PHOTOREALISTIC LANDSCAPE VISUALIZATION: A STEP TOWARDS A DIGITAL EARTH

by

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Abstract

A Digital Earth is a visualization tool that uses the latest technologies to embed vast quantities of geographic data into easily understood information. By creating three-dimensional landscape visualizations that look as photorealistic as current technology allows, it becomes possible to see, explore, and spatially understand parts of the Earth as if we were actually there. This research describes a method that can be used to generate photorealistic computer-generated landscape images, and five such images were created which replicated real-world photographs as closely as possible. This research provides a basis for continued research into the development of a Digital Earth.

The Concept of a Digital Earth

Traditional two-dimensional maps have been used for centuries to help understand the spatial relationships of Earth's features. Using a top-down view, geographic information is displayed on a flat surface, even if the data are naturally three-dimensional, such as mountains or canyons.

Various methods have been developed to visualize three-dimensional information, terrain in particular, on a two-dimensional map. These methods include elevation tinting, contour lines, and relief shading. While these methods do assist a map viewer in mentally visualizing the look of the terrain, they are an abstraction of reality and do not directly show what the terrain looks like. People are accustomed to visualizing terrain in profile as opposed to from the top-down because that's how they see the real world (Patterson 1999, 217). Three-dimensional visualizations remove abstraction from geographic data.

Artists, such as Heinrich Berann, have created panoramic views to show a more realistic perspective view of landscapes, rather than the top-down approach of two-dimensional maps. Considered the father of modern panoramic maps, his work spanned the disciplines of art and cartography (Premože 2002) by incorporating cartographic techniques into his landscape paintings.

The limitations of these artistic perspective views were their manual, and sometimes highly subjective, production. They are stunning pieces of art (Troyer, 2005), and required a skilled artist to create. However, there was no guarantee the information portrayed was spatially accurate, and in fact Berann routinely adjusted the scene to improve its artistic aspects (Premože 2002).

Technological advances have had a large impact on geography and cartography (Olson 1997). By the 1980's, computer storage and displays were replacing the need from hand-drafted paper maps for the display of geographic information (Monmonier 1985, 4). The growth of computer technology has allowed some degree of automation in the modern production of three-dimensional landscape renderings. Computer software, such as ArcScene and Terragen, is being designed specifically to display three-dimensional datasets, removing some of the abstraction present in two-dimensional maps. The U.S. National Park Service, realizing the need to portray geographic information in easily understandable formats, is increasingly using three-dimensional visualizations (Patterson 2003).

In January 1998, Vice President Al Gore purportedly gave a speech outlining his (and others) vision of a "Digital Earth". He foresaw the creation of a tool that would embed "vast quantities of geo-referenced data" into one integrated visualization program (Gore 1998). Such a tool would provide a way to turn the huge amounts of geospatial data presently available into understandable information that can be used, explored, and learned from.

By creating three-dimensional maps that look as realistic as current technology allows, it becomes possible to see, explore, and spatially understand parts of the Earth as if we were actually there. These maps remove all data abstraction by putting the user in a map, making it much easier to interpret the information they are seeing.

Research Justification

The Digital Earth initiative as proposed by Vice President Al Gore is a promising new concept in geographic information visualization. A three-dimensional digital representation of the Earth will allow users to visualize data in a more realistic manner. Two-dimensional maps can only show abstract representations of geographic data, but three-dimensional photorealistic renderings can show the same data with very little abstraction. They show users what the data in a 2D map would really look like. It immerses them within the map.

The ability to visualize geographic information in three dimensions has a wide range of useful applications in education, planning, and entertainment (infotainment). For all these uses, it can beneficial to have photorealistic output to increase the believability of the rendered landscape. Gaming has traditionally been on the cutting edge of technological advancement. Flight simulators and other games requiring immersive outdoor environments will be the among the first to implement the concepts of the Digital Earth. Similarly, military training simulators have a need to include the most accurate and realistic information possible to ensure the safely of missions. Artistic works, a modern equivalent of Heinrich Berann's panoramas, can be produce quickly, and could easily fit in on the pages of National Geographic magazine.

Virtual tourism is one of the most interesting applications for Digital Earth techniques. Using such a program, a user could explore national parks, foreign countries, and virtually any place that is difficult or expensive to travel to. They can visit the world without leaving home, and explore Earth as it really is.

The Requirements for a Digital Earth

A fully realized Digital Earth that includes three-dimensional landscape visualization requires the integration of many forms of technology and information. These technologies already exist, or are being developed, and early versions of the Digital Earth are beginning to emerge as a result. These requirements are outlined in Gore's Digital Earth speech (Gore 1998).

Computer power is a key factor that determines the capabilities of a Digital Earth. As computers become more powerful, they are able to store and utilize more data and process them in more complex ways. Moore's Law predicts that computer power doubles every eighteen months, and the capabilities of a Digital Earth application should do the same.

High precision and high resolution data from satellites and ground-based sensors are needed for display in a Digital Earth. There are already massive volumes of data available, and more are constantly being collected. Landsat satellites have been orbiting Earth collecting data since the 1970's, and there are hundreds or thousands of other satellites and ground-based sensors doing the same. These data need to be stored digitally, making data storage technologies just as important.

Broadband Internet access is needed to access the data, since most will be stored in data warehouses and accessed by clients via the Internet. Data warehouses will serve vast quantities of data to users spread around the world. It is possible to store small subsets of data on the user's computer, but this requires the data to be physically transported to the user.

The Future Needs of Digital Earth

The technological needs of a Digital Earth already exist and are being used for current prototypes. As technology progresses, the capabilities of a Digital Earth will continue to improve. Better satellite and ground-based sensors will be developed that can collect more accurate and more precise data. Bigger and faster computers will be created to render more complex and realistic visualizations. A Digital Earth application will be a concept that is constantly evolving to utilize these new technologies.

As technology progresses, and new geographic datasets become available, tools and applications need to be developed that can take advantage of advances. This is also an ongoing process, and a continued interest in the Digital Earth initiative will generate support for the development of these tools. Google Earth is a good example of a tool integrating current technology to stimulate user interest (Google 2005). Google Earth collects free terrain elevation data and satellite imagery and distributes it to users over the Internet using a standardized interface, at no cost to the end user.

The Role of this Research

Research needs to continue to aid in the development of methods and procedures to enable the creation of three-dimensional visualization tools that promote the use and understanding of complex geographic datasets. The goal of this research paper is to describe a method for creating photorealistic computer-generated landscape images, incorporating current data and technology, along with one of the industry-leading visualization tools.

Photographs were taken at several locations around Oregon, and physical data about the landscapes photographed were collected. These data, along with publicly available elevation and land cover datasets, were used to re-create the photographs on a computer (as realistically as possible). This computer rendering was done using Visual Nature Studio 2.53, which is terrain visualization software developed by 3D Nature in Morrison, Colorado (3D Nature 2005). The images produced were displayed alongside the original photos to allow for quick comparison between the photographs and the computer-generated renderings.

It should be noted that the images produced were technically 2.5-dimensional, not three-dimensional. While a viewer perceives the image as three-dimensional content, it is impossible to display three-dimensions on a two-dimensional surface, such as paper or a computer monitor (Haeberling 2002).

This research will hopefully serve as a small stepping stone toward the goals of a Digital Earth. It will outline one method currently available to create photorealistic computer-generated renderings of real-world locations, and provide several side-by-side comparisons of photographs and landscape renderings.

The Process

Selecting Study Locations

The Oregon Cascades were selected as the setting for the source photographs, due to their diverse and picturesque scenery (and proximity to the researcher). Five locations were chosen that fit several criteria. First, each location needed to be publicly accessible and relatively easy to get to. This would allow tourists to feel as if they could travel to these locations and view the landscapes for themselves.

The other requirement for a potential location was that it needed to offer a "postcard" view, one that is visually interesting and showcases some of Oregon's fantastic scenery. This requirement would also contribute to tourism as well as give a glimpse at the potential that computer-generated landscape rendering can offer.

The locations selected did not focus on the full range of landscape characteristics and content possible. This variety could include snow, beaches, night time, landscape types (desert/forest), and cloud types. While diversifying the locations selected to include these various characteristics would provide a more comprehensive test of the current rendering capabilities, it was decided that doing so would de-emphasize the focus of this paper on the creation of photorealistic imagery.

Based on these criteria, five study locations were selected for the purpose of this research: the Three Sisters, Crater Lake, the Columbia River Gorge, Mt Hood, and the ridgelines of foothills in the Cascade Mountains as viewed from Mt Hood. Figure 1 shows these locations within Oregon.

Data Collection

At each of the five selected locations, in addition to the photograph, a set of data points was collected to assist in re-creating the photograph on a computer. This information was recorded using a "Photograph Information Sheet". The data for each location are provided in Appendix A.

The data collected included six measurements to record the camera position and orientation. These measurements are latitude, longitude, elevation, roll (sideways rotation), pitch (up and down), and bearing (compass direction of view). When combined with the field of view of the camera, these six measurements are sufficient to record the precise location and extents of what should be visible in a photograph.

Several tools were used to record these locational measurements. A tripod ensured that the camera remained motionless during the entire data and photo collection process. The other tools included a GPS receiver, a tape measure, a magnetic compass, and a plumb-bob level.

A handheld GPS receiver was placed on the ground beneath the camera and recorded position data in geographic (WGS84) degrees latitude and longitude. The positions were also recorded in UTM zone 10 North in case they were needed in the future. These position measurements were averaged over several minutes to increase the accuracy of the readings. This is done within the GPS unit to correct for errors that occur during the positioning process due to poor satellite coverage and interference that could degrade the signal . Additional error checking with USGS topographic maps showed the positioning errors recorded on the GPS to be very small at each location. For the purposes of this research, a positioning error of less than roughly twenty feet was unnoticeable in the final products, and the handheld GPS provided accuracy well within that limit.

A tape measure was used to measure height of the camera above the ground. This height was added to the GPS-measured elevation on the ground to find the elevation of the camera. This corrected height variations that occurred depending on how the camera tripod was set up and leveled. The differences, however, turned out to be unnecessary due to errors in GPS-measured elevation information. These errors will be discussed in more detail later.

A compass was used to measure bearing, or the direction the camera lens was pointing. This was done by visually (and somewhat inaccurately) aligning the compass to the line created between the camera body and the target found at the center of the camera view finder. Unfortunately, this method only allowed for a precision of roughly 10 degrees, which provided a reasonable, but not fully accurate measurement. Luckily, errors in camera bearing could easily be detected and corrected for during the computer rendering phase by comparing the side extents of the photographs to those of the images produced.

Camera pitch, which is the angle up or down the camera was pointing, was measured using a plumb-bob level. This tool was constructed with cardboard, with a weighted string used to measure degrees of rotation. The plumb-bob always points straight down due to the affects of gravity, and was calibrated to zero degrees of rotation when the tripod was in a level configuration. This tool was able to measure true camera pitch to within 2° of rotation.

The final camera location and orientation measurement, roll, was not measured in the field. The tripod was adjusted to provide a level photography platform, and the camera roll was not changed from this level position. It was found that loose gravel affected the roll of the Cascades photograph, but this was detected and accounted for in the image creation process.

In addition to locational information, physical data about the landscapes were collected. This information included date and time of day, lighting conditions, weather information, and a description of the components of the scene, such as tree distribution and cloud types.

Information about the camera, which remained constant throughout this research, was also collected. The photographs were captured using an Olympus C-5050Z with five megapixel resolution, but similar results could be obtained using any camera. The most important camera parameter was field of view. This varied based on zoom settings, and ranged from 19° to 53° degrees.

A series of photographs were taken for each of the five locations. These photographs varied in lens aperture and exposure settings to ensure the best possible photograph was recorded. Information for each of the photographs in the series was recorded on the Photograph Information Sheet.

Data Processing

Once the photographs and associated data had been collected, work began on recreating them on a computer. Two important electronic datasets were needed for this process: a digital elevation model (DEM0 and land cover information for the study area.

The DEM selected for this research was the National Elevation Dataset produced by the United States Geological Survey. This DEM has a resolution of 10 meters between data points, and is currently the most complete and highest resolution dataset available.

The DEM was attained from the Oregon Geospatial Data Clearinghouse (Oregon Geospatial Enterprise Office 2005) in nine tiles covering all of Oregon. Using ArcGIS 9, these tiles were merged into a single dataset in the Oregon Lambert projection, which allowed the entire dataset for Oregon to be used without border and seam problems.

The DEMs were then subsetted for each of the five photograph locations. These subsets were square or rectangular areas, roughly thirty kilometers on a side, and with extents chosen to maximize the amount of terrain in the camera's view. These subset maps are seen in Figure 2.

For the Columbia River Gorge, the DEM subset was merged with a National Elevation Dataset DEM for Washington so that both sides of the Columbia River had seamless data. The Washington elevation data were obtained directly from the USGS website.

In the case of the Columbia River Gorge and Cascade Ridgelines, the thirty kilometer DEM subsets weren't large enough, since the photograph captured more distant terrain. In these instances, a larger DEM subset was created in the direction of the photograph's view. These subsets were down-sampled to thirty meter resolution to save disk space and processing times. Visual comparisons showed that the difference between ten and thirty-meter resolution DEMs could not be detected with distant terrain.

The second digital dataset used was the National Land Cover Dataset (NLCD), also produced by the United States Geological Survey. Published in 1992, the NLCD dataset classifies Landsat TM imagery into 21 land cover categories and has a resolution (grid size) of thirty meters. (USGS 2005a) The categories were mostly types of vegetation, such as "evergreen forest" and "shrubland." The dataset was utilized in its native Albers Conic

Equal Area projection and to save disk space and processing time, it was subsetted to four large areas surrounding the five study areas: North (Washington and Oregon), Middle, and South.

Image Composition

The third, and most important, phase of this research was using the digital datasets, in conjunction with the photograph information data gathered in the field, to create photorealistic, but computer-generated, landscape imagery that matched the actual photographs as closely as possible.

The terrain visualization software chosen to do this was Visual Nature Studio 2.53, (VNS) from 3D Nature. This software package has been in development for more than ten years, and constantly incorporates new technologies to remain one of the best tools available for computerized landscape visualization.

Many of the procedures used in this section are program-specific. While they may be similar in other programs, these procedures outline how the research was done with Visual Nature Studio.

The first step was to create a project file for each of the five locations. This set many of the variables to default settings to serve as a basis for production. The re-creation work was done for each location separately, since there was very little in common between the photograph locations.

The next step in the process was to input the elevation data. Visual Nature Studio provides an import tool that detects the projection and file format of the DEM, and projects it to VNS's internal format. One issue this import tool experienced was that it had difficulty interpreting the Oregon Lambert projection of the elevation data. It treated the units of resolution and extent values as meters instead of feet. This was manually corrected by explicitly converting the input values (which were in feet) to their meters equivalent (divide by 3.28084).

Next, the National Land Cover Data for the photograph location was loaded as a "color map" in VNS terminology. A color map is a raster image file that is draped over the terrain elevation data. It defines a color for each pixel of the color map, and is used when rendering the image.

In this research, the color map was used to define the positioning of vegetation within the landscape. This was easily setup using the "National Land Cover Data Template" package produced by 3D Nature. This package defines 22 ecosystems to match the 21 land cover types in the National Land Cover Dataset (plus one "blank" ecosystem). In VNS, an ecosystem is simply a definition of what types of vegetation should be drawn. Tree images are placed in the terrain to correspond to the ecosystem distributions.

For each pixel color in the NLCD color map, an ecosystem was defined and populated in Visual Nature Studio. Instead of draping the color map over the terrain, it was used to define the spatial extents of the various land cover types. Using this template data provided by 3D Nature saved time (compared to manually creating the vegetation information) and increased the accuracy of placement by eliminating subjective decisions concerning ecosystem placement.

After the DEM and land cover data were loaded, the next step was to set the variables that were directly measured in the field, including camera information and sun position. Within VNS, a view camera was established to mimic the photographic camera and its positioning was set, including latitude, longitude, elevation, roll, pitch, and bearing. The camera target latitude and longitude needed be set independently of pitch and bearing, but since this information was impossible to determine in the field, it was decided to set the camera target directly north of the camera position. This orientation allowed pitch and bearing settings to "adjust" the target to match the photographic camera's orientation.

In a few instances, particularly with the Mt. Hood image, it was determined that the field measurements of latitude and longitude were not as accurate as possible, likely a result of poor GPS satellite coverage. Using USGS topographic sheets, the longitude and latitude of the camera location was checked. For Mt. Hood, this check resulted in moving the camera in Visual Nature Studio about 30 feet southwest. For the other four locations, lateral errors in camera positioning were also present, but did not present noticeable differences in the rendered image.

The elevation measurements for all five photograph positions were also insufficient for use in Visual Nature Studio. The elevation of the photographic camera was measured using the handheld GPS, but was found to be imprecise when used to set the elevation of the VNS camera. When set to the GPS elevation, the camera was routinely buried beneath the terrain or significantly above it. The GPS elevation data were discarded, and more accurate elevation information were obtained by querying the elevation defined in the DEM for the camera position.

The sun position was set to correlate with the date and time the photographs were taken. Visual Nature Studio provides a tool that calculates the correct sun position in the sky based on this time information. Setting the sun position adjusted the lighting of the rendered image to closely imitate that in the photograph, as well as create shadows where they would logically be located.

Many other variables were set for each location in order to better represent what was seen in the photograph. This step involved a good deal of artistic interpretation, because it required the subjective estimation of variables that were not be directly measured in the field.

Visual Nature Studio provides hundreds of variables that could be set, and listing each one is impractical, if not impossible. The majority of these variables, such as the diameter of the planet, were left at default values since they were either pre-selected to conform to frequently used data, or had little or no influence on the images rendered in this research. There were several variables important for realistically recreating the photograph, and those settings will be discussed individually.

Haze and atmospheric effects make a significant contribution to the perceived realism of a computer-generated image. They add depth to a scene by helping the viewer distinguish relative distances from the camera. There are two variables that can be set in VNS to define the haze in a scene. These are the amount of haze close to the camera and the amount of haze further away from the camera (and the distance for which that distant setting is valid). The values range from 0 to 100%, with 100% totally obscuring the view. The haze increases from the near setting to the distant setting, which imitates the cumulative affects of haze in the real world. These variables were set using trial and error, comparing rendered images to the original photographs.

While there are many realistic sky colors, it was important to match the hues of the photograph. To do this, the sky color at the top of the photograph as well as near the horizon were sampled using Adobe Photoshop. These two colors were entered into Visual Nature Studio, which used them as endpoints of a color gradient with dark colors at the top. This gradient emulates the look of a natural sky and partially represents atmospheric light scattering.

Adding clouds to a rendered image requires a lot of subjective and artistic input to render realistically. Clouds in VNS require the specification of type (stratus, cumulus, cirrus), along with size, distribution, and altitude settings. Testing showed that it was quite difficult to mimic clouds seen accurately due to the many variables associated with them. Luckily, Crater Lake was the only photograph to have significant clouds.

Reflections and waves on water surfaces are crucial to the realism of a rendered landscape. These were added by first creating a water surface (a "lake" in VNS). This water surface has several variables that can be set, including transparency, and reflectivity. For the research photographs, the visible water bodies had no transparency and varying amounts of reflectivity. This reflection variable was set through trial and error, slowly changing the value until the water surface exhibited reflections similar to the photograph. For the Mt. Hood image, ripples were also required on the water surface. In Visual Nature Studio, this is done by displacing the water surface in varying amounts based on variations within a small source texture, which can be altered in size and pattern. These ripples give the indication of a breeze blowing across the water surface.

Fractal Depth is the final variable that has an important impact on the realistic qualities of a rendered landscape. In Visual Nature Studio, increasing the fractal depth subdivides each square of the DEM (based on four corners of defined height). Each square is divided into four smaller squares, increasing the complexity of the rendered elevation data. Ranging from values of 0 to 6, each increase in fractal depth subdivides the DEM an additional time, doubling the number of data points in the elevation data. Each of these points is then moved vertically, up or down, based on a vertical displacement variable. This displacement has the effect of making the terrain look rougher, or more textured, which tends to increase a viewers sense of realism. For this research, fractal depths were set between three and five, with a constant vertical displacement of five percent.

The final, and most important step in the photograph recreation process was rendering the results. This is a relatively simple process in Visual Nature Studio, allowing the user to create an output image with just a few clicks. Behind the scenes, though, VNS takes all of the many settings and variables and uses them to determine what the rendered image should look like. The variables are used along with "rules of nature" to create a landscape that looks like it does in the real world. The more accurate the data and information input into VNS, the more realistic the rendered image will be.

Results

Each of the five images produced in Visual Nature Studio was placed side-by-side with its corresponding photograph to allow for easier comparison. These images can be seen at the end of the text in Figures 3 through 7. Each image will be discussed individually, outlining its success along with what problems occurred to limit its realism.

Three Sisters

The Three Sisters is a series of volcanoes in the central Oregon Cascades. Photographed from a scenic highway to the northwest, the photograph focused on North and

Middle Sister, with the view of South Sister blocked by Middle Sister. In the foreground, lava flows can be seen featuring rough, rocky terrain. On the flanks of the volcanoes, and in the saddle between them, glaciers dominate the rocky slopes.

The rendered image accurately re-creates the shape of the terrain and positioning of the forests and lava fields. There are, however, several noticeable errors in the details. In the foreground of the photograph, several trees rise to frame the volcanoes and add to the visual photographic quality. There trees are not present in the rendered image. On the right side of the rendered image, on a hill in front of Middle Sister, two yellowish-green areas of shrubland are quite noticeable, but do not exist in the photograph. This is the result of a misclassification error in the Nation Land Cover Dataset.

Crater Lake

Nestled in the southern Oregon Cascades, Crater Lake is Oregon's only national park. The caldera lake was formed when ancient Mt. Mazama erupted and collapsed in on itself roughly 7,700 years ago. Photographed from the West Rim Overlook, Wizard Island (itself a volcano) dominates the foreground. On the far side of the deeply-hued lake, Mt. Scott rises to almost 9,000 feet.

There are several issues limiting the quality of the rendered image. The small area of land at the lower left of the rendered image is devoid of vegetation, revealing the detail of the rendered terrain. This is a weakness of the NLCD dataset and the ecosystem definitions used in this research. The ecosystem defined for that area of land does not have enough detail to provide the woody shrubs and short grass seen in the photograph. Large blue areas rise from the lake surface near Mt. Scott, showing another instance of misclassification errors in the NLCD.

There are also several "artistic" errors, which were purposely left to help illustrate the break in realism that can occur without total attention to detail. The lake is much more vibrant blue than in the photograph, and reflects the clouds above it too crisply. The clouds themselves, while similar in nature to those in the photograph, do not match in size and distribution. These mistakes could be corrected with more time spent adjusting the scene's variables in Visual Nature Studio, but require a skilled user to fix.

Columbia River Gorge

Perhaps one of Oregon's most recognizable postcard locations, Crown Point overlooks the dramatic gorge Lewis and Clark followed enroute to the Pacific Ocean. Photographed from Chanticleer Point just to the west, the historic Vista House at Crown Point is dwarfed by the river and surrounding landscape. The state of Washington is on the northern side of the Columbia River, to the left side of the photograph.

The forests of the Gorge appear greener in the rendered image than they do in the photograph. This doesn't decrease the realism, but is a noticeable difference. Setting the proper elevation for the river was difficult. There are many very low-lying areas close to the river, and several sand bars. Even by adjusting the water elevation a few inches at a time, a value could not be found that left the proper amount of ground near the river exposed above the water surface.

An interesting error that occurs in the rendered image only becomes obvious when looking for where the Vista House would be located (man-made structures were not placed in the rendered images). Crown Point, with its dramatic cliffs, is actually missing completely, as if the entire bluff crumbled and fell into the river. The source of this error is in the digital elevation data. The DEM has a ten-meter resolution, and the bluff was measured to be roughly 75 to 100 meters wide. This should provide enough space for several elevation data points to define the top of Crown Point, but its absence in the rendered image shows that there is some inaccuracy in the source data. These inaccuracies probably exist throughout the dataset, but are quite noticeable here.

Cascade Ridgelines

The Oregon Cascades have a large number of foothills on their western flanks. These foothills are actually the eroded remains of more ancient mountain building events. Viewed from the right location, these foothills can provide seemingly endless layers of ridgelines fading into the horizon. The southern flank of Mt. Hood, roughly 200 feet of elevation above Timberline Lodge, is the perfect location to capture these ridgelines. Photographing the landscape near sunset allowed the minimal light available to filter from the west into the low-level haze and accentuate the ridgelines.

There are relatively few errors in the rendered image, perhaps because the low light conditions hid the minor problems. As with other rendered images, most of the detail of the foreground is absent. This is partially a NLCD misclassification error, but is also noticeable due to the lack of sunlight highlights seen on the ground in the photograph.

The other noticeable difference between the image and the photograph can be seen on the closest ridgeline in the center of the image. This area is classified as "clearcut" in the

NLCD, which vividly stands out from the surrounding evergreen forest. It could not be determined from the photograph whether the area in question is actually clearcut.

Mt. Hood

Oregon's best known volcano, Mt. Hood rises more than 11,000 feet to dominate the northern Cascades of Oregon. Photographed from a popular swimming and fishing area on Trillium Lake, trees and hills help frame the magnificent view. A light breeze caused ripples to break the mountain's reflection in the water, but provided a good opportunity to showcase the water capabilities of Visual Nature Studio.

The most interesting difference between the photograph and the rendered image is the subtle differences in glacial extents near the summit of Mt. Hood. The rendered image shows more extensive glaciers than does the photograph. An obvious reason for this would be misclassification in the NLCD, as has been seen in previous rendered images, but that may not be the case here. The photograph used for comparisons was taken in late August, the time of year when snow packs are at their minimum. If the Landsat imagery used to produce the NLCD dataset was taken at a different time of year, such as April or May, there could be a significant discrepancy in the extents of the glaciers. The other possibility is also related to time. The NLCD dataset was produced in 1992, thirteen years prior to this research. In that time, its entirely possible that the glaciers have melted and retreated significantly.

Problems

The images produced in this research show that creating photorealistic landscapes that re-create real-world locations is visually promising. There are, however, several issues that need to be addressed to improve the future usefulness of terrain rendering, and more importantly, meet the goals of the Digital Earth initiative.

As discussed in the previous section, low quality source data can result in visual errors in rendered images. The types of quality issues seen in the source data used in this research fall into two categories: accuracy errors and precision limitations.

The primary accuracy error was pixel misclassification in the National Land Cover Dataset. According to the accuracy assessment conducted by the USGS, the dataset is sufficient for use in regional to continental scale applications (USGS 2005b). The assessment also cautions users against using the data for "highly localized studies," since the accuracy of individual pixels has not been verified. This research shows that, while the data are mostly correct, there are pixel-level errors that hinder accurate re-creation of photographs.

The National Land Cover dataset also exhibited precision problems, where there data resolution was insufficient to clearly define the extents of land cover types. The NLCD was created using Landsat TM source imagery which has a native resolution of thirty meters. Any land cover patch smaller than this size is not clearly detectable in the satellite imagery. The accuracy of the NLCD pixel classification drops as land cover patch size decreases to smaller than the precision of the Landsat TM imagery used (Smith et al. 2002).

The accuracy and precision errors of the source data used in this research are consequences of the technology used to collect the data. Since technology is constantly improving, more advanced sensor and satellite technology will help mitigate these errors in future datasets.

Much of the needed sensor technology is already available, but has yet to be implemented into a single useful satellite platform. Landsat ETM+ imagery has a resolution of 30 meters, similar to Landsat TM, but can be sharpened to 15 meters using its Panchomatic Multispectral Sensor. Other satellites, such as Quickbird, have resolutions in the one-meter range, but don't capture enough wavelengths to make accurate land cover classifications.

In addition to the technical limitations of implementing a Digital Earth application, the artistic requirements needed to design a realistic computer-generated landscape are still a major hurdle. Creating images in Visual Nature Studio is a much more automated process than the hand-painted landscapes of Heinrich Berann, but a skilled artist is still needed to interpret data not directly measured in the field. Time is needed to "massage" the many variables to perfection. While many steps in the design process have been automated through the use of geographic datasets and technology, photorealistic landscape rendering is still an artistic endeavor.

Conclusions

The goal of the Digital Earth initiative is to turn the vast quantities of geographic data currently available into a three-dimensional virtual Earth that can be used to visualize and explore data in a way that is both interesting and easy to understand.

When the goals of Digital Earth are fully realized, a personal desktop computer will be able to re-create any place in the world, and do so in a way that is visually indistinguishable from physically being there.

This research serves as a small but important step towards the goals of a Digital Earth. It outlines one method currently available to create photorealistic computer renderings of real-world locations. It provides a basis for continued research into the development of tools and applications that take advantage of the latest data and technology. Photorealistic computer-generated landscapes are the cutting edge of geographic visualization, and the Digital Earth is the future.

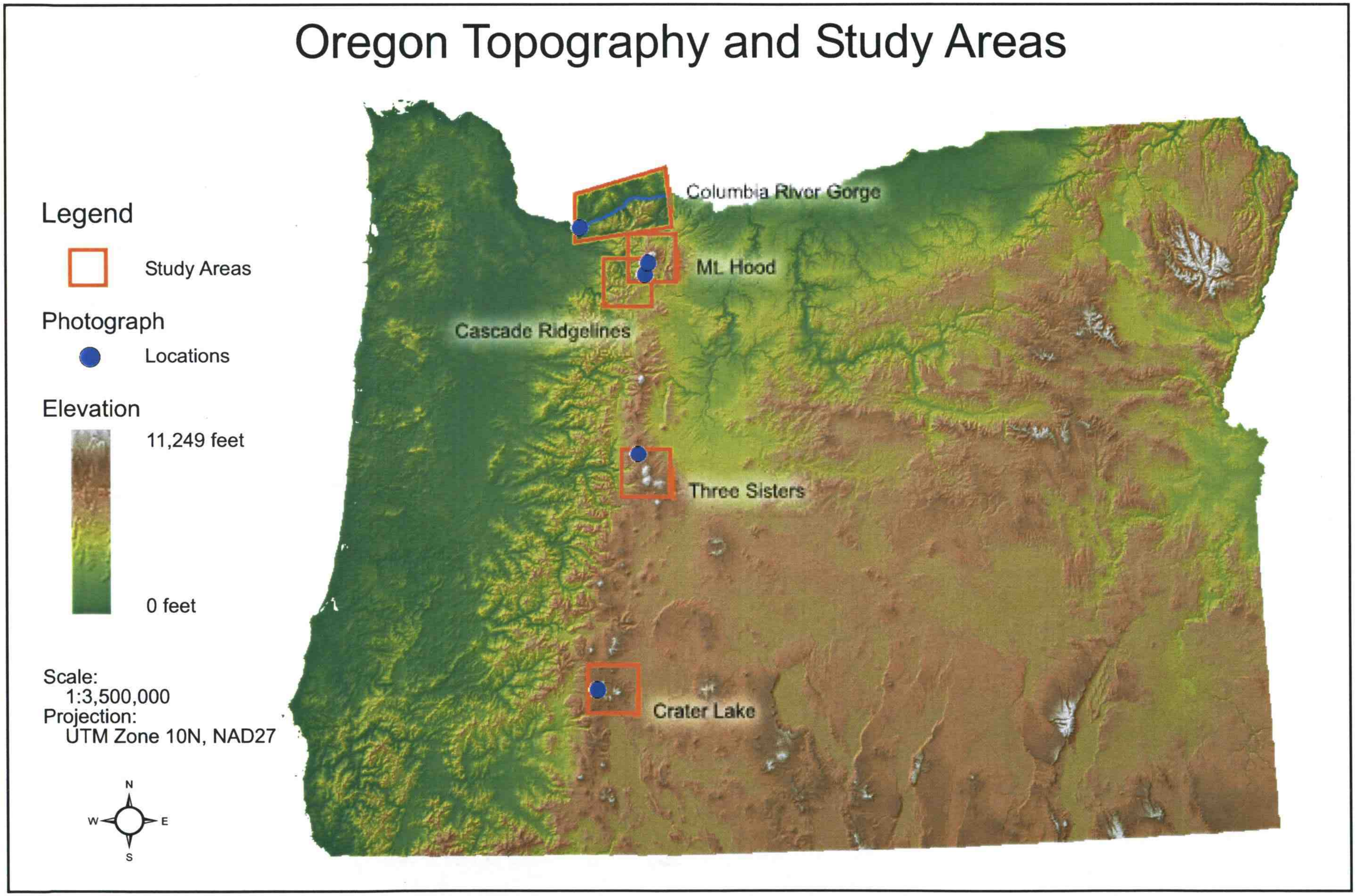

Figure 1 - Map of Oregon topography and study areas

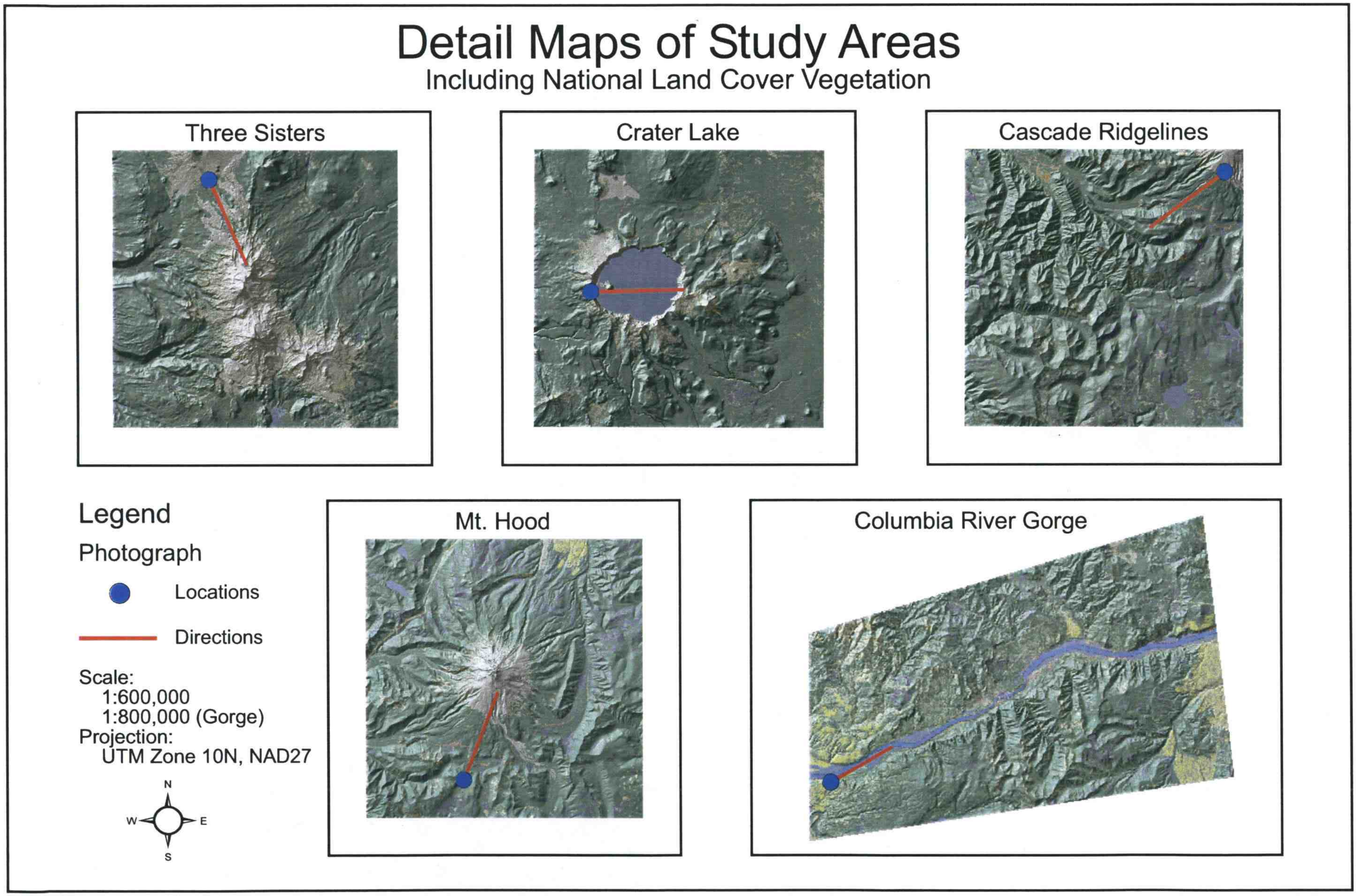

Figure 2 - Detail maps of study areas

Photograph   Render

Figure 3 - Side-by-side comparison of Three Sisters images

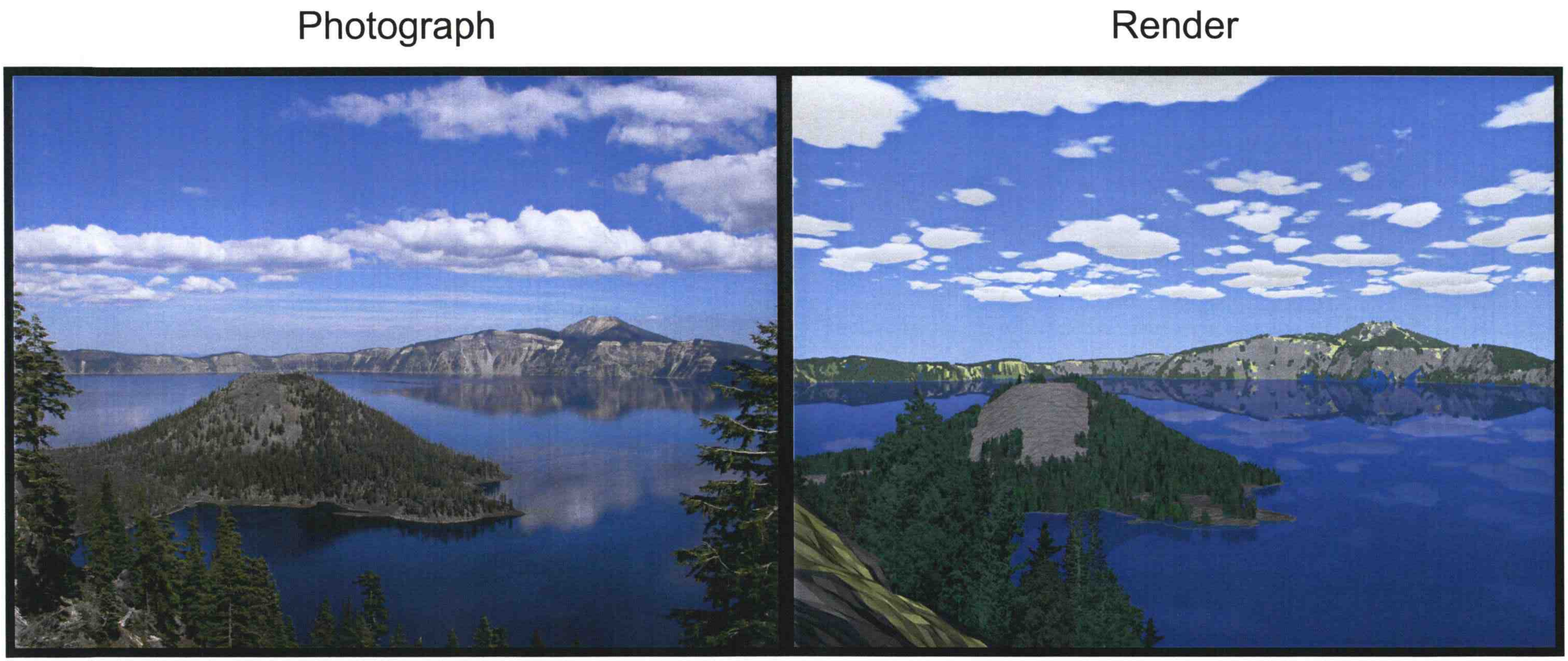

Figure 4 - Side-by-side comparison of Crater Lake images

Photograph Render

Figure 5 - Side-by-side comparison of the Columbia River Gorge images

Photograph Render

Figure 6 - Side-by-side comparison of Cascade Ridgelines images

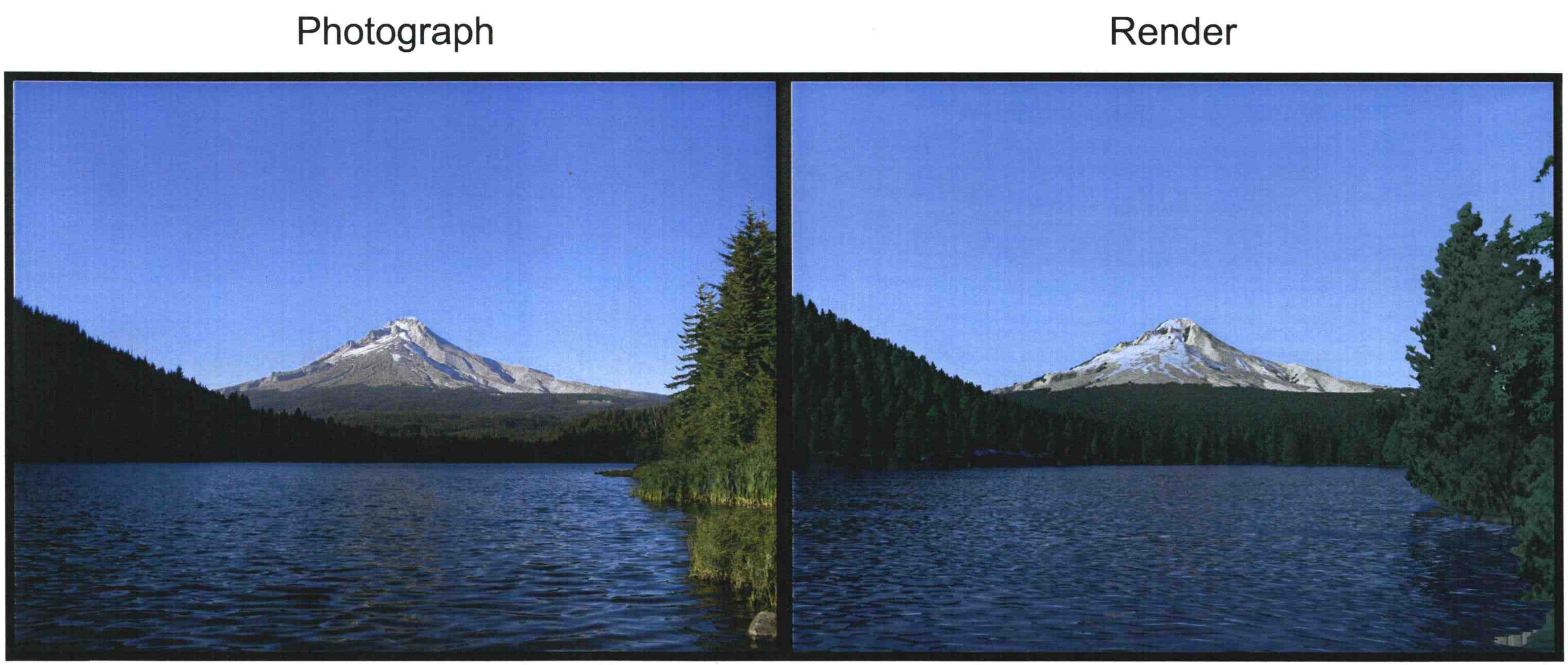

Figure 7 - Side-by-side comparison of Mt. Hood images

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Appendix A – Photograph Information Sheets

Photograph Information Sheet

Site: Three Sisters – North Middle   Date: 8/10/05

GPS:		**Orientation:**	
Latitude:	44° 15.139' N	Elevation:	5175 feet
Longitude:	121° 49.491' W	Height:	57 inches
Northing:	4900569 m	Inclination:	4° up
Easting:	593817 m	Direction:	140°
Averaging Time:	12 minutes	North Reference:	Magnetic

Site Description:

View of North & Middle Sister, Lava and trees in foreground, Bright Glacier between mountains, Zoomed all the way in

Weather:

Clear, light haze, sun to the front right

Pictures	Time	Bracketing	F-Stop	Shutter Spd	ISO
1-5	2:05 pm	0.7 x 5	4.0	1/800 s	64
6-10	2:06 pm	0.7 x 5	8.0	1/200 s	64
11-15	2:08 pm	0.7 x 5	6.3	1/320 s	64
16-20	2:08 pm	0.7 x 5	3.6	1/800 s	64
21-25	2:10 pm	0.7 x 5	8.0	1/200 s	64
Chosen:					
23	2:10 pm	0.7 x 5	8.0	1/100 s	64

Photograph Information Sheet

Site: Crater Lake – West Rim 2 Date: 8/19/05

GPS:		Orientation:	
Latitude:	42° 55.996' N	Elevation:	7143 feet
Longitude:	122° 10.166' W	Height:	59 inches
Northing:	4753738 m	Inclination:	-4° down
Easting:	567772 m	Direction:	73°
Averaging Time:	15 minutes	North Reference:	Magnetic

Site Description:

Wiz Island, Tree framing (pine), boat pulling away, all in sunlight, reflection on lake

Weather:

Light haze, clouds at 15,000, other clouds near horizon

Pictures	Time	Bracketing	F-Stop	Shutter Spd	ISO
1-5	3:50 pm	0.7 x 5	4.5	1/650 s	64
6-10	3:51 pm	0.7 x 5	8.0	1/200 s	64
11-13	3:53 pm	0.7 x 3	8.0	1/200 s	64
14-18	3:54 pm	0.3 x 5	8.0	1/250 s	64
Chosen:					
17	3:54 pm	0.3 x 5	8.0	1/320 s	64

Photograph Information Sheet

Site: Columbia River Gorge – Chanticleer Point 2 Date: 8/27/05

GPS:		**Orientation:**	
Latitude:	45° 32.089' N	Elevation:	809 feet
Longitude:	122° 15.630' W	Height:	80 inches
Northing:	5042631 m	Inclination:	1° up
Easting:	557733 m	Direction:	43°
Averaging Time:	9 minutes	North Reference:	Magnetic

Site Description:

Gorge - further out on bluff, ZOOMED IN on Crown Point, Cars in Parking lot

Weather:

Lots of haze, no wind

Pictures	Time	Bracketing	F-Stop	Shutter Spd	ISO
1-5	2:03 pm	0.3 x 5	4.0	1/650 s	64
6-10	2:04 pm	0.3 x 5	8.0	1/160 s	64
11-15	2:05 pm	0.3 x 5	5.6	1/320 s	64
16-20	2:06 pm	0.3 x 5	3.6	1/800 s	64
Chosen:					
4	2:03 pm	0.3 x 5	4.5	1/800 s	64

Photograph Information Sheet

Site: Mt. Hood – Ridges (Cascade Ridgelines) Date: 8/27/05

GPS:		**Orientation:**	
Latitude:	45° 20.146' N	Elevation:	6163 feet
Longitude:	121° 42.749' W	Height:	57 inches
Northing:	5021056 m	Inclination:	-2° down
Easting:	600822 m	Direction:	217°
Averaging Time:	6 minutes	North Reference:	Magnetic

Site Description:

View of Ridgelines, Sun Setting to the Right (west)

Weather:

Windy, low haze up to top of ridgelines, no clouds

Pictures	Time	Bracketing	F-Stop	Shutter Spd	ISO
1-5	7:35 pm	0.3 x 5	4.0	1/200 s	64
6-10	7:36 pm	0.3 x 5	8.0	1/50 s	64
11-15	7:36 pm	0.3 x 5	8.0	1/50 s	64
16-20	7:37 pm	0.3 x 5	5.6	1/100 s	64
Chosen:					
8	7:36 pm	0.3 x 5	2.0	1/50 s	64

Photograph Information Sheet

Site: Mt. Hood – Trillium Lake		Date: 8/27/05

GPS:		**Orientation:**	
Latitude:	45° 16.014' N	Elevation:	3591 feet
Longitude:	121° 44.472' W	Height:	55 inches
Northing:	5013370 m	Inclination:	6° up
Easting:	598752 m	Direction:	5°
Averaging Time:	15 minutes	North Reference:	Magnetic

Site Description:

Lake with Mt Hood in background, Wind on lake kills reflection, Canoe on Lake

Weather:

Low Haze, Sun to left, Dark pines behind lake

Pictures	Time	Bracketing	F-Stop	Shutter Spd	ISO
1-5	6:22 pm	0.3 x 5	4.0	1/320 s	64
6-10	6:23 pm	0.3 x 5	8.0	1/80 s	64
11-15	6:27 pm	0.3 x 5	8.0	1/100 s	64
16-20	6:28 pm	0.3 x 5	2.6	1/800 s	64
21-25	6:29 pm	0.3 x 5	8.0	1/80 s	64
Chosen:					
19	6:28 pm	0.3 x 5	2.6	1/1000 s	64