

Methodology Used in Preparing Photomontages and a Nighttime Photosimulation for the Proposed Windfarm in Jordanville, NY

Prepared by James A. Zack, President
Xtra-Spatial Productions, LLC.

zack@spatialexperts.com

2 August 2006

1. Introduction

A digital photomontage is the end result of a computer graphics operation in which portions of two (or more) digital images are combined or composited into a single digital image. The technique of photomontaging has been used to present photosimulations of proposed construction projects that may alter visual resources such as scenic vistas, skylines, and nighttime scenes. The digital photomontage is a specific type of photosimulation where a portion or portions of a computer-generated scene are “pasted” onto an actual, real-world image captured with a camera in the field. This contrasts with the more prevalent form of photosimulation where the entire image is computer-generated.

The advantage of a digital photomontage over the computer-generated photosimulation lies in the higher degree of verisimilitude—a work with a high degree of verisimilitude means that the work is very realistic and believable; works of this nature are often said to be “true to life”—conveyed by the photomontage since most of the image is derived from an actual image of the subject matter. Moreover, by alternative displaying the unaltered image and the photomontage, changes can be seen in their natural context.

This document describes the methodology used by Xtra-Spatial Productions, LLC in the creation of a set of photomontages and a nighttime photosimulation of a proposed seventy-five turbine Windfarm in Jordanville, New York.

The requisite inputs and the process of creating a digital photomontage are described below. Additional requirements for the nighttime photosimulations are described in §6.1 and §6.2.

2. Required Data

This section describes the requisite data inputs to create a successful digital photomontage.

2.1 Imagery Depicting Baseline Conditions

One of the two imagery streams feeding into the photomontage process is the *in situ* digital image of the scene. A necessary component of this imagery is the data about the image, or the image *metadata*.

For this project, a single digital image was selected to demonstrate the visual impact of the project from a single location in the Jordanville vicinity.

2.1.1 Digital Imagery

This data is the actual digital image captured in the field with a digital camera. A Nikon D100 six-megapixel digital camera with a zoom lens was used to acquire a digital image from a location deemed to be representative of areas where visual resources may be compromised by the construction of the Jordanville Windfarm.

The image captured was an uncompressed RGB TIFF file with pixel dimensions of 3008 wide by 2000 high. No filters or special effects were used when capturing the image.

2.1.2 Metadata for Digital Imagery

Data about the data (metadata) were required to expedite the process of camera matching described in §3.1.2 below. Many of these data are recorded to the TIFF image and accessible through the Image Editing software Photoshop (Adobe, Inc.).

2.1.2.1 Digital Camera Specifications

The dimensions of the Nikon D100's imaging sensor were needed to assist in determining the horizontal and vertical fields of view of the camera for a specific focal length. From Digital Photography Review (http://www.dpreview.com/reviews/specs/Nikon/nikon_d100.asp), the sensor size is 23.7 x 15.5 mm.

2.1.2.2 Time of Day

Time of day is captured both on camera's memory card file system and in the file's metadata tags. The owner of the camera failed to properly set the AM/PM switch and to compensate for Daylight Savings time, so the times were actually 13 hours behind actual time. An adjustment was made to correct this error.

The time of day is critical for replicating the position of the Sun when simulating illumination of the turbines in the Computer Model.

The digital image used in this project was captured at 12:24 PM Eastern Daylight Time.

2.1.2.3 Day of the Year

The day of the year is captured both on camera's memory card file system and in the file's metadata tags. The owner of the camera failed to properly set the AM/PM switch and to compensate for Daylight Savings time, so the times were actually 13 hours behind actual time. This resulted in the recorded date as being one day earlier than the actual date for many of the images. An adjustment was made to correct this error.

The day of the year is critical for replicating the position of the Sun when simulating illumination of the towers in the Computer Model.

The digital image used in this project was captured on Monday, July 24th, 2006.

2.1.2.4 Location of Camera

A GPS unit was used to capture the 2D (latitude and longitude, but no elevation) of the location of the camera station. This location was used to create an ESRI Shapefile in the UTM Zone 18N NAD83 coordinate system. The location is commonly referred to as Point Florence on Lake Otsego.

The location of the camera station was examined in ArcMap (ESRI, Inc.) using digital orthophotographs (described in §2.2.1.4) as a backdrop to ascertain the validity of the coordinates.

The location of the camera is crucial in replicating the camera positions in the Computer Model.

2.1.2.5 Orientation of Camera

The parameters defining the exterior orientation of the camera is crucial for the camera matching operation described in §3.1.2 below. These parameters include:

- *Bearing* of the camera's optical axis in compass degrees using true North (as opposed to magnetic North) as zero degrees; this measure is also known as the *azimuth* of the camera or the camera's *heading*; the bearing was measured in the field using an orienteering compass aligned to the camera lens; the values were bearings from magnetic North; these were converted to bearings from true North by subtracting 13.6 degrees.
- *Inclination* or *pitch* of the camera's optical axis, where a perfectly horizontal camera has a pitch of zero degrees, and a camera pointing straight up has a pitch of -90 degrees.
- *Bank* (or *tilt* or *roll*) of the vertical axis of the camera's sensor; ideally, there should be no bank in the camera, but unless a bubble level is incorporated into the camera body, this is a difficult proposition
- *Horizontal Field of View (HFOV)* of the lens which has a trigonometric relation to the focal length of the lens and the image sensor (defined in §2.1.2.1 above); the HFOV can be calculated as
$$\text{HFOV} = 2 * \tan^{-1}((\text{image sensor width} / 2) / \text{focal length})$$

The image was taken with a 50.0mm focal length setting on the zoom lens. Thus, the HFOV for this image is calculated as

$$\begin{aligned}\text{HFOV} &= 2 * \tan^{-1}((23.7\text{mm} / 2) / 50.0\text{mm}) \\ &= 2 * \tan^{-1}(0.237) \\ &= 26.66^\circ\end{aligned}$$

2.1.2.6 Atmospheric Conditions

In order to match the atmospheric conditions of the Computer Model with that of the imagery, a qualitative assessment of the amount of haze and direct light is needed. The image was acquired on a day where it appeared that bright Sun (as opposed to overcast) and a light haze were present. A linear haze model with a 90km 100% haze (all colors blend to a light blue hue beyond this distance) was used in the Computer Model.

At the request of the project team members, the photomontage from Point Florence was produced using a volumetric atmospheric model that more closely simulates “clear sky” conditions typical of the area. These conditions were not present during the date of acquisition of the digital image. The composition of this volumetric atmosphere included only those molecules found in an arid, uncontaminated atmosphere (*i.e.*, no dust, particulates, water vapor, oxides of nitrogen or sulfur, or other anthropogenic or biogenetic gases such as carbon monoxide, carbon dioxide, terpenes, etc.).

2.2 Computer Model of Altered Conditions

The second input stream to the Photomontage is generated by creating a Computer Model of the study area replete with the additional 3D Objects (wind turbines). This Computer Model should be as close to reality as possible. The methodology used in the generation of the Computer Model is beyond the scope of this document, but the required data are briefly described below.

2.2.1 GIS Data

All data used in the creation of the Computer Model is in the form of Geographic Information System (*GIS*) datasets. There are two basic types of GIS datasets: vector-based (discrete points, lines, and polygons), and raster-based (arrays of values representing either continuous variables, such as elevation, or nominal values, such as land cover).

2.2.1.1 Camera Stations

The GPS data describing the camera station location (see §2.1.2.4) were used to create an ESRI Shapefile containing a single point. This point corresponded to the camera station and contained additional attributes such as image sequence number, nominal bearing, and location name.

2.2.1.2 Terrain Model

A set of raster Digital Elevation Models (*DEMs*) was obtained from the USGS Seamless Database at two resolutions. For the immediate study area (encompassing the towers and the camera locations), 10-meter DEMs were used. For the surrounding area that may be visible beyond the towers, 30-meter DEMs were used. These two datasets were merged to produce a 50-meter DEM outside the immediate study area with a “hole” where the 10-meter DEMs were used as a high-resolution insert.

2.2.1.3 Land Cover Data

A raster dataset describing the Anderson Level 2 Land Cover classification was obtained from the USGS Seamless Database website. This National Land Cover Dataset (*NLCD*) has a nominal resolution of 30-meters, and reflects the land cover present in 1992. This data was used only for purposes of camera matching and nighttime photosimulation as described in §6.1 below.

2.2.1.4 Orthoimagery

County-wide 1-ft Color Infrared imagery was obtained from Stone Environmental, Inc. and used to verify the camera location.

2.2.2 3D Object Data

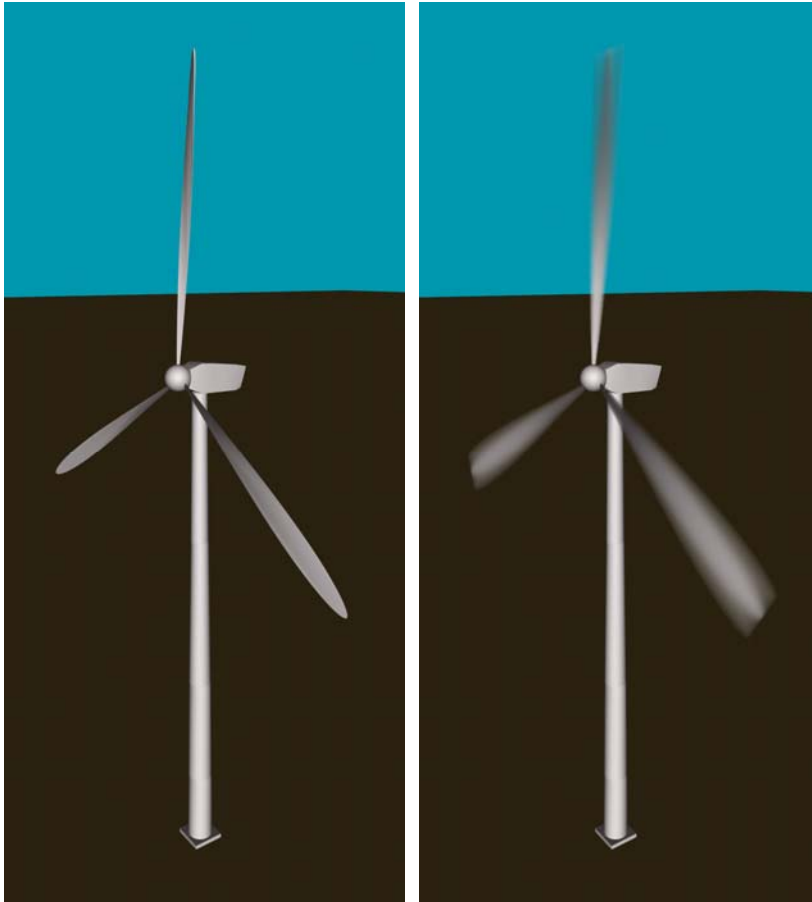
The wind turbines represent the difference between the *status quo* and the proposed alteration of the visual resource of the study area. Therefore, the turbines had to be modeled as entities and then placed in the correct locations in order to depict them in their proper scale, appearance and locations in the digital photomontage.

2.2.2.1 Geometry of 3D Objects

Xtra-Spatial Productions, LLC already had a three-blade, horizontal axis wind turbine model that was used for another project. The dimensioning, however, did not conform to the dimensions proposed for the Jordanville Windfarm. Using 3D Studio MAX (Kinetix, Inc.), the model was modified to conform to the specified dimensions:

- 256 ft (78 m) height to rotor axis and
- 399 ft (121.5 m) maximum height to blade tip at top-dead-center

Additionally, all dimensioning as described in Gamesa Eólica's document titled *FT Characteristics and general operation of G8X 2.0MW Wind-turbine* (General specifications G8x 50-60 Hz.05.04.15th1.pdf) were used to build a highly realistic model of the G87 turbine. The turbine 3D model is depicted below both with the rotor still and with the rotor in rotation.



Turbine with rotor still

Turbine with rotor spinning

From this “master 3D model,” six derivative models were built representing the blades in various positions along their rotation:

- Blade #1 at top-dead-center (0°)
- Blade #1 at 20°
- Blade #1 at 40°
- Blade #1 at 60°
- Blade #1 at 80°
- Blade #1 at 100°

This was done to simulate the random nature of the spinning blades at 20° increments. Note that due to the trifold radial symmetry of the blade configurations, no further variations were needed to simulate a full revolution of the turbine rotor. In other words, a 120° rotation of Blade #1 would look the same as a 0° rotation of Blade #1.

2.2.2.2 Materials of 3D Objects

A single material was assigned to the entire turbine. The material was a semi-glossy white paint that maximizes visibility to aircraft.

2.2.2.3 Locations and orientation of 3D Objects

A Shapefile of turbine locations was provided by Stone Environmental Inc. (through Community Wind). The elevations of the base of the tower were assumed to be the terrain elevation from the 10-meter DEM (§2.2.1.2) at the towers' locations.

The towers were oriented to face due west or 270° (the direction of the prevailing winds) with a +/- 10° random variation.

3. Processing

This section describes the steps necessary to convert the data into a digital photomontage.

3.1 Creation of the Computer Model

The Computer Model was created using Visual Nature Studio (VNS) version 2.71 (3D Nature, LLC). The entire process of creating the model is beyond the scope of this document, but the highlights are presented below.

3.1.1 Integration of GIS Data and 3D Object Data

VNS models are created by applying textures, billboarded images, and 3D models to a terrain surface. The terrain surface was imported from the DEMs described in §2.2.1.2 above. The two DEMs were merged to create a high-resolution (10m) insert of the immediate study area within a low-resolution (50m) background terrain model.

Shapefiles for the camera location and the turbine locations were added to the VNS project. The six 3D Models of the turbine (see §2.2.2.1) were imported into the project and assigned at random to all seventy-five turbine locations.

The Sun's position was set to match the time of day that the digital photo was acquired.

3.1.2 Camera matching

The process of creating a model camera that matches the orientation of the actual digital camera is the most time-consuming aspect of the project. Fortunately, the position and HFOV of the camera was specified with a high degree of confidence. The estimated bearing was useful to set up a crude orientation of the camera, but an iterative approach to tweaking this, and other parameters (*i.e.*, pitch and bank) was necessary. This iterative approach was achieved using a down-sampled version of the original digital image and a preview render of the terrain model of the same pixel dimensions. The digital image was displayed in Photoshop and the preview render was superimposed on it with 50% transparency. The preview render was then moved horizontally and vertically, as well as rotated, until the skylines and foreground ridgelines were coincident. The amount of displacement and rotation of the preview was noted, and the heading, pitch and bank parameters of the VNS camera were adjusted. A new preview render was generated and the process repeated until the camera match was optimal. Since the wind turbines were all on the skyline, some degree of mismatch was tolerated in the foreground as long as the skyline was congruent with that of the digital image.

Once the camera's orientation was matched, the parameter values were keyframed to prevent accidental changes to the parameter values.

3.2 Rendering of Computer Model to Match Digital Images

The terrain and the turbines were rendered at the same resolution as the digital images (e.g., 3008 by 2000 pixels). To facilitate masking operations described below, the terrain was rendered in a shade of green with 100% luminosity. The sky was rendered using the volumetric atmospheric model described in §2.1.2.6 above for the “clear sky” photomontage. Render times for this operation was approximately ten minutes. The inclusion of the “clear sky” and its calculation consumed the majority of the rendering process.

3.3 Compositing of Computer Model Output and Digital Images

The process of compositing two images involves the preservation of parts of each image and the discarding of the complimentary parts of the image. The only parts of the rendered image that were retained were the portions of the sky and turbines above the horizon visible in the rendered image.

To initiate the compositing operation, the digital image was loaded into Photoshop. Next, the rendered output was opened, copied, and pasted as a new layer over the digital image.

3.3.1 Sky Masking

The portions of the rendered sky that fell either below the horizon line in the digital images or behind foreground trees were selected using a combination of the Magic Wand, the Magnetic Lasso, and the Polygon Lasso tools.

3.3.2 Ground Masking

Similarly, the terrain portions of the rendered image were added to the selection in Photoshop using the Magic Wand tool (tolerance of 25) and Shift-clicking (to add to the selection) on a green pixel.

3.3.3 Skyline Masking

By disabling visibility of the rendered image layer, but retaining it as the active layer, the selection was expanded by using the Lasso tool to add to the selected areas those pixels that were below the skyline in the digital image. Turning on visibility of the rendered image layer and clearing the selected set of pixels deleted all those parts of the rendered image that were not to be drawn on top of the digital image.

3.3.4 Application of Gaussian Blur to Computer Model Output

Since the rendering of the computer model is done without optics, the image is often “too sharp” and doesn't look like it was captured optically as was the digital image. Therefore, after selecting the transparent portions of the rendered image layer and

inverting the selection to select only the visible portions of the turbines, a Gaussian Blur filter with a radius value of 0.75 pixels was applied to “soften” the rendered image. Thus the turbines appeared to be similar in sharpness as the digital image.

4. Results

For purposes of direct comparison, a clear sky with no turbines layer was created in Photoshop and masked to include only the above horizon and unobscured portions of the original digital images. The three-layer (*i.e.*, original digital image, clear sky without turbines, clear sky with turbines) composites were saved as Photoshop documents and also “flattened” to a pair of single-layer TIFF images for compatibility with other software packages such as PowerPoint (Microsoft, Inc.) or for hardcopy printing. The two photomontages (“blue sky with no turbines and blue sky with turbines) are included in the August 4th, 2006 submittal along with the original digital image.

5. Caveats

There are several caveats to consider when presenting photomontages to an audience that may be unfamiliar with this form of analysis. Lack of awareness of these caveats can create mistrust and even deception among the audience and the presenter.

5.1 Digital Imaging versus Human Visual Perception

Human visual perception represents millions of years of evolutionary progress and is indeed a marvel of Nature. Photography has been around for 150 years or so, and digital imaging is a product of the late Twentieth Century. There are some important differences in the way the eye/brain system perceives visual stimulus and the way digital images present themselves to this system.

Most notable is that human visual perception is not constant across the entire field of view. While the distribution of the sensing rods and cones are more or less constant from the fovea of the eye to the peripheral areas of the retina, the distribution of the optical ganglia is not. At the fovea, there is a one-to-one ratio of sensors (rods and cones) to ganglia; each sensor has its own ganglion. As one moves away from the fovea (*i.e.*, increases eccentricity), more sensors feed into a single ganglion, which “averages” their photoreceptive impulses. Thus the eye is a variable resolution imaging system. The digital camera is a constant resolution imaging system. We have no way to create digital raster images that mimic this characteristic of the eye/brain system. The resolving power at the fovea of the eye is incredibly greater than any digital imaging device. So even if a turbine appears to be an insignificant smudge on our digital photomontage, the eye may see an actual turbine in detail if a turbine actually was to be there.

5.2 Proper Viewing Distances

In order to preserve the scale of objects in a photograph of digital image, the viewer must be placed at the correct distance from the photograph or image. For purposes of this project, all images should be viewed at the distance that preserves the 26.67° HFOV. So, for example, if the image is projected onto a screen such that it is 10 feet wide, the viewer should stand such that she is approximately 21 feet away from the screen. Likewise, if

the image were printed on an 8" x 10" sheet, the viewer should hold the sheet at a distance of approximately 21 inches.

5.3 Tradeoffs between Full Resolution and Full Field of View

Since the human eye has much greater resolving power than any extant digital imaging system, a tradeoff must be made between resolution and field of view. The binocular eye/brain system has a HFOV of 180 degrees if one includes low resolution portions of peripheral vision and about 40 degrees if one limits it to the highest resolution portions of the retina. If one were to produce a fisheye (~160° HFOV) image of a vista, it is most unlikely that anything on the horizon would be discernable since there are only a finite number of pixels that can be used to cover such a wide field of view. Likewise, if one were to replicate the resolving power of the foveal region of the retina, she would need to restrict the HFOV to only a couple of degrees! This would not give the viewer the context of the scene that is so often crucial to the decision-making process. This tradeoff should be considered when presenting a photomontage to the public.

6. Nighttime Photosimulation from Point Florence

Creation of the nighttime photosimulation from Point Florence posed technical and perceptual challenges. Firstly, the lighting model within Visual Nature Studio is designed for natural illumination. Although it is possible to simulate artificial light sources, the calibration of such lights, in terms of intensity and attenuation, and the perception of the human eye-brain system is neither intuitive nor verifiable. In other words, what an imaging system records on film or pixels is not necessarily the same as what is perceived by each individual human observer. There are several factors that can bias the human perception of nighttime scenes including:

- The adaptation power of the eye. This is the ability of the eye to open or close the pupil to allow more light to strike the retina and the corresponding change in the range brightness levels over which the 1000:1 contrast ratio is perceived. The brightest object the eye can perceive is one million times as bright as the dimmest object it can perceive. The eye/brain system, however has a contrast ratio of only 1000:1. Above that range, objects are perceived as white and below that range, objects are perceived as black. Adaptation is the "sliding" of that 1000:1 range to maximize contrast in a given scene; and
- The difference between the neuro-responses of daylight photoreceptors (primarily cones) and nighttime photoreceptors (primarily rods);

There are also challenges inherent in the production of hardcopy images of nighttime photosimulations. Hardcopy images are viewed using reflected light. The actual nighttime scene is composed of some reflected light, but in the case of stars and lights, also emitted light. Viewing of hardcopy images would optimally be performed using a lightbox and a hardcopy image printed on transparent film in a pitch-dark room (to allow the eye to accommodate to the low ambient light levels). Since this is often not practical, use of reflective viewing is employed instead. There is no guarantee that the light levels

used to view the photosimulation will be constant from one viewing session to another. Therefore, the quantitative and, to a lesser degree, the qualitative properties of the photosimulation may not be verifiable or reproducible.

With these caveats in mind, Xtra-Spatial Productions, LLC undertook the task of producing a nighttime photosimulation from Point Florence.

6.1 Additional GIS Data

In addition to the data described in §2.2.1 above, a Shapefile containing locations of those towers with nighttime illumination beacons was provided by Stone Environmental Inc.

6.2 Additional 3D Models

In addition to the 3D Models of the turbines described in §2.2.2 above, a model of the beacon light system was created in the same coordinate space as turbine models. The beacon light system 3D model “inherited” the same random rotation value as turbine model associated with it. This 3D model was attached to those points of the Shapefile (described in §6.1 above) that were flagged as being lighted.

The beacon lights were modeled as luminous red cylinders, 17.5-inch (44.45 cm) diameter and 17.5-inch (44.45 cm) high. Each illuminated turbine contained two beacons, one on each top, lateral edge of the nacelle cover. Since there was a paucity of information regarding the height of the base of the beacons above the top of the nacelle cover, five photosimulations were conducted: one with the beacon base at the same height as the nacelle cover and the other four with offsets between the nacelle cover and the base of the beacon of 0.5 meters, 1.0 meters, 1.5 meters, and 2.0 meters. This constitutes a sort of sensitivity analysis since it was observed that the nacelle itself might obstruct visibility of the beacons if the vertical angle from the observer to the nacelle is above a certain value. The clients selected the view with a 2.0-meter offset to demonstrate the worst-case scenario.

It was assumed that both beacons on all lighted towers would pulse on and off simultaneously.

6.3 Modeling Lake Otsego

Since Lake Otsego does not exist as a lake in the Digital Elevation Model, but instead is simply an area of constant elevation, it needed to be converted to a lake for photorealistic rendering. This was accomplished using ArcGIS to extract a contour line that encloses the flat area to define the shoreline. To simulate the lakebed, the area within the shoreline was “dug out to a depth of 50m at a distance of 500m from the shoreline.

Finally, a buffer around the shoreline was created to define the lake as all areas inside the buffer that had an elevation lower than the shoreline contour elevation.

To simulate the lake further, waves of very low amplitude (less than 2 inches) were added as was some surface roughness based on a mathematical model of fractal noise. Such a surface of the lake would reflect light from above the lake in a mirror-like fashion.

The waves and surface roughness were held constant for the five simulations.

6.4 Starfields

To simulate a crisp, clear night, a random starfield was inserted into the sky. Thus the red beacons on the turbines would not be the only sky objects visible above the horizon and in the reflections on the lake.

6.5 Rendering

The set of images were rendered in between five and eight minutes for each image. The NLCD dataset (described in §2.2.1.3 above) was used to simulate the vegetative and cultural land cover (circa 1992, the most current data available). Tree images were automatically placed and rendered at a nominal height of 40 feet to correspond with the viewshed analysis performed by Stone Environmental, Inc.

6.6 Post Processing

As mentioned in §6 above, the eye/brain perceptual system is quite different from a machine-based imaging system. There is a tendency for relatively bright objects that exceed the 1000:1 contrast ratio limits to “bleed” into surrounding photoreceptors on the retina causing a glow that is disproportional to their actual sizes. For this reason, a post-rendering process known as “Glow” was applied to create a five-pixel radius red glow emanating from beacons that were directly visible to the observer.

To compensate for the process of ocular adaptation described above, the rendered image was given an “exposure” correction of +1.5 f-stops, corresponding to increasing the luminance of all parts of the scene by a factor of 2.25. This value was selected based on trial-and-error iterations using +0.5, +1.0, +1.5, and +2.0 f-stops. The effect was achieved through the “Exposure” post-rendering process.

6.7 Results

The results of the sensitivity analysis show that for all nighttime simulations (*i.e.*, all offsets of the beacons above the nacelle cover), some beacons would be visible above the horizon and that most of them would reflect in Lake Otsego to be visible on its surface to the viewer at Point Florence. Moreover, it is apparent that the greater the offset between

the nacelle cover and the base of the beacons, the more beacons that would be visible to the observer at Point Florence.

As with the daytime photomontages, the caveats explained in §5 above should be considered when viewing the nighttime photosimulations. Furthermore, viewers should consider that these simulations model only one set of conditions (*e.g.*, lake roughness, wave orientation and height, and turbine rotor orientation). It is quite possible that under a different set of conditions the visual impacts might be considerably increased or diminished.