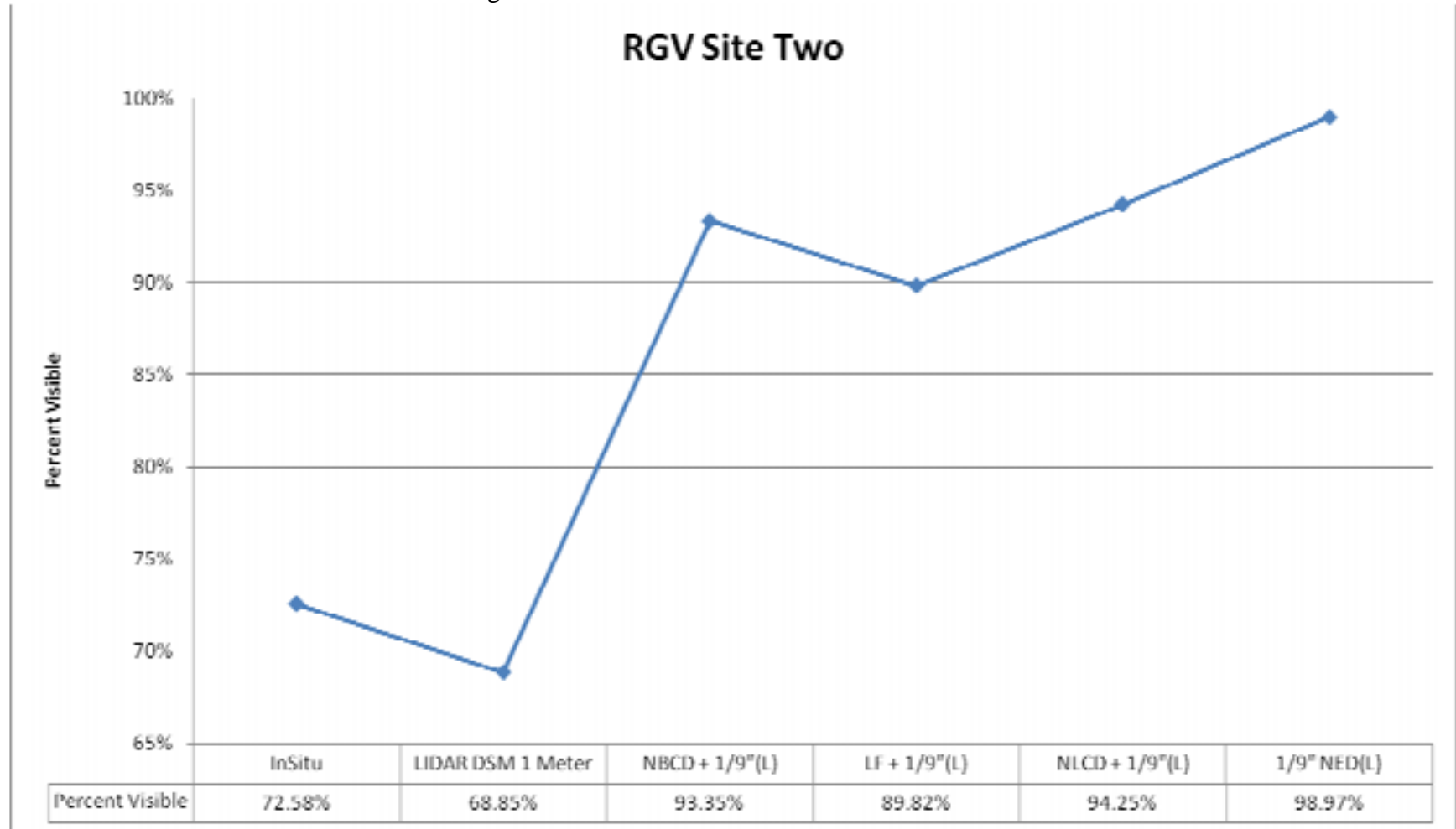


Figure 21. Maine study area 2 with NBCD, Landfire, and NLCD composite DSM viewsheds. Also DSM LIDAR viewshed. Overlaid LIDAR DSM.

Table 11. Percent visible at RGV site 2 using different DEM data.



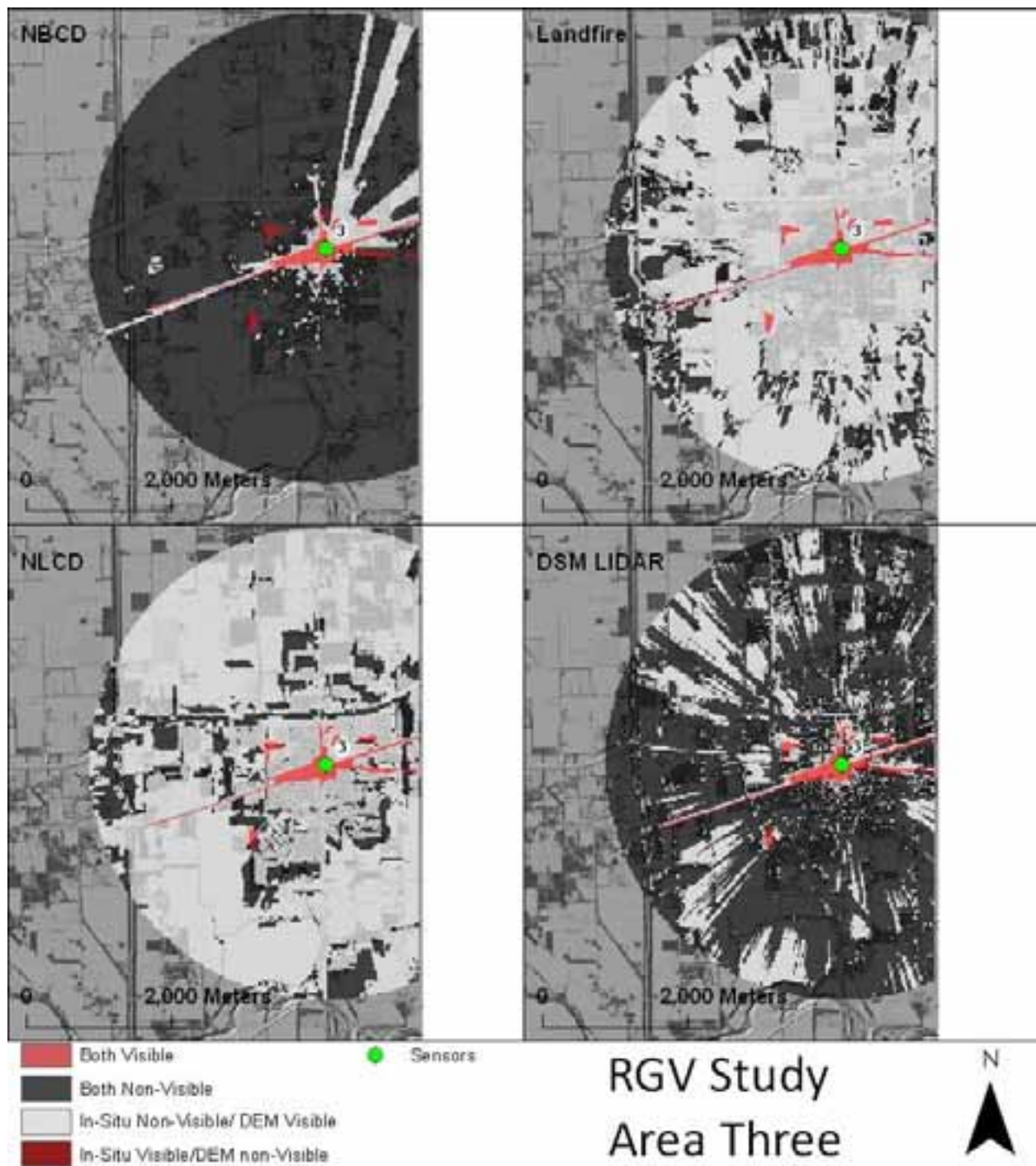
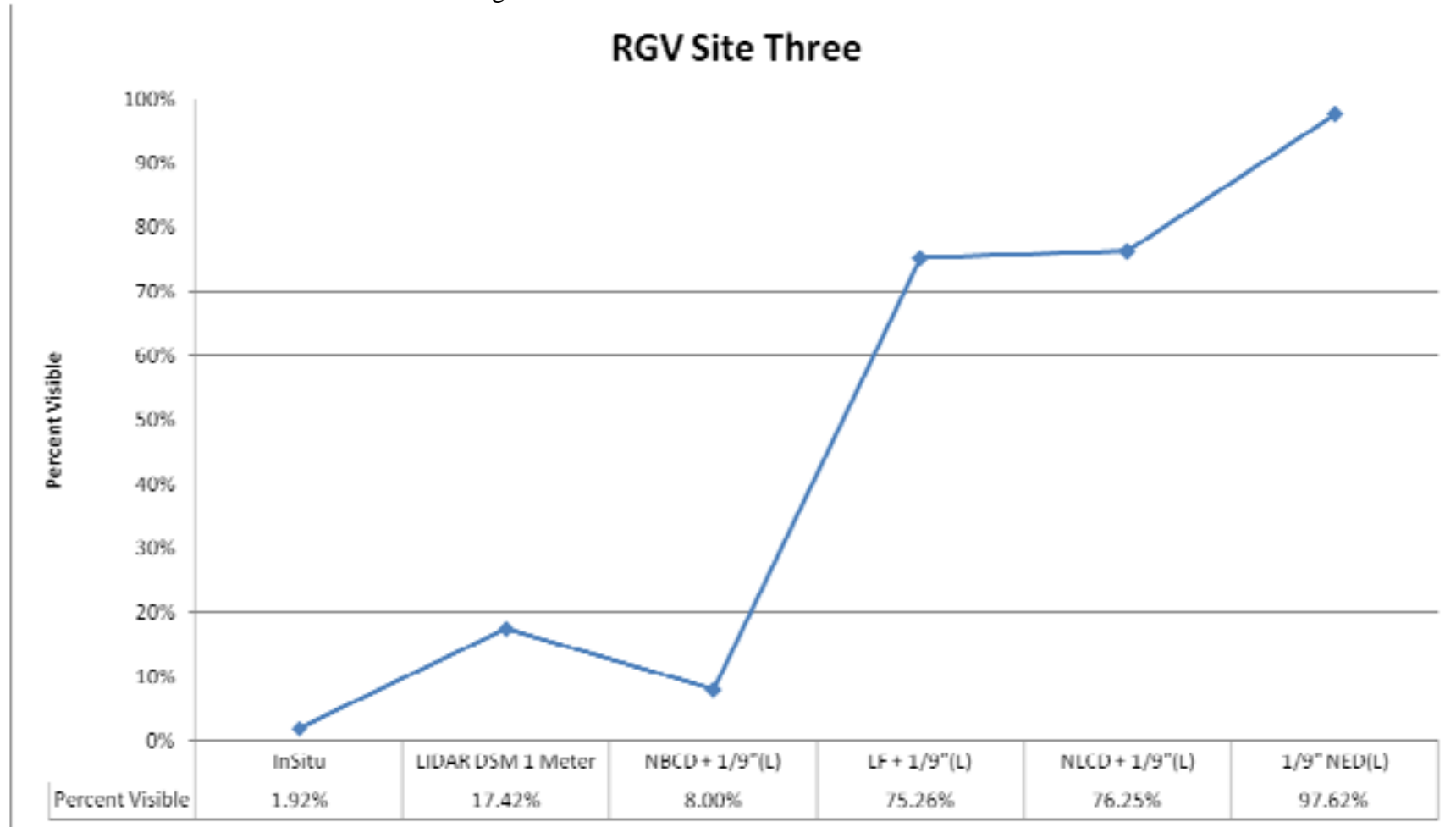


Figure 33. Maine study area 3 with NBCD, Landfire, and NLCD composite DSM viewsheds. Also DSM LIDAR viewshed. Overlaid LIDAR DSM.

Table 12. Percent visible at RGV site 3 using different DEM data.



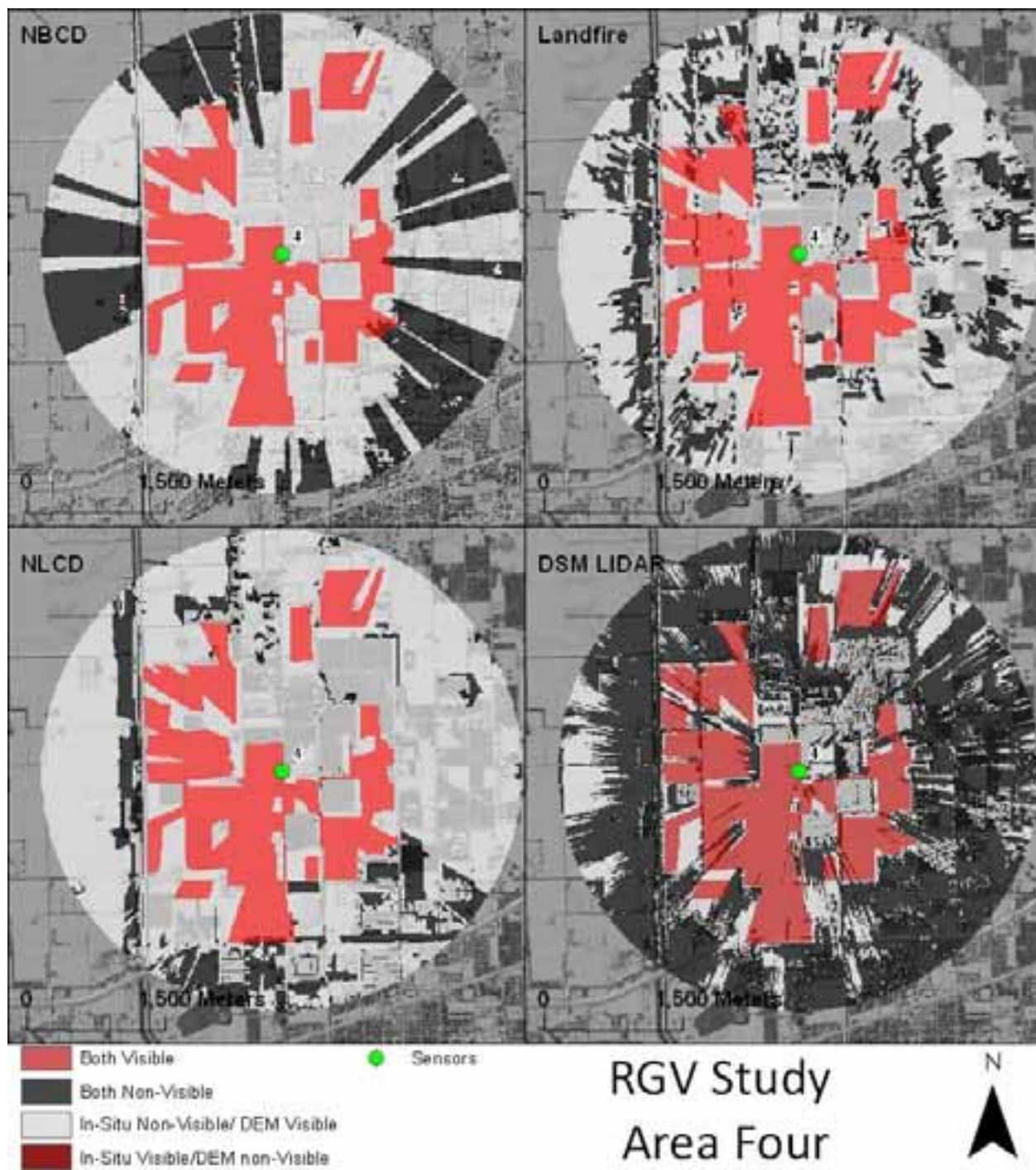
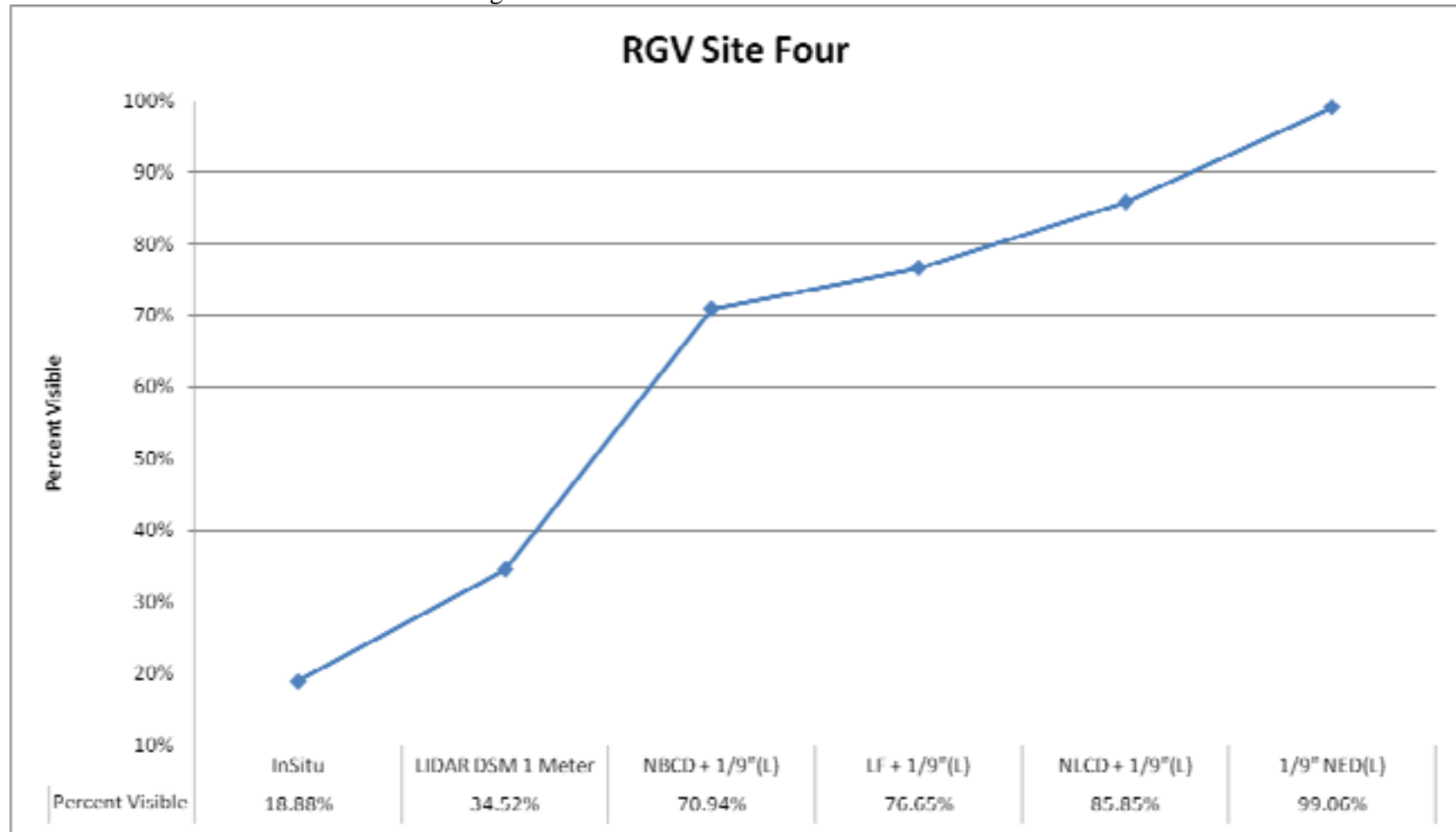


Figure 34. Maine study area 4 with NBCD, Landfire, and NLCD composite DSM viewsheds. Also DSM LIDAR viewshed. Overlaid LIDAR DSM.

Table 13. Percent visible at RGV site 4 using different DEM data.



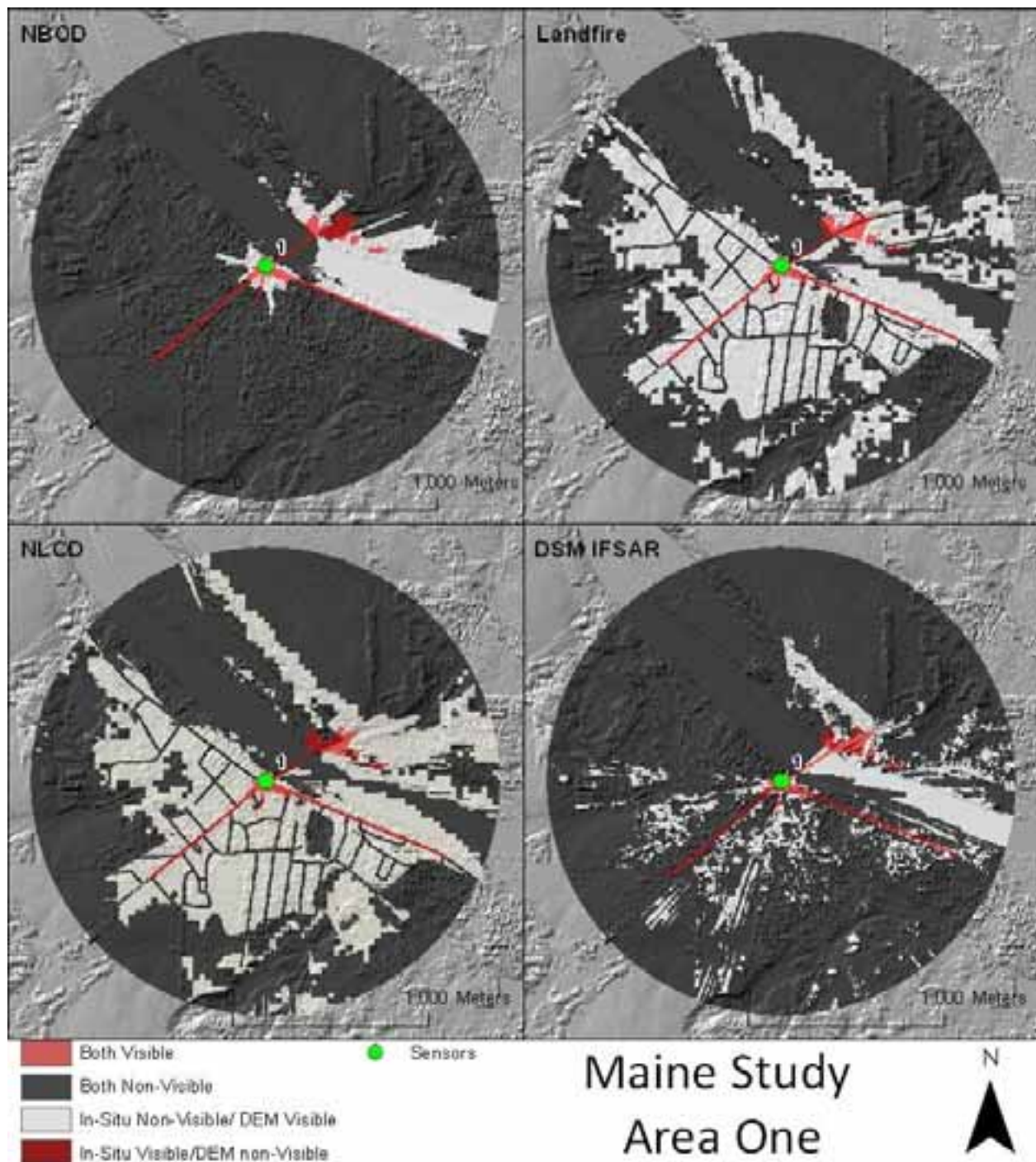
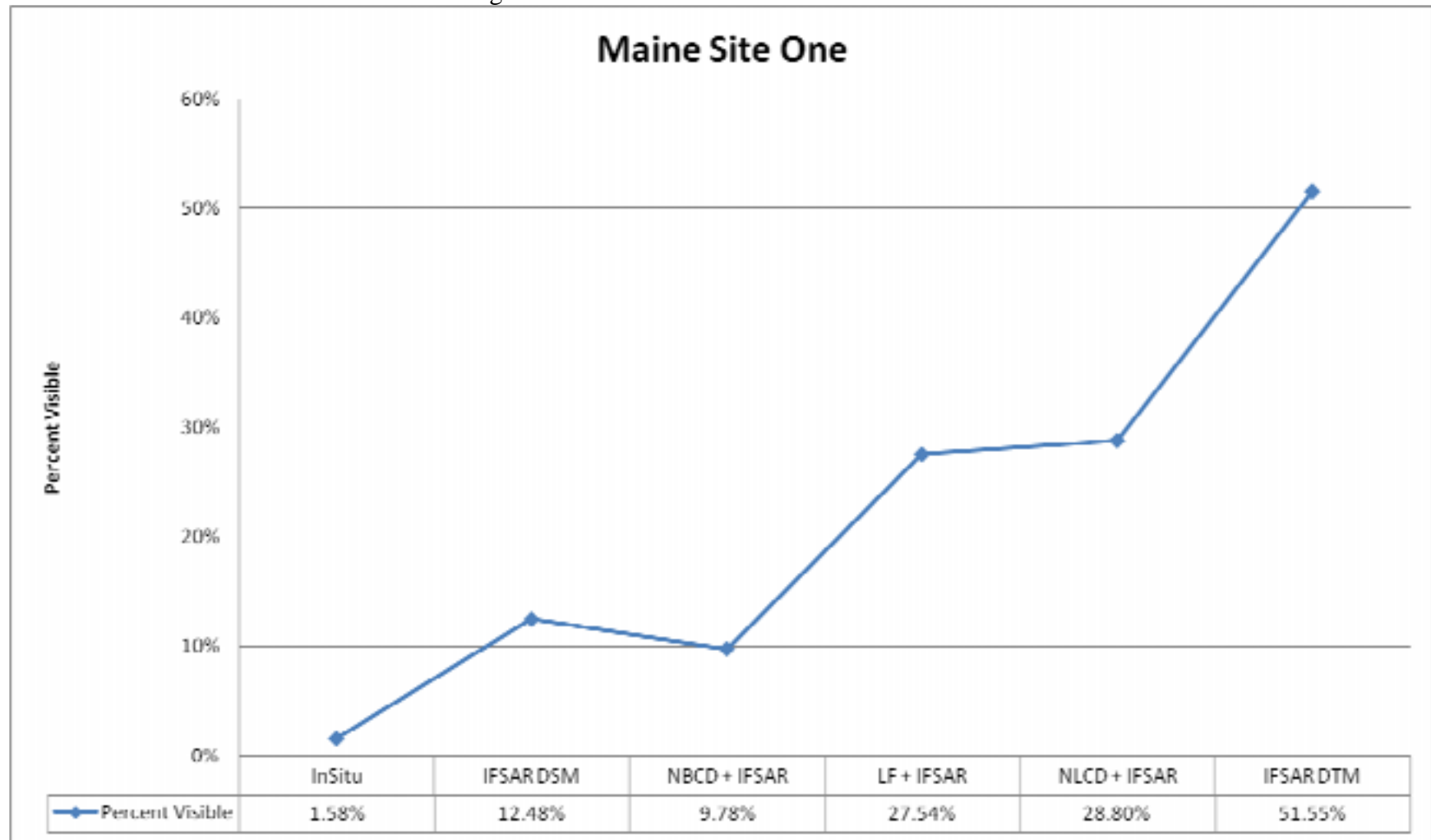


Figure 35. Maine study area 1 with NBOD, Landfire, and NLCD composite DSM viewsheds. Also DSM IFSAR viewshed. Overlaid IFSAR DSM.

Table 14. Percent visible at Maine site 1 using different DEM data.



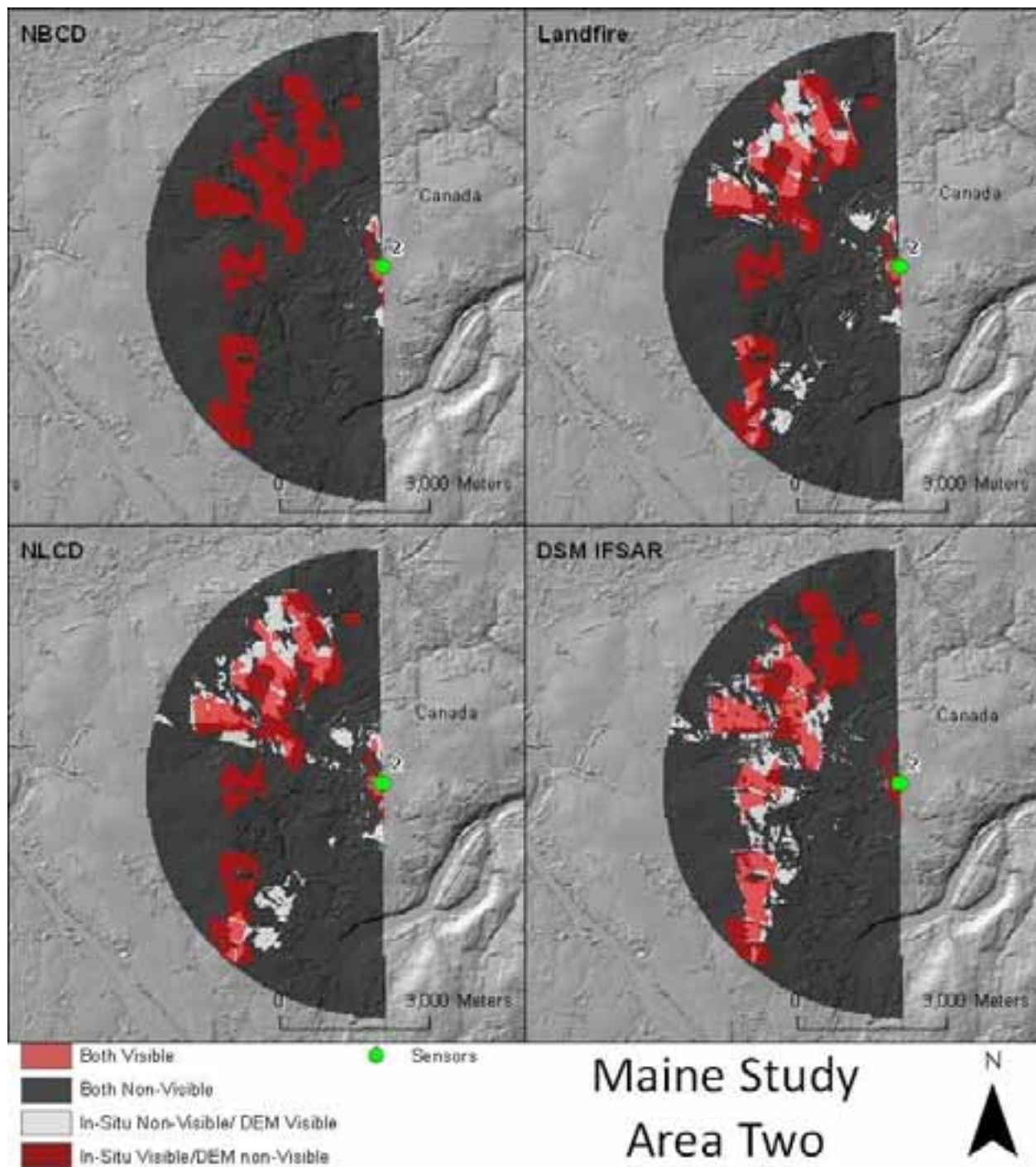
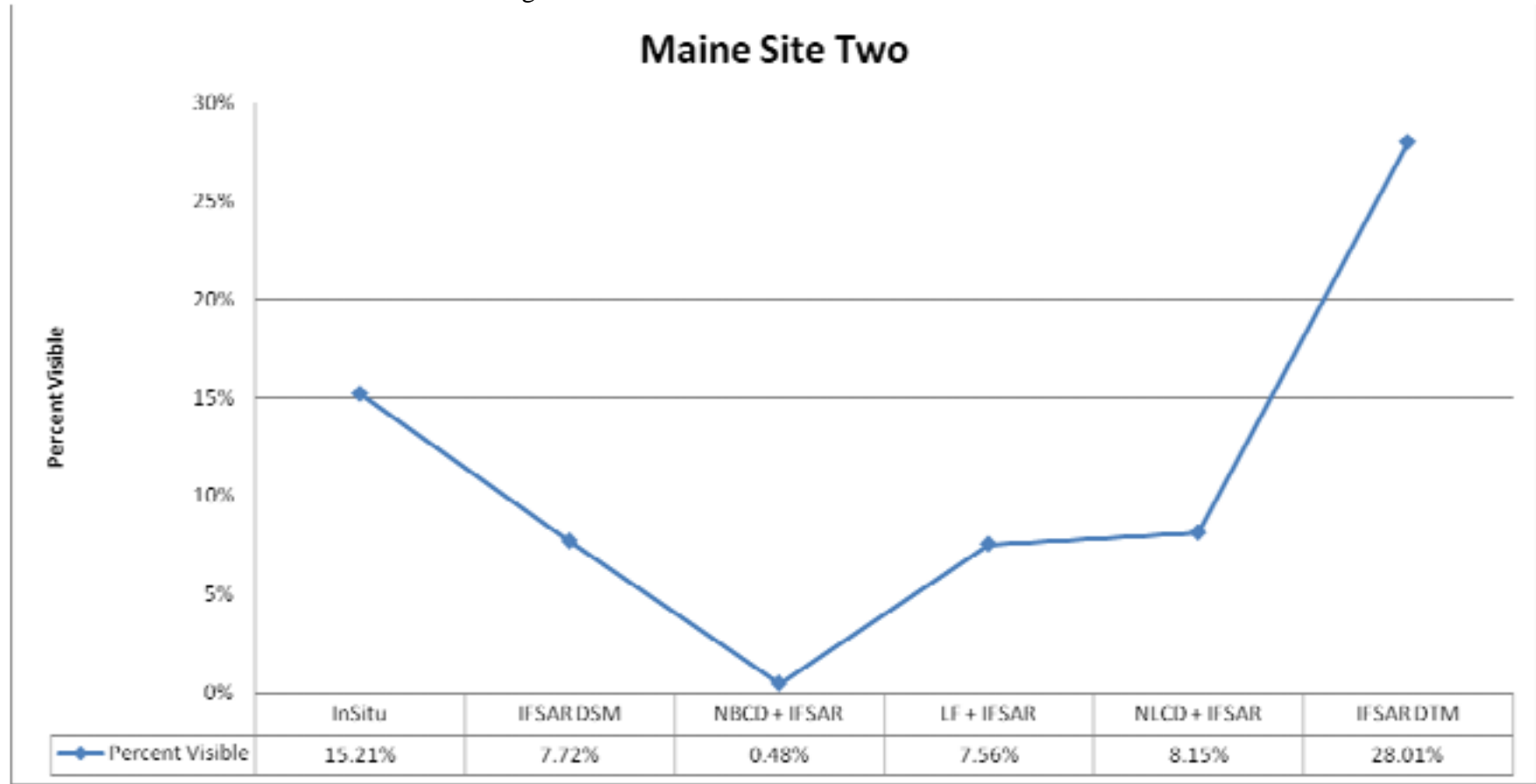


Figure 36. Maine study area 2 with NBCE, Landfire, and NLCD composite DSM viewsheds. Also DSM IFSAR viewshed. Overlaid IFSAR DSM.

Table 15. Percent visible at Maine site 2 using different DEM data.



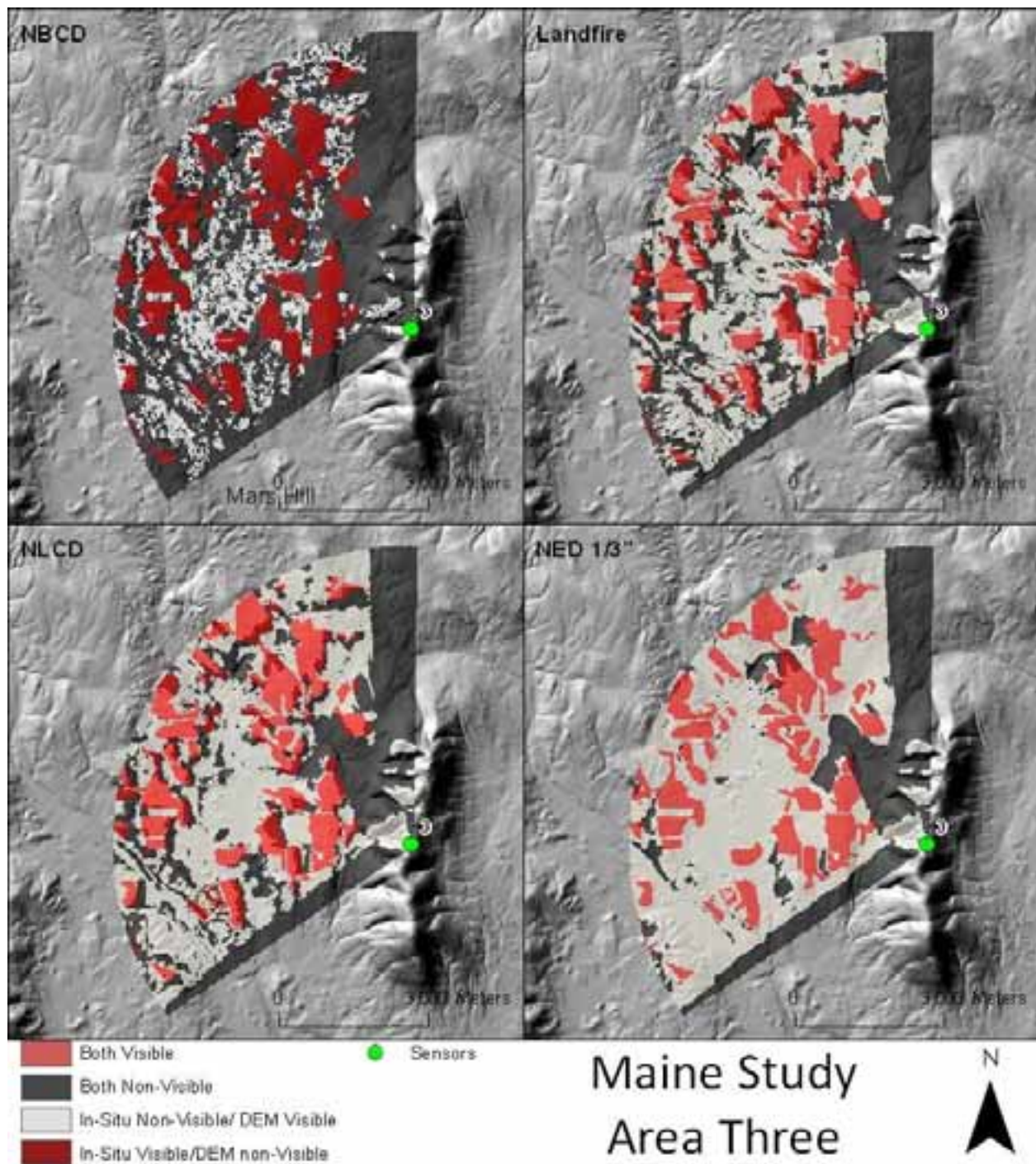
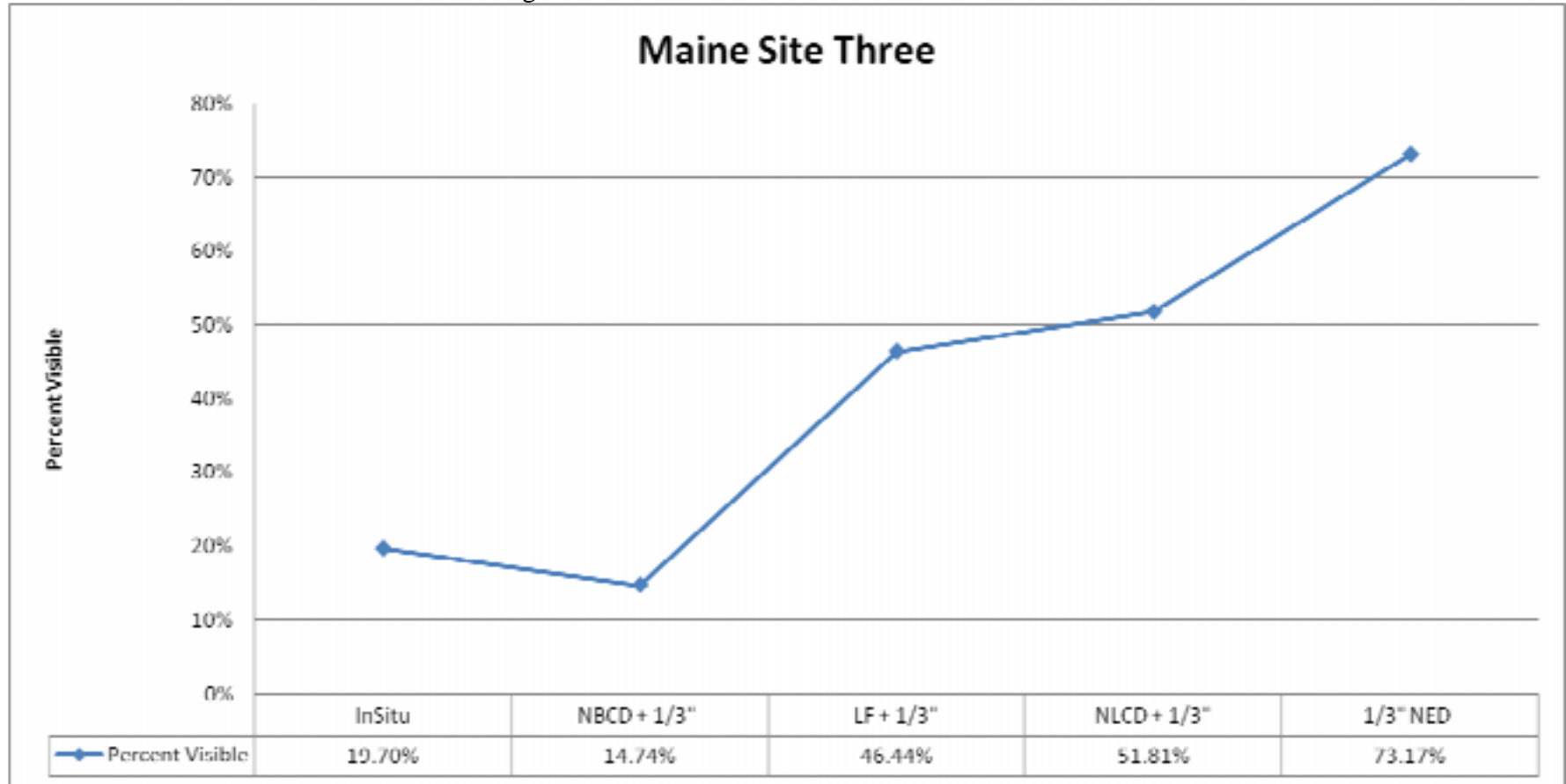


Figure 37. Maine study area 3 with NB/CD, Landfire, and NL/CD composite DSM viewsheds. Also NED 1/3" viewshed. Overlaid NED 1/3".

Table 16. Percent visible at Maine site 3 using different DEM data.



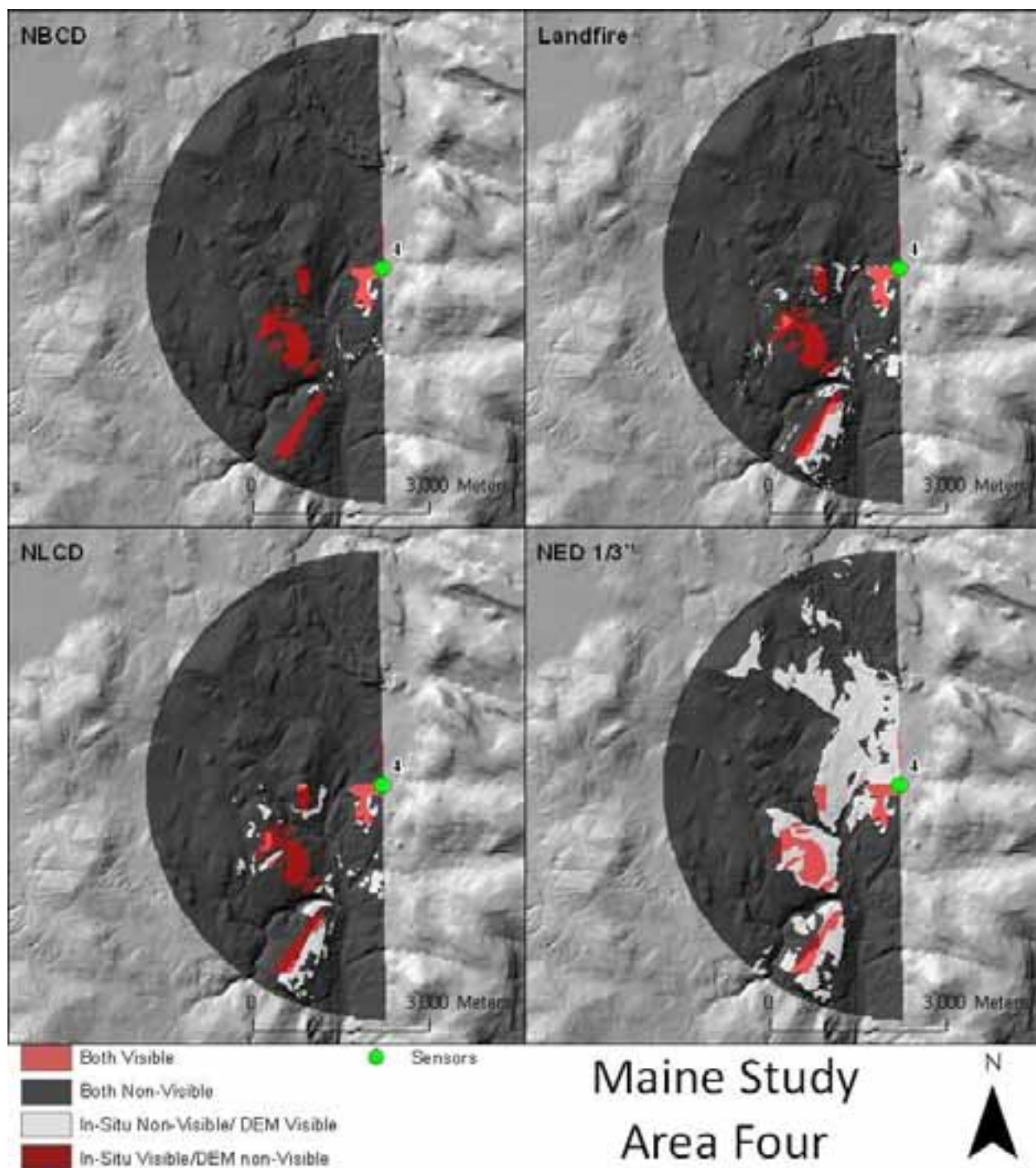
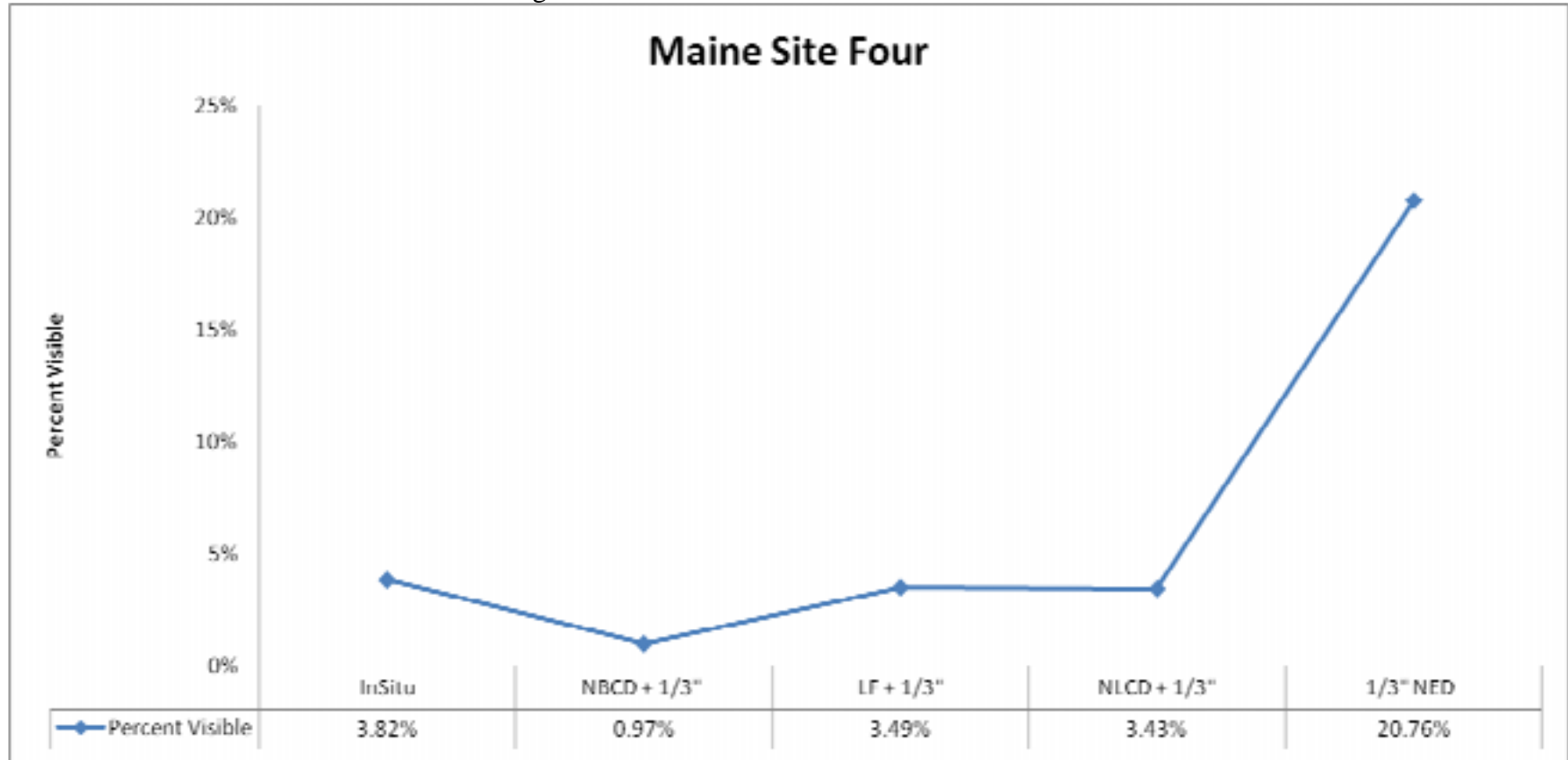


Figure 38. Maine study area 4 with NBCD, Landfire, and NLCD composite DSM viewsheds. Also NED 1/3'' viewshed. Overlaid NED 1/3''.

Table 17. Percent visible at Maine site 4 using different DEM data.



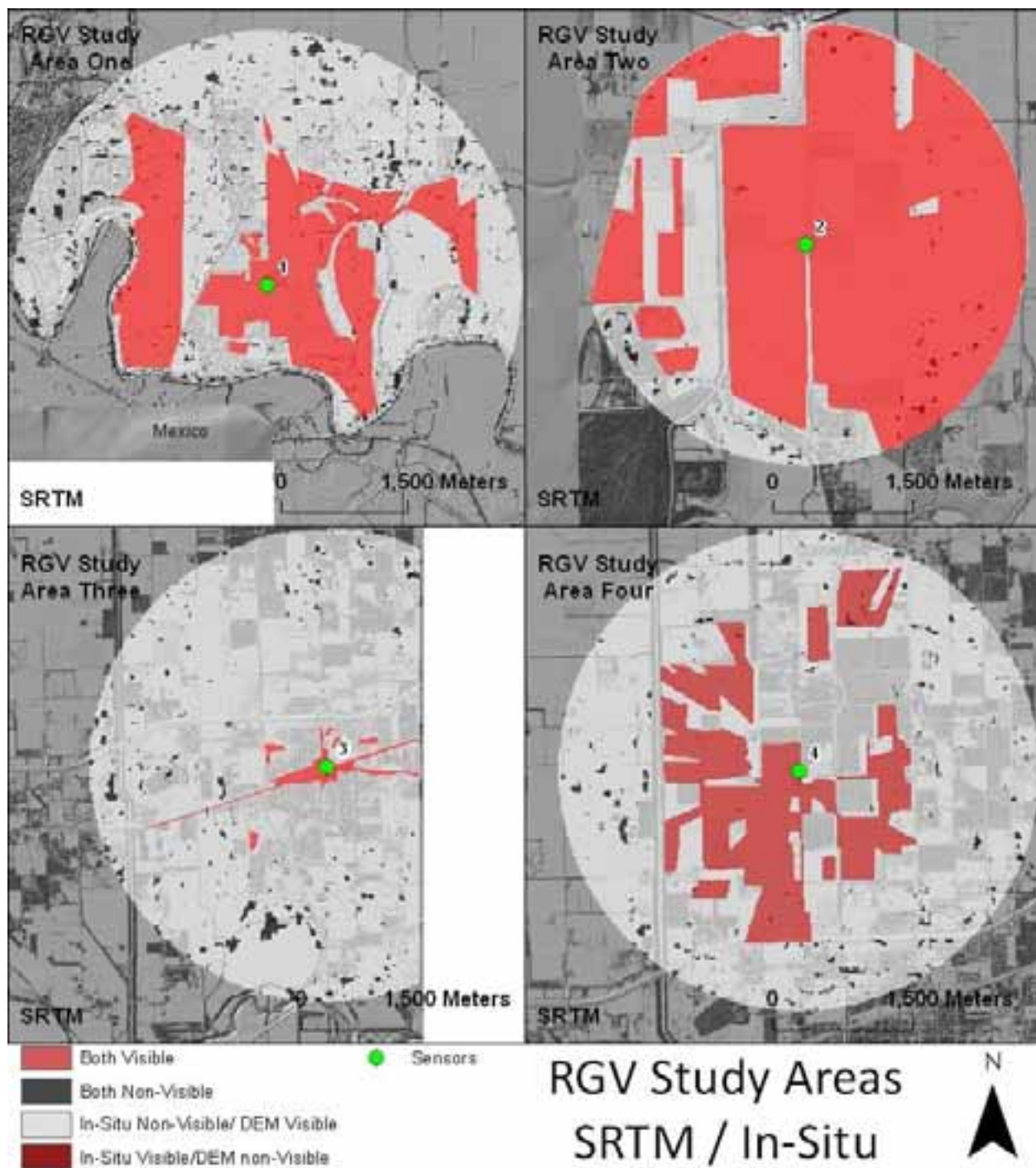


Figure 39. RGV study areas SRTM 1'' v. 2 compared in-situ observation, overlaid LIDAR DSM.

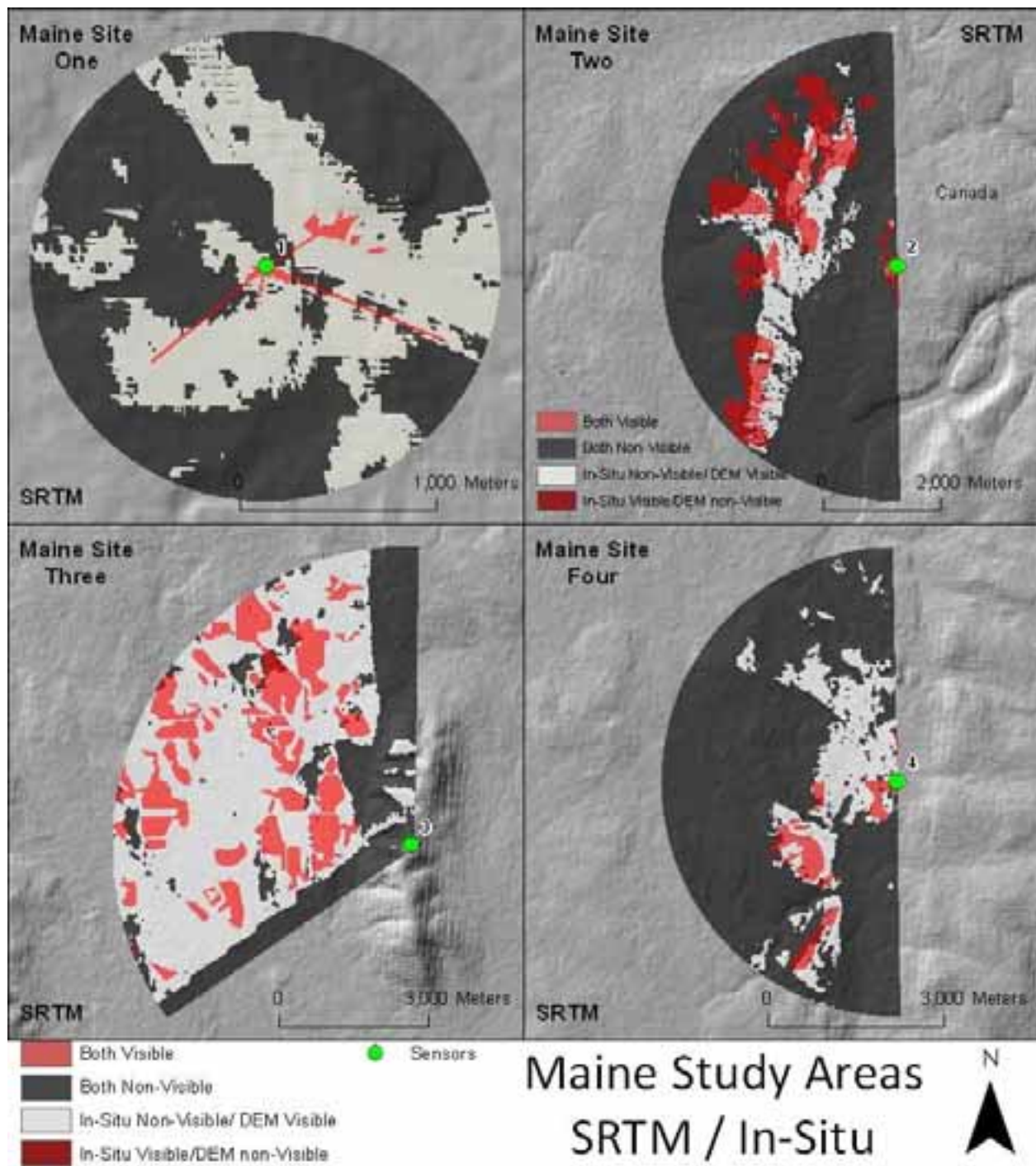


Figure 40. Maine study areas SRTM 1" v. 1 compared in-situ observation, overlaid SRTM 1" v. 1.

Appendix D

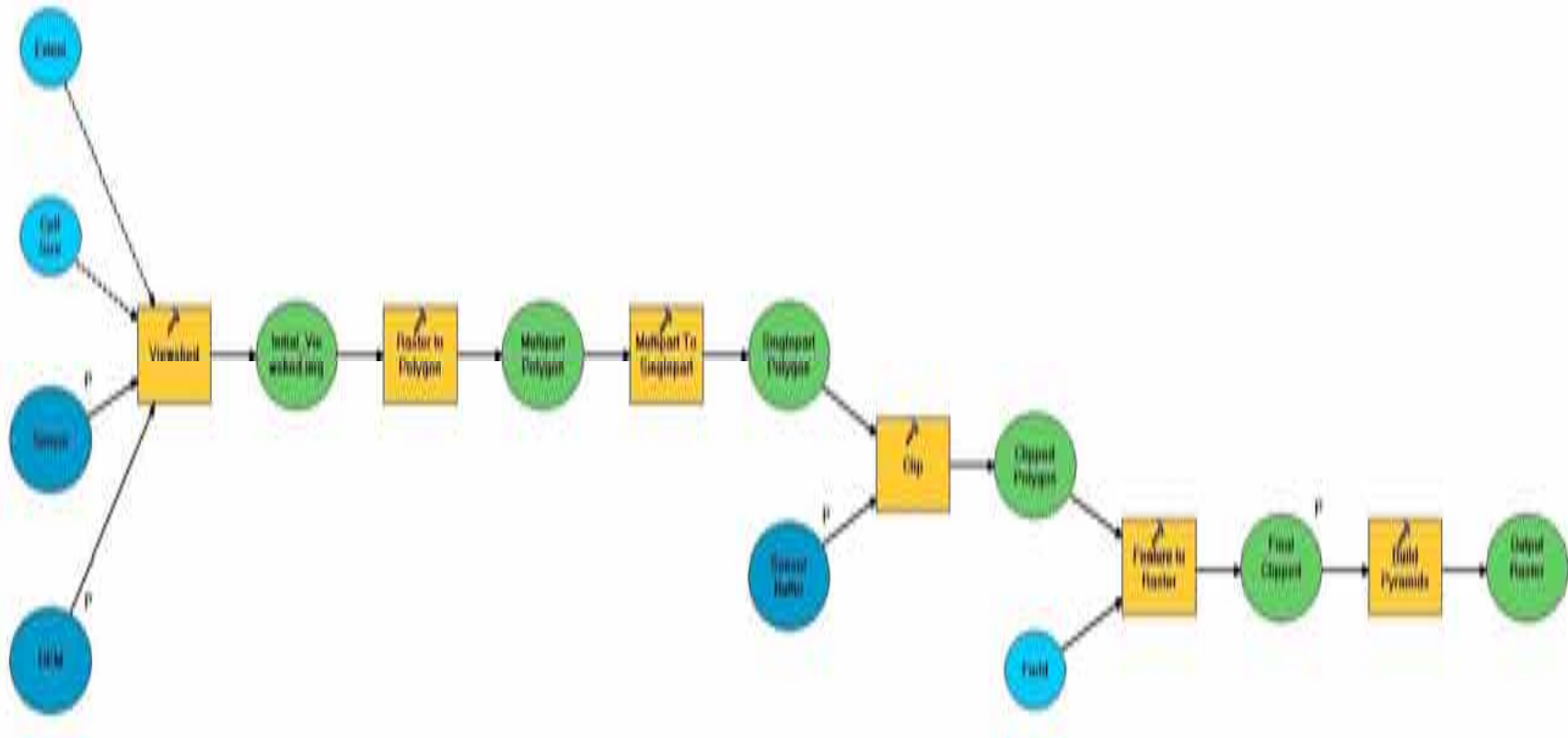


Figure 41. Arc-model used to create viewsheds.

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