WILDFIRE VISUALIZATION USING GIS AND FOREST INVENTORY DATA

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Abstract

Advances in technology and the collection of remotely sensed data have provided researchers with even more powerful tools for constructing realistic models and visualizations. The goal of this study was to test the use the Visual Nature Studio (VNS) software in visualizing a wildfire in the New Jersey Pine Barrens based on available GIS and forest inventory data. A digital elevation map was used for base heights for the landform model and digital orthophotographs for visualizing surface features such as roads and buildings. Image models for vegetation were constructed from digital photos of actual species edited in Photoshop. Forest ecosystems were created using the image models linked with the forest inventory data. Fire visualization was performed using shapefiles for fire spread and intensity provided by the FARSITE model. Color maps were created from these shapefiles and served as a guide in VNS to visualize different stages of the wildfire. The resulting visualization provided both still frame and animated views of the wildfire. A protocol for wildfire visualization using the VNS software was also established. Some advantages and limitations for using VNS for wildfire visualization are noted.

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Introduction

Visualization is defined as any technique for creating images, diagrams, or animations in order to convey a message. Advances in computer hardware and software over the past 30 years have allowed researchers to simulate and visualize complex forms, phenomena, and dynamics in natural systems such as plant growth or changes in atmospheric conditions (Ervin and Hasbrouck, 1999). Visualizations, which previously required specialized computer systems and hardware, can now be done on more affordable desktop systems. With this increased accessibility, visualization has become a tool available to even more researchers as a means of analyzing data.

In the field of landscape management and forestry, visualization can be used to analyze data from Geographic Information System (GIS) or remotely sensed systems such as aerial photographs or satellite images. Through the commercialization of hybrid 2D/3D visualization software such as Bryce 3D (DAZ Productions), World Construction Set (WCS) and Visual Nature Studio (VNS) (3D Nature Inc., 2002), and VistaPro (Virtual Reality Laboratories Inc., 1993), 3D modeling of landscapes possessing a high degree of realism, from different viewpoints, and having animation paths, is now possible (McGaughey, 1998; Muhar, 2001). Due to the availability of these programs, the use of visualization has become an important tool for analyzing existing forest landscape resources and for assessing the impact of proposed management practices (Lange, 1994; Orland, 1994; McCarter 1997; McGaughey, 1998). Furthermore, it can aide in the understanding of succession dynamics and spatial patterns within a forest ecosystem. It may also be of aid to forest managers when selecting management practices that in turn help to efficiently utilize forest resources.

The purpose of this study is to be an extension of the visualization research done by Wang et al., (2006). Wang et al.'s research involved visualizing the landscape of the Chequanmegon National Forest in northern Wisconsin using publicly available data sources such as forest inventory and GIS data. The visualization was performed using VNS, a relatively newer visualization software package (3D Nature Inc., 2002). Mathematical models were then applied to the forest data to determine changes with future succession and growth. The resulting data were applied to initial forest visualization to show changes in forest stand structure and composition that may occur due to harvesting or some other disturbance event. Resulting visualizations that came from this data were time-lapsed images showing the changes of the forest over extended periods. This study aims to do something similar for a wildfire event in the Pine Barrens of New Jersey. An initial forest environment will be constructed using publicly-available topographic, vegetation, and GIS data for the study area. Data output from the FARSITE fire behavior model will then be applied to the visualization in order to show the spread and effects of the fire.

There are two main goals of this study, the first of which is to determine if wildfire visualization can be performed using VNS. There have been past attempts to visualize wildfires, such as the study done by the Los Alamos National Laboratory in the early 1990s (McCormick and Anrens, 1994). However, past visualization studies such as these have required both specialized equipment and programming knowledge in order to carry out. Likewise, the resulting output was rather crude and not very realistic. With the availability of more user-friendly visualization software packages and more powerful computer hardware, the potential for more realistic visualization is much greater, and the ease of use has been increased. However, no recent studies have been performed exploring the possibilities of visualizing wildfires with this new technology. This study aims to determine if such wildfire visualizations can be performed. It will also determine if some of the advanced features of VNS such as atmospheric effects, light effects, and ability to include user made models can yield a more realistic visualization.

The second goal of this study is to determine the compatibility of different data formats among VNS and other GIS related software. With the rise of GIS, certain data formats have become associated with particular type of data, such as shapefile for forest stand delineations. While some software was written with these data formats in mind for use, other software may not readily accept some formats. If not readily accepted, some data may have to be converted or reformatted into a useable form to be used in some software packages. If this conversion process is long and cumbersome, it might reduce the ease of use of the software. Thus examining the data format compatibility for a software package may play an important role in determining how potentially useful it may be.

Methods

Study Site

The study site is located at New Jersey Pine Barrens, a unique natural area covering nearly a million acres of the eastern Coast Plain of New Jersey (Moore, 1939). The area consists of low relief and has sandy soils except for areas along steams and poorly drained depressions. Climate for the region is characterized by annual precipitation of between 46 to 48 inches, of which 24 inches falls in a period from April through September. The number of frost-free days is approximately 180, lasting from around April 25 to October 20 (U.S. Department of Agriculture, 1941). The term “barrens” was given to the area by the original European settlers due to the sandy soil and droughty conditions that prevented crops from growing (Georgian Court University, 2006). Due to geologic and climatic effects, partly related to glaciations, many plant species are at a northern or southern range limit within the Pine Barrens. Because of these conditions, most of the pinelands are protected by state and federal agencies. The New Jersey Pinelands Commission is the organization that oversees the management of the protected outer regions and the inner Preservation Area of the Barrens. The area was designated as the Pinelands National Reserve in 1978 and as a United Nations International Biosphere Reserve in 1983. Major conifer species in the area include pitch pine (*Pinus rigida),* scrub pine (*Pinus virginiana)*, and shortleaf pine (*Pinus echinata)*. Some of the common oak species in the area are white oak *(Quercus alba*), scrub oak (*Quercus ilicifolia)*, black-jack oak *(Quercus marilandica*), and chestnut oak (*Quercus prinus*). The area also is home to several species of carnivorous plants such as spatulate-leaved sundew (*Drosera intermedia*), round-leaved sundew (*Drosera rotundifolia*), and the pitcher plant (*Sarracenia purpurea*).

A 10 square mile section of the Cedar Bridge area in the Pine Barrens was selected as study site. This area consisted of mainly a mature pitch pine canopy with a small amount of hardwood species and high shrub loads present in the understory. Most of the area is forested; however, there are some small areas with buildings and several highways. There is also one large lake and several smaller water bodies within the area.

Visual Nature Studio Visualization Approach

One of the first steps in this visualization was to recreate the forest environment in the Pine Barrens. Elevation and base heights for the landforms were obtained from a 10 meter digital elevation map (DEM) that was imported into VNS. A georeferenced aerial photograph was then used to digitize surface features such as roads, urban areas, and bodies of water. Surface features were digitized from the photograph using ArcMap as shapefiles. The shapefiles were imported into VNS in order to visualize the surface features. Road and water features were visualized using the included models in VNS that looked similar to the features observed in the photograph. Urban areas were similarly visualized with a model similar to asphalt, but with little or no buildings. This was done to reduce the total number of models in the visualization and to increase rendering speed.

To visualize the forest vegetation, user-made tree models were employed instead of the models included with VNS. These tree models were made from photographs of local Pine Barren tree species taken with a Nikon D70 digital camera during a visit in the summer of 2006. The photographs were loaded into Adobe Photoshop where surrounding vegetation was removed to leave the tree of interest alone in the foreground and the background was painted black (Figure 1). They were saved as a JPG file and imported into the VNS graphics library to use as models.

To visualize the forest environment in a realistic manner, it was necessary to link the tree models with the actual forest structure in terms of characteristics such as tree height and density. This was done using forest inventory data and a georeferenced Canopy Bulk Density (CBD) map. The forestry inventory data from test plots included tree height, species, diameter at breast height (DBH), basal area, and tree density. An analysis of the data was performed to determine the average and standard deviations for the tree height and DBH in each plot. Test plot density was compared to values from the CBD map based on the equation for deriving CBD in mixed conifer environments developed by Cruz et al. (2003):

$$\ln(\text{CBD}) = (0.319 \times \ln(\text{basal area})) + ((0.859 \times \ln(\text{tree density})) - 8.445$$

When solved for density using the values from inventory data and the CBD map, the values obtained were very close to the measured density in the test plots. Due to this correlation, the CBD map was deemed to be a suitable link between the visualization and physical inventory data. It was imported into ArcMap, where each map symbology value was given a significantly different RGB color code, and then exported as a GeoTIFF file (a TIFF image retaining its spatial coordinates). When imported into VNS, this GeoTIFF acted as a color map to allow one to visualize varying forest ecosystems of different structure based upon the CBD value.

Varying forest ecosystems were constructed using the ecosystem function in VNS. Appropriate tree models were placed in the canopy and understory layers based on species from the inventory data. Average height was used for the main tree height while the standard deviation was used as an offset factor to vary tree height. One of the default models included with VNS representing a

Figure 1. Custom tree models used to visualize vegetation in Visual Nature Studio.

forest floor with leaf litter was assigned to represent the ground. Due to the uniform nature of the site, most of these ecosystems were essentially the same in terms of species type, tree heights, and DBH classes. The most noticeable differences were in tree numbers and density, which was reflected in the CBD values used for color mapping.

Wildfire data was obtained from FARSITE simulations performed by Matthew Duveneck of Southern Maine Community College. The simulation was performed based on the conditions in the area for April 4, 2005. Temperature ranged from 40 to 66 degrees Fahrenheit with a humidity range of 16 to 61%. Wind speed ranged from 9 to 13 miles per hour for the day. The wildfire was simulated over a series of 30 minute increments from 12:30 to 6:30 PM EST. The simulation was run over the entire forest environment originating from a single location that was the fire ignition point. Within this time period, FARSITE treated the fire as a single entity. Furthermore, landscape features such as roads were not considered to be firebreaks which allowed the fire free movement throughout the environment. Results from the simulation included a shapefile outlining the spread of the wildfire over each 30 minute increment and several raster files with data pertaining to flame length, fireline intensity, and crown activity.

The custom tree models for tree visualization were recolored using Photoshop to represent burned trees. Models representing slightly burned trees remained mostly green, but had a small amount of brownish hue in the lower foliage and trunk. Additional yellow and red hues were added to the foliage to represent trees receiving more medium type damage. For more severe damage, a larger amount of red hue was added to foliage along with darker brown color or black marks to the trunk. Completely burned tree models had all foliage removed with very dark brown or black trunks and branches. A collection of flame models were also used to show fire occurrence (Figure 2). A few models were drawn with Photoshop for representing ground and understory fires. Another group of flame models came from a collection of Photoshop brushes created by Shimerlda (2007). These flame models were combined with the burned tree models to represent fire burning through the various layers of the canopy. Each tree model of different burn severity was merged with a corresponding flame model to represent fires occurring on the ground and in the understory, in the mid-story, and in the overstory. To represent fire moving through canopies of a group of trees, the larger flame models were merged with groups of three or four of the tree models.

Visualization of the wildfire was performed in a similar manner to different ecosystem placement using the CBD map. In examining the fireline intensity and flame length output in ArcMap, we found a strong correlation, where areas of intense fire typically had flames of greater length. Due to this, the flame length output was chosen to serve as a color map to guide proper fire visualization. Four different fire severity environments were constructed based on flame length; ground and understory fire for lengths of 0 to 9.84 feet, mid-story from 9.85 to 19.69 feet, overstory from 19.70 to 32.81 feet, and fire extending over the top of the canopy from 32.82 to 52.93 feet. Three different burned environments were also constructed to show the effects of a fire passing through the forest; one for areas in which the flame front had just moved through it, another for areas with low intensity and flame length, and one for areas with high intensity fires. These environments were constructed similarly to the regular forest environments in which the appropriate burned tree models were selected for each one. Ground textures were

Figure 2. Flame models for visualizing fire intensity in Visual Nature Studio.

made using Visual Nature Studio's texture editor. The basic ground texture was edited to show increasing amounts of damage with increasing fire intensity. These different environments were then assigned to each of the different forest ecosystems as a material. Materials in VNS act much like an ecosystem, with each possessing tree heights, density, ground models, etc. However, materials inherit all their characteristics from their parent ecosystems. As with the CBD map, the flame length raster and fire shapefiles were imported into ArcMap for editing to make a color map. Within each 30 minute increment of the fire as defined by the shapefile, the map symbology of the flame length raster was changed to a varying grayscale RGB value for each type of fire ecosystem. As the fire progressed, it was necessary to change the type of ecosystem present in already burned areas to reflect the behavior and effects of the fire. Based on consultation with Matthew Duveneck (personal communication, 2007), it was estimated that a lowering of fire intensity would usually occur sometime 30 minutes after the passage of the flame front, with a complete burn-out occurring within an hour. Each of these edited images were saved as a GeoTiff and imported into VNS as a color map. The individual images were placed as a second color map overlying the original CBD color map. The use of both color maps was needed so that the proper forest ecosystem type was selected, and the proper fire and burn materials within that ecosystem could be visualized.

Results and Discussion

As demonstrated by this study, Visual Nature Studio is capable of producing visualizations for wildfires, with both still and animated images being produced (Figures 3 and 4). Furthermore, it shows that such visualizations are capable of being produced on a computer system running standard equipment. Despite being custom-built, the system used for this study possessed hardware easily purchased at most computer specialty stores. Likewise, the software applications used were standard for their given use; Photoshop for graphics and ArcGIS for GIS analysis. Some specialized skills were needed for the graphics work to produce the custom models or for using VNS, however, no real programming experience was needed in order to construct the visualization. Unlike some past studies which required custom programming to extend the capabilities of the visualization program, all the features needed for this study were included as part of VNS.

The still frame images and animations produced effectively showed the spread of the wildfire and its effects on the environment. By combining the burned tree models with different flamemodels, the fire's movement through the canopy could be shown. The different models used illustrated the movement from the forest floor to the upper canopy of the forest and beyond. The different burn environments also showed the effects of the fire on the forest. Tree models in each of the environments reflected fire severity and intensity, with high areas having almost total burned trees and low areas having trees with little or no damage. The edited ground textures served to show fire effects on ground and understory layers. With increasing severity, the textures grow darker with more and more understory material being burned out.

Several aspects were detrimental to the realism of the visualized wildfire. One of these is the occurrence of a solid wall of flame for each fire type. Ordinarily there should be an active fire front with varying levels of fire intensity behind it based on fuel types and amounts. Something

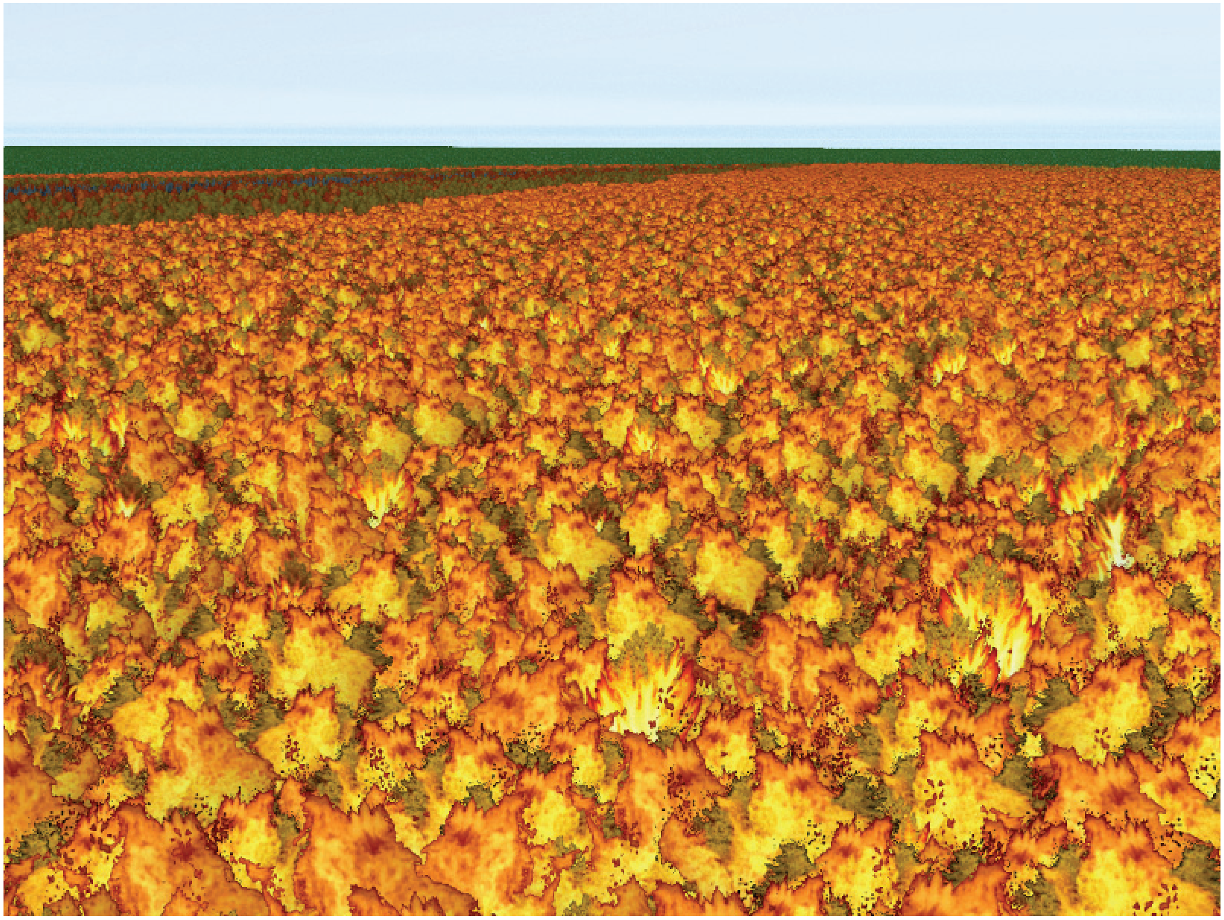

Figure 3. Still frame image of Visual Nature Studio fire visualization.

similar was planned for the visualization but the mechanics of the shape file prevented it from being implemented. The area for each 30 minute increment within in the shape file extended outward from the initial point of ignition. Using the outline of that area for a flame front would have yielded an unrealistic image resulting in a flame front occurring all the way back to the original ignition point that may have already burned out. Likewise, the raster images for flame length had to be reclassified into smaller groups more easily managed for visualization, so not a lot a variety could be done. Therefore, areas of fire are best thought of as representations of the fire severity occurring over the area at the time, not as the fire actually occurring. Another problem for realism was the large extent of the study area. The large size made showing events over the whole area difficult to illustrate. Just to show the first three hours of the fire required the camera to be at height of nearly 150 meters. Such a height made showing areas further away difficult because many of the details were lost or they were almost indistinguishable. Attempting to show the entire wildfire in one scene would be extremely difficult and result in nearly all the details of faraway viewpoints being lost.

Visual Nature Studio has several advantages for producing realistic visualizations of a scene. One of these advantages is the ability to import user-made images as custom models. This

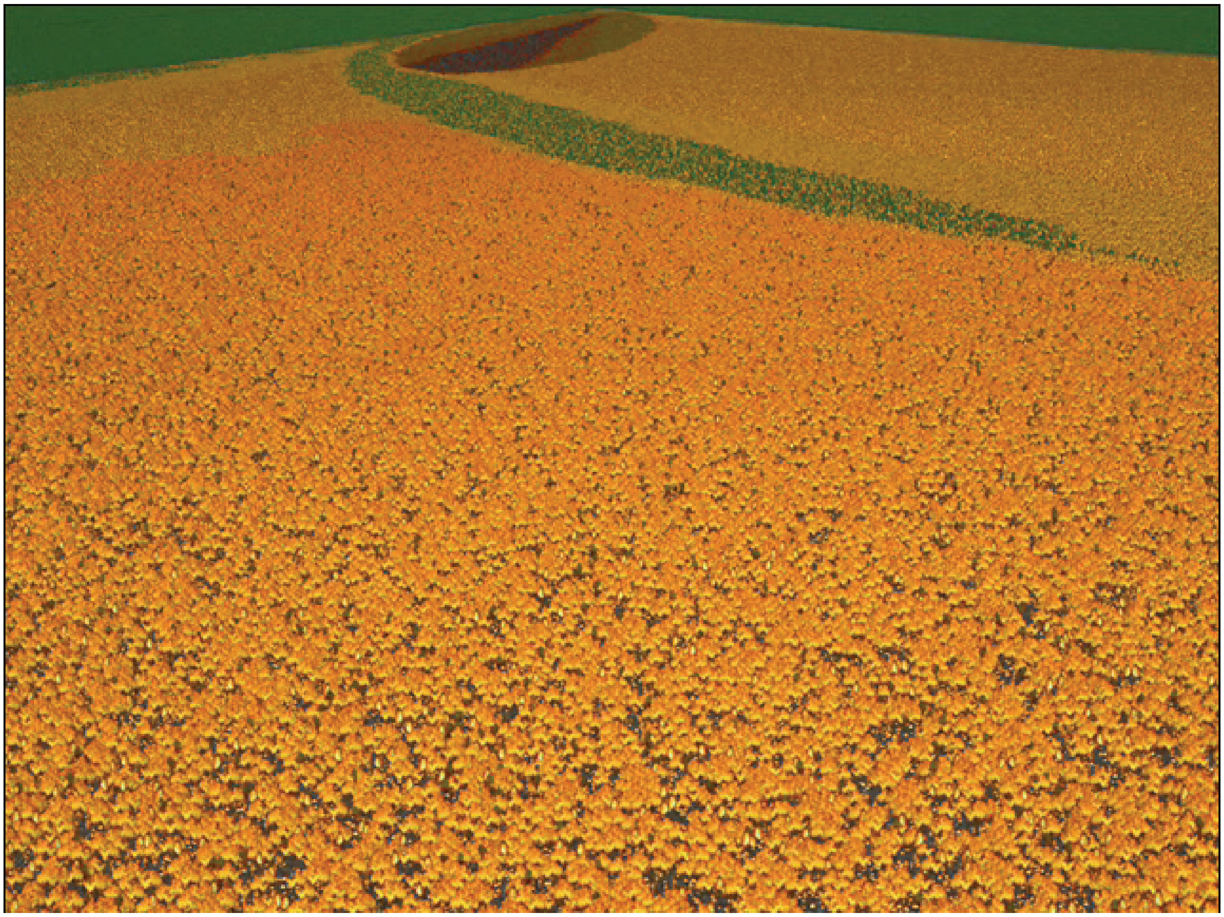

Figure 4. Animated sequence of Visual Nature Studio fire visualization.

feature is extremely useful for constructing more realistic tree models. Many of the other visualization applications such as VistaPro, Bryce 3D, and even ArcScene have tree models that are either very simplistic or composed of geometric shapes. While functional, these models may not look quite realistic or be recognizable by observers. By using photographs of the actual tree as models, they look much more real and recognizable. In addition, there are options to vary the height and direction for the custom tree models. Custom models help recreate the variation among trees that is found in a natural forest. The custom model feature also allows the user to utilize models that are not part normally part of VNS' graphics library, such as the flame models used in this study. It extends the function of VNS so that aspects not originally part of the application can be modeled and visualized.

Another advantage is the ability of VNS to use georeferenced images as color maps. Using each unique color as a guide, ecosystem matching can be accomplished on the visualized landscape. Through this matching, forest ecosystems can accurately match they appear in nature. They can be shown in the correct locations within the environment. Furthermore, two or more different color maps can be used for the same set of ecosystems. This facilitates before and after visualizations of a disturbance event, or allows one to illustrate how a forest landscape changes over time. Another feature of the ecosystem mapping process is the option to blend the edges of two different groups together. Raster images used for coloring maps result in divisions with blocky shapes due to the discrete information stored in each pixel. The blending of edges allows ecosystems to better represent how they would appear in nature, merging two adjacent forest types instead of abruptly stopping at an imaginary line.

While using VNS has several advantages, there are several characteristics of the application that can be seen as a disadvantage. One of these disadvantages is the somewhat high hardware requirements needed for running VNS. In terms of hardware, VNS should be run on a system having at least 1 gigabyte of RAM, a 128 megabyte OpenGL video card, and at least an 80 gigabyte hard drive. Many consumer computer systems sold today can be purchased with this level of hardware. However, users operating laptops or older computer systems may not have the necessary hardware to run VNS. Upgrading systems to higher specification hardware in these cases may be expensive or not possible at all.

Another feature of VNS that may be seen as a weakness is its rendering speed. Rendering in VNS occurs from the camera point out to edge of the horizon along the DEM of the landscape. In cases where a landscape covers a large area, the DEM is broken up into several smaller portions for rendering. VNS attempts to optimize rendering speeds by drawing only those portions of the scene that are immediately visible. However, in many instances this is not the case, and VNS processes other partial DEMs and image objects that are not present in the immediate scene. The processing of these unnecessary items can lead to a reduction in rendering speed due to the time required to process the information needing to be rendered. Increased rendering times can also complicate the production of animated images. With each additional individual key frame scene added to the animation, even more information is accumulated for processing. The time necessary for rendering these sequences can increase dramatically with the addition of additional key frames. Even short sequences running up to a minute at 30 frames per second can take up to 72 hours to render.

VNS is a very powerful application capable of performing many different functions. However, many of these functions are quite complex, requiring many steps to carry out. There exists a tutorial that explains the basic functions of the application, but many of the more advanced functions and settings are not explained. Likewise, the manual fails to explain processes in great detail. This lack of explanation can be a potential problem for new users not familiar with VNS. Users may require an additional amount of time to learn the features and experiment with settings to determine their function. Extra time taken to obtain this familiarity can add to the time needed to complete visualization. An improvement in both the tutorials and documentation included with VNS can users with more information and better understanding of the application.

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