Assessment of LIDAR for Identification of Present and Past Forest Roads

by

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Abstract

In this study, LIDAR, light detection and ranging, was examined as to its ability to depict the existence of forest roads and 'legacy' roads. LIDAR is most often used to 'see' though the trees or vegetation to get an accurate representation of the terrain. As opposed to trying to remove the vegetation for description of the landscape, the detection of maintained roads was accomplished successfully by examining the breaks in the forest canopy. These roads can then be delineated and used to update an existing database. This process was also semi-automated in a GIS, creating linear features in a coverage based on the break in the slope of the canopy. The resulting coverage was much more accurate than the existing database. Examination of the TIN created from the LIDAR points allowed for a manual detection of 'legacy' roads in areas of very high shot density. Mass wasting and landslides are also detectable from the LIDAR. The accuracy of the identification of 'legacy' roads and landslides will greatly increase as the scanning technology improves and greater shot density becomes available at lower costs.

Keywords: LIDAR, Remote Sensing, Forest Practices, Canopy Assessment, Road Networks, Forest Engineering

Introduction

Landslides are a problem that affect us in many ways. For some people it is a loss of life and property through direct contact. Mass wasting also disturbs natural ecosystems and the habitat of different species and in some cases threatens biodiversity. The occurrence of landslides has been linked to roads and other forest management practices (Cafferata and Spittler, 1998). These practices have improved over the last thirty years, decreasing the amount of erosion and the possibility of landslides that could affect riparian ecosystems. Problems arise from roads and remnants of these management practices that remain on the landscape long after they have been abandoned. In many cases when an area has been logged to the desired extent, the old roads are simply blocked off to any further use and are left to deteriorate. These 'legacy' roads are a significant part of the landslide problem that exists in mountainous environments.

The goal of this project is to use LIDAR (light detection and ranging) in conjunction with a GIS to locate and identify forest roads. The intent is to be able to identify not only maintained or current logging roads, but also 'legacy' roads. This project will demonstrate how LIDAR technology can facilitate the detection of linear features in a forest environment. The identification of 'legacy' features is important so that management decisions can then be made in terms of their inspection and removal or maintenance. This may eventually lead to the protection of environmentally sensitive habitat.

Roads Relation to Landslides

Roads, clear cutting, and forest management practices have long been identified as the major factors contributing to landslides. Cafferata and Spittler (1998) identified in their study area in Northern California that at a number of the shallow landslides found, road, landing and skid trail design were the dominant controlling factors. They also noted that those roads and skid trails that were constructed prior to the Forest Practice Act continue to cause slope failure and impact riparian areas. Rice (1999) estimated that the erosion rate on newly engineered roads is close to one-tenth what it was on ‘legacy’ features. Past management practices impact their environs even years after these ‘legacy’ features are no longer in use. When large storm events occur, like during the winter of 1996, these ‘legacy’ features initiate failure (Rosenfeld, 1999). These features need to be identified and then management decisions made based on what is relevant to their future use and what will be best for the concerned ecosystem. Cafferata and Spittler (1998) took a stronger stance on the subject stating, “It is imperative that forest managers develop long-term road management plans that inventory these source areas and quickly reduce their numbers with an organized schedule based on watershed sensitivity and vulnerability of downstream beneficial uses (p 113)”. These roads do need to be inventoried in some way and it needs to be done in a cost effective and timely manner.

Landslides

Landslides are a natural geologic process caused by the gravitational pull on the surface of the earth. Landslides are a part of the natural regime of landscape forming processes. When there is this mass movement of materials that were assumed to be stable there are issues that arise. There is the possibility of loss of life, property, and at the very least damage to the natural ecosystem. It was estimated that the annual indirect costs of landslides in the United States was approaching $1.5 billion in 1986, with close to 25 deaths (Brabb, E. E., 1999). When it really becomes a problem is when these processes have a direct impact on human beings or the things on which they place value, whether this is monetary, aesthetic, or environmental. During the spring of 1996, there was concern related to the widespread floods and landslides that were occurring in the Oregon Coast Range. Much of the attention was focused on those areas adjacent to highways, because this is where humans are actually impacted, and those areas that damaged sensitive salmon habitat. Rosenfeld (1999) flew aerial videography over a transect of the Coast Range which depicted 71 large-scale feature related to the recent storms. This was only a small portion of the extensive range where this type of mass wasting was occurring, but if this is even remotely representative of what was occurring throughout the region then the numbers of landslides would be staggering. Yet the public focus is centered on those that have a direct effect on a large number of people.

Damage occurs to fish spawning and rearing habitat as a result of large amounts of sediment being deposited and higher sediment load. Erosion and sedimentation are essential for the ecosystem to function correctly, but when these events are violent and occur on a large scale then there is often widespread destruction of the terrestrial and aquatic organisms (Naiman et al, 1992). The occurrence of natural disturbances creates a dynamic equilibrium for riparian corridors, resulting in efficient and resilient ecosystems (Naiman et al, 1992). It is these riparian habitats that are essential to the health of the entire watershed. At this point in time the protection of these habitats has become a sensitive issue since salmon are protected under the Endangered Species Act. If any management activity is resulting in the destruction of this sensitive habitat then it is possible that the federal government could intervene with regulations or fines.

Figure 1 Landslide and debris flow cutting across road in H J Andrews Experimental Forest

The identification of landslides in the Pacific Northwest dates back to the end of the 19th century when I. C. Russell describes the topographic features that came about as a result of landslides (Peck, 1989). At this same time N. S. Shaler discussed the possibility that the construction of roads might cause landslides. Roads can have direct effects on nearby streams by accelerating erosion and sediment loading, altering channel morphology, and by altering the runoff characteristics (Furniss et al, 1991). All of these mechanisms have an effect on fish habitat. The location of the road is essential because it affects how all of the other variables will interact. Many processes such as slope failure will eventually occur, but it is the introduction of management practices, like road building and clear cutting that accelerate the rates of failure. The most frequent causes of road related mass wasting include the unsuitable road location, lack of maintenance, extremely steep slope gradient, undercutting of the slope, and modification of the drainage patterns (Furniss et al, 1991).

GIS in Mountain Environments

There is quite a lot of diversity in the make-up of mountainous areas, from the physical and topographic aspects to the biologic and human systems. These varied aspects make the use of Geographic Information Systems and Remote Sensing techniques difficult in these regions. The actual use of GIS in a mountainous area is no different than the applications that are used in flatter or lowland areas. The differences arise in the methods used and the variation that is necessary to accommodate for the varied spatial and temporal scales that are present. The modeling of the topographic landscape is an area where unique problems arise from the great variations in the relief and the shape of the terrain. GIS is essentially a two dimensional technology, but it is being used to model objects that are three-dimensional in the real world. This forcing of GIS past the second dimension allows us to model things such as drainage basins and flow maps as well as landslide susceptibility ratings.

Digital Elevation Models or DEMs are the basis of creating something that resembles a three dimensional GIS. Two and a half dimensional DEMs are created using aerial photography and a stereoscope where the technician estimates the elevation of the ground based on what is seen in every 30-meter square. In flat areas and in areas of little to no vegetation, this process is easier and much more accurate than when it is performed for a mountainous region. Extreme variation in the elevations found within the area and thick vegetation where the ground is not visible disrupt this process. In the case where the ground cannot be detected, then the elevation is depicted as the best estimate of the ground. In areas such as the Cascades where both the problems of thick vegetation and extreme terrain exist, the quality of the DEMs has to be questioned. This has been one of the reasons why LIDAR is being so widely used in the creation of Digital Terrain Models or DTMs.

Another problem that arises from the use of remotely sensed data and models created from the GIS is that due to the nature of the environment in which this data lies, ground-truthing becomes extremely difficult. If there is no method of on-site accuracy assessment of a model or data, then the confidence is decreased dramatically. This is one of the reasons that the LIDAR was flown in and around the H. J. Andrews. The ground data and the accessibility of the location made it possible for areas to be checked and rechecked with relative ease.

LIDAR

LIDAR is an active remote sensing technique, meaning that it supplies its own energy source to illuminate the features of interest unlike “passive” systems that sense the reflection of naturally available energy, such as the sun. LIDAR uses an airborne mounted laser, in conjunction with an onboard GPS (Global Positioning System), that pulses light towards the ground and measures the time that it takes for that pulse to return. The time that it takes to return to the sensor is later calculated to determine the actual location that was sensed based on the coordinates given by the GPS and the angle of the laser. Some systems are able to record multiple returns (up to four) for every shot that is made. So if a shot were to hit the upper branches of a tree it would return that location and continue on down through the canopy until the pulse either hit the ground or hit three more levels of plant growth. This makes LIDAR a technology that is good for determining aspects of the vegetation and features in three-dimensional space, along with having the ability to, in a sense, 'see through the trees' and return a measure of the ground.

Forestry was one of the first areas where LIDAR was used commercially. LIDAR, unlike other sensors, can map the canopy, ground and tree height simultaneously, which makes it a very attractive option. The accurate information pertaining to the terrain under the canopy is important to those dealing in forest resources. LIDAR has been used to determine many of the measurements that are useful in forest management. Work has been done in predicting the forest stand characteristics of height, basal area, and volume, with better and better results as time goes on (Means et al, 2000).

There has been quite a bit of work done in the area of feature extraction from LIDAR data. Much of the work has been in the extraction of buildings and trees in urban areas with considerable success (Halla and Brenner, 1999; Maas and Vosselman, 1999). Rieger et al (1999) did have success with the extraction of roads and buildings in forested area, but the area in which the LIDAR was flown was a deciduous forest and it was flown in the winter months. As a result there were no leaves on the trees and an extremely high percentage of the shots were able to reach the ground. They were also able to create 20 cm x 20 cm pixels because of the extremely high shot density that was obtained.

There are many applications for this technology. One of the main applications, and probably the most prevalent is that of the creation of high resolution DTMs that can be used in conjunction with GIS. Other applications include flood plain mapping and urban modeling. LIDAR is an extremely useful tool for dealing with measures of volume and location. It is practical when exact measurements of volume and location are wanted.

H. J. Andrews Experimental Forest

The H. J. Andrews Experimental Forest is located approximately 45 miles to the east of Springfield, Oregon. It was created in 1948 by the United States Forest Service to test the development of better forest management techniques, providing for sustained production of timber, water and wildlife within the ecosystem. When the H. J. Andrews Experimental Forest was created, the entire 15,000 acre drainage was covered with virgin Douglas Fir, some of it being close to 400 years old with only foot and horse trails on the ridgetops surrounding the drainage. In just five years, more than 72 miles of road had been constructed and within the first 25 years close to 60% of the area had been logged in some manner. In 1980 the National Science Foundation designated the Andrews as a Long Term Ecological Research (LTER) site. The intent of the LTER Program is to carry out long-term ecological research on vegetation succession, site productivity, and the decomposition process (National Research Council, 1995).

The National Forest Service and Oregon State University College of Forestry jointly manage the H. J. Andrews Experimental Forest. As a result of this cooperation and the focus of research in this area (over 1,000 thesis and articles have been published derived from research that has been conducted in the Andrews). It was as a result of this extensive research that the LIDAR was flown in this region. There are hundreds of data sources that are available for the H. J. Andrews on the College of Forestry's computer network that provide the supporting data that facilitates research in this region.

Project Description

The LIDAR data was obtained from Spencer B. Gross in Portland, Oregon who provided the data and preprocessing as part of a partnership in the NASA sponsored Affiliated Research Program (ARC) that examined the ability of LIDAR to make accurate forest measures (Means et al, 2000). The data was collected by the AeroScan LIDAR instrument that is flown in a fixed wing aircraft and the instrument collects 15,000 LIDAR reflections per second. The instrument scans from side to side laying down and receiving a zigzag of points on the landscape. The raw data consisting of points of an x, y, and elevation coordinate.

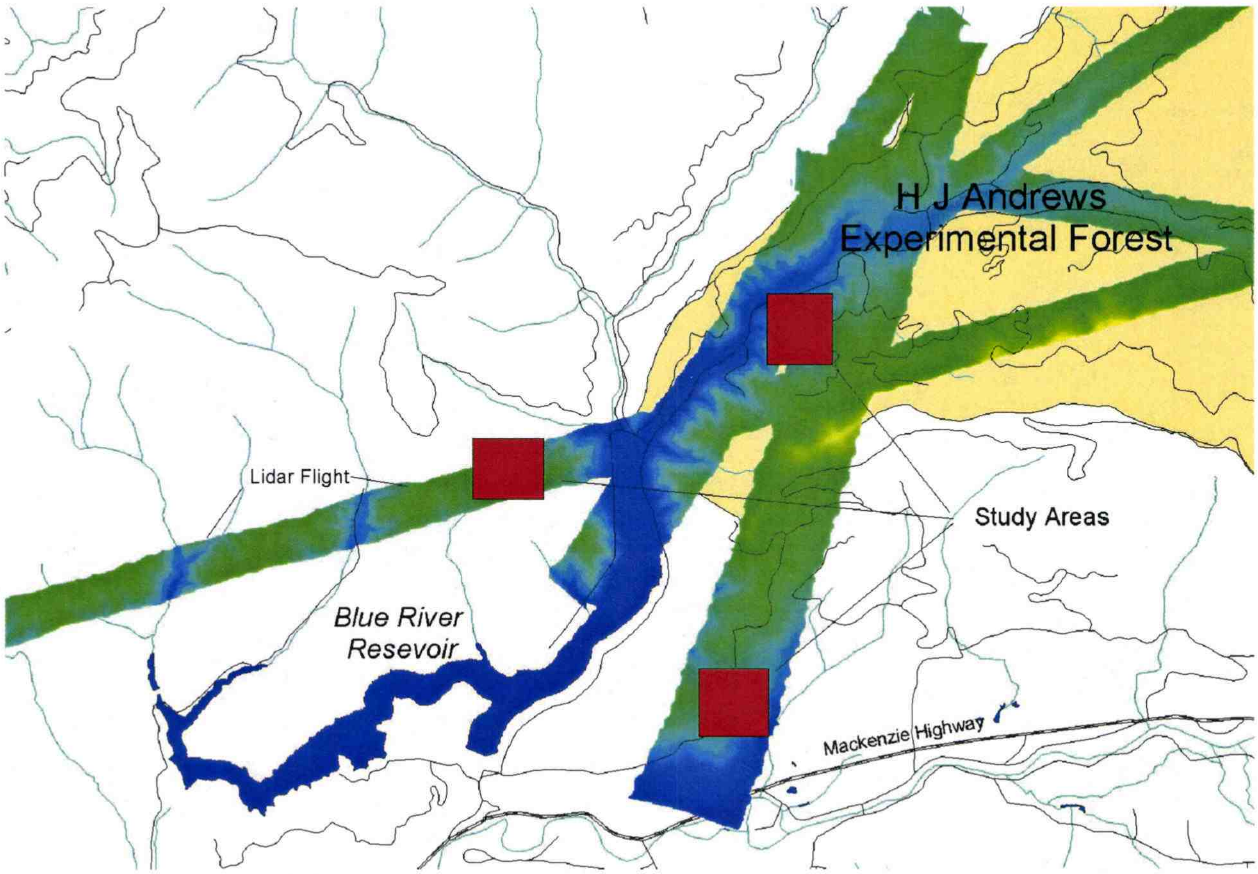

Figure 2 Location of Study Areas

For the purposes of this project three separate study areas were chosen within the flight path of the LIDAR. The first of these was chosen because of the high shot density that was found in this area. The shot density of the LIDAR is calculated as the number of LIDAR shots, or laser impulses, per square meter. Areas of high shot density have a larger number of data points compared to an area of low density. The best usable shot density that was acquired in the study areas was from 1.0 to around 1.8 shots per square meter. The mean shot density for all of the flightlines that were flown was 0.748 shots per square meter. So on average there was only one LIDAR return for every 1.34 square meters. Determining the characteristics of very large features is possible with this shot density, but in attempting to represent smaller features the results become less accurate. The higher density results in larger data sets with much more detail.

A gridded dataset was created for the entire flight line of the LIDAR shot density. This grid was then masked so that only those areas that contained a shot density greater than 1.2 shots per square meter were left visible. The proximity of these areas to roads was next examined to allow for easier access to the study area. Finally an area was selected in which close to 90 % of the grid cells in the 800 meter by 800 meter study area would be those with high levels of shot density. This area was first selected for a NASA ARC Project that was conducted earlier in the year that utilized LIDAR for the predicted measurement of individual tree crown sizes and volumes (Means et al., 2000). It was selected because of the high shot density and the fact that the area had been harvested within the last 30 years. This area is located in the Millridge area, which is Forest Service land that is directly south of the Andrews.

The second study area that was chosen is an 800-meter by 800-meter plot of land located completely within the H. J. Andrews Experimental Forest. The plot is located at the base of Watershed 3 and was selected because it contains two separate treatment units. Much of the Andrews is old growth Douglas Fir, so a GIS was used to locate those areas where treatment had occurred within the past 35 years, those areas with proximity to roads for easy access, and those areas that had coverage from the LIDAR flight. The GIS showed the existence of a primitive road in the plot, but the data is fifteen years old, so the actuality of this road being in working condition was questionable. This plot was also selected because of the unique aspects of management that have occurred in the H. J. Andrews. This plot in Watershed 3 was one of the initial watersheds that were intensively studied upon the creation of the Andrews in 1948. As a result, the management practices that have occurred on this land are not typical of the way land was managed within the National Forest System. This makes this plot unique from plots of land containing harvest units of the same age that would occur within the commercial world.

The third study site was chosen to be located to the West of the H. J. Andrews Experimental Forest. The land to the west of the Andrews has not been managed in the same fashion as the land contained in the second plot. This area is commercially productive timberland that is representative of typical Forest Service management. It is the Forest Service's goal to use its lands in a way that maintains the health, diversity, and productivity of the forests for future generations. This plot of land is approximately 2 miles to the south-west of the Andrews. It was selected by examining the LIDAR flight path for proximity to existing roads and also the existence of roads and logged areas on aerial photography that do not exist on the GIS coverages. In this case, the existing coverage of roads that was obtained from the Forest Service did not show any roads in this region, but the evaluation of the aerial photographs showed identifiable roads lying under the LIDAR coverage. This was an important factor in selecting this area, because it was important to examine an area of which there was little prior familiarity or GIS data.

Methods

LIDAR points were clipped to the three selected study areas from the 1.6-gigabyte collection of LIDAR points by software written by Dr. Joseph E. Means. The resulting clipped data consisted of around 325,000 individual points of an x and y coordinate and a z elevation value, within each 800 meter by 800 meter study area. The points were processed to create grids of elevation resembling a DEM. This was interpolated into an 800 meter by 800-meter square with 1-meter pixels using the inverse distance weighted function in ArcView. Triangulated Irregular Networks (TIN) were also created from the point coverages. LIDAR data provides the user with elevation values for both the first and last returns, which if everything goes perfectly will be the top of the canopy and the ground respectively. In working with a technician that produces DTMs for a company commercially it was observed that approximately 5% of the last returns are actually of the quality that they can be considered ground points and used in the creation of DTMs (Emerson, 2000). This means that 95% of what was supposed to be ground is actually getting caught up in the canopy. This poses a problem in the identification of maintained and legacy roads. Instead of identifying these features based on breaks in a smooth slope as was done by Rieger (1999), it would be necessary to extract them with the help of the surrounding vegetation.

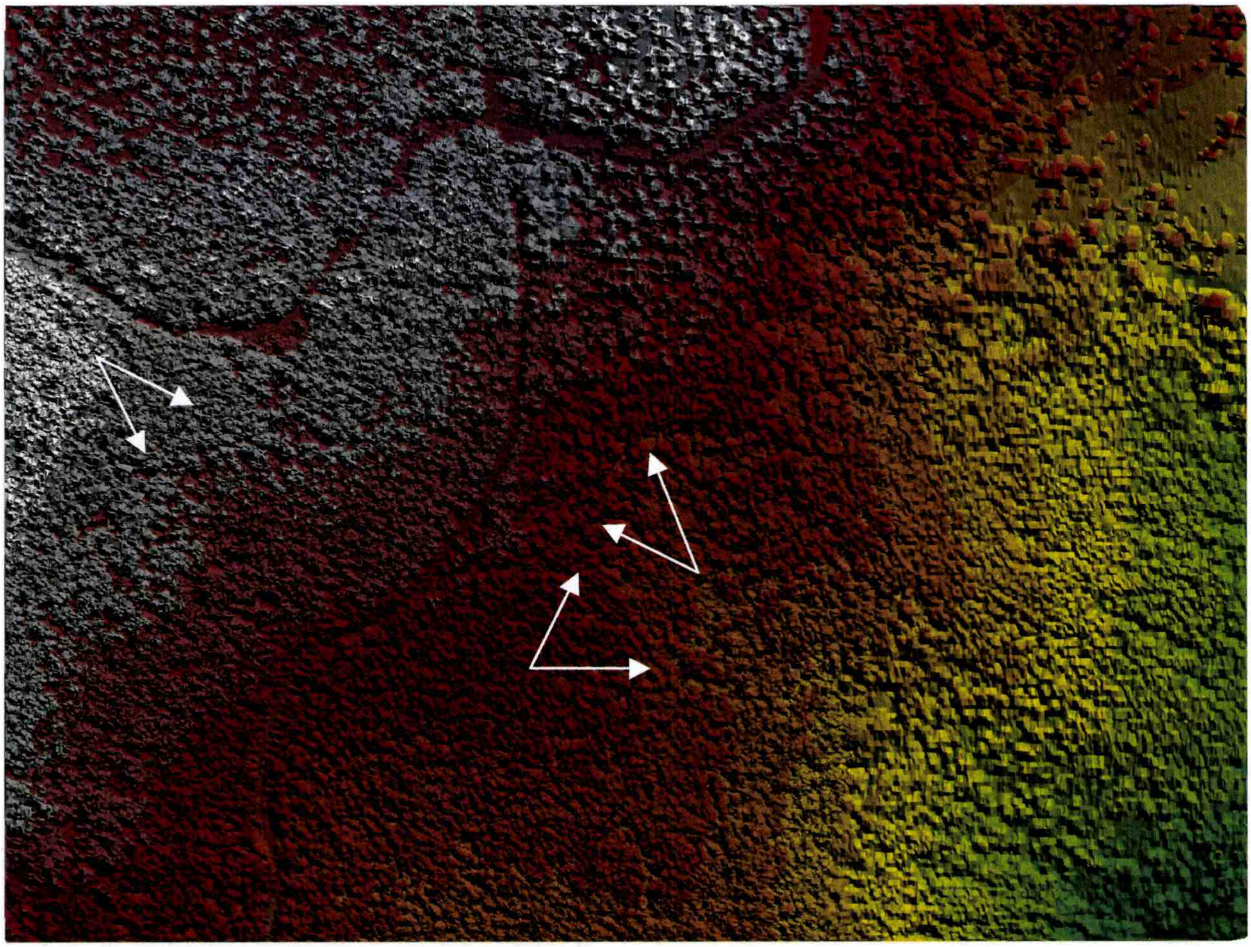

Figure 3 TIN of the first study area with suspected 'legacy' road marked by arrows

In order to incorporate the vegetation in the process, the DEM and TIN were recreated using the first returns. The resulting models were representations of the canopy from the LIDAR. Hillshading was performed on each of these to aid in the visual identification of ridges and valleys within the surface of the vegetation. The process of hillshading was repeated from many different angles in order to illuminate linear features that might exist in the various directions. The hillshaded grids and TINs were visually inspected for the presence of linear features or possible roads. These can often be identified by gaps in the canopy or as artifacts that develop from the existence of a road in the past. All suspected roads were digitized and verified using 1-meter orthophotos. The othophoto was also analyzed in a graphics program where the photo and a negative of the photo were overlaid and offset by a pixel. This resulted in good representation of the main roads and was helpful in verifying their existence, but did not aid very much in the identification of 'legacy' roads. A ground survey of the three study areas was performed in order to check the accuracy of the suspected roads and to discover if there had not been any possible roads that were unidentified. From this the relative accuracy of the road identification was determined.

In this first study area to the south of the H. J. Andrews, there is very high shot density. In fact this level of shot density, is higher than what is typically flown commercially. Generally the airplane with the sensor makes two passes over a location, but in this case the data was for research related purposes so the plane made an additional pass. In this area there were three features that warranted investigation as to the possibility of there being legacy roads. Field surveys verified that these are in fact legacy roads (Figure 4).

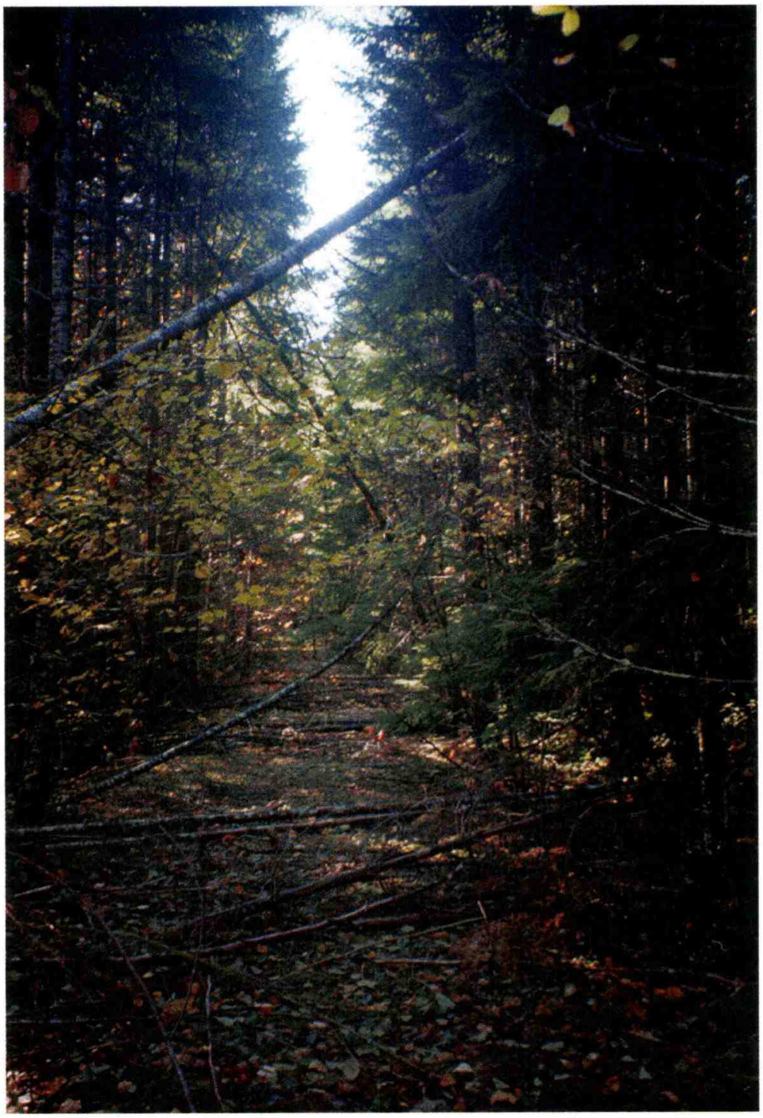

Figure 4 One of the 'legacy' roads in question from site 1

In the second study area, located within the Andrews the main road located in the watershed was easily identified with the LIDAR. This road was not in the roads layer in the GIS, but was verified with the digital orthophoto. There were a few linear features that were suspect as possibly being legacy roads. In the field survey of the study area, no 'legacy' features were found, but those suspected areas (Figure 5) turned out to be landslides that cut across the road and left debris blocking the path (see Figure 1). The landslides were seen by the LIDAR as features similar to roads because of the linear break that is created in the tree canopy. Upon reexamining the LIDAR data, it is possible to see the debris that is located on the road.

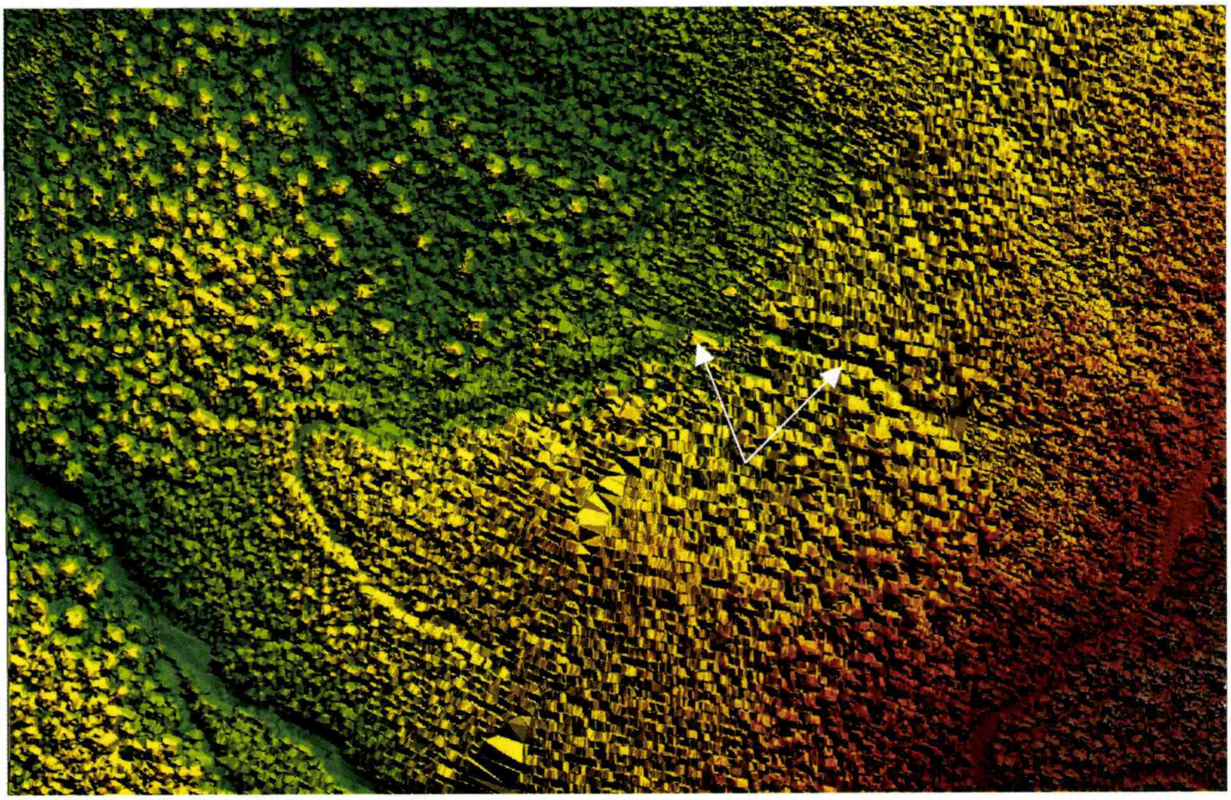

Figure 5 TIN of second study area with landslide identified with arrows

Within the third study area, there was no indication of 'legacy' features from either the examination of the LIDAR data or the field survey. This is commercially managed land with very steep terrain and no evidence could be seen of other roads on the hillslope. There is a debris slide that was blocking the road, which appeared to be slope failure as a result of the road prism. This was not detected prior to going into the field, but was visible on the TIN once the location was known.

A slope map, or grid of the first derivative, was created to help accentuate flat areas and regions of homogeneity. The slope, or maximum rate of change, from each cell to its neighbors is calculated in the GIS and returned as a grid. Roads are identified as those areas with only minor changes in elevation from one cell to the next. These areas that contain a low value for the percentage slope are locations in which there was a large enough gap in the tree canopy for the LIDAR to reach the ground. In areas where there are only trees, there exist high slope values because of the rapid changes in elevation that result from values being taken in the tops of the trees and then closer to the ground in the adjacent cell. This rapid and varying change of elevation over small areas results in large tracts of extremely high slope values. Linear features were created in the GIS that represented the contiguous cells of low slope. The slope grid was resampled so that only those areas of low slope remained. A majority filter was passed over the resampled grid to remove speckling. The resulting pixels were then converted to linear features in a vector coverage (Figure 6). The roads that were delineated by this automated process follow the lie of the road exactly, while the roads database from the Forest Service are simplified and deviate from the actual path of the road by as much as 30 meters.

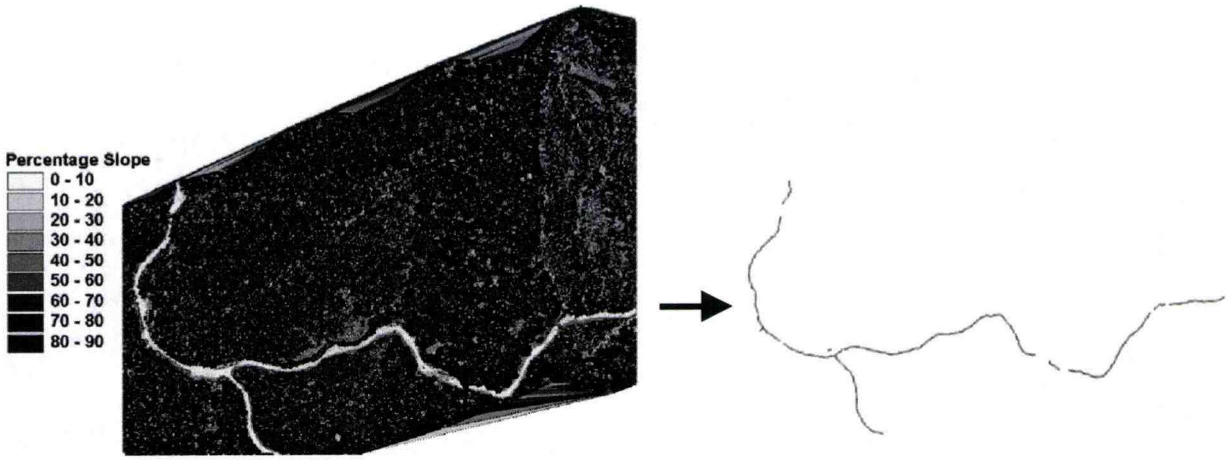

Figure 6 Grid of Slope in Area 3 with resulting vector coverage

Discussion and Conclusion

In remote areas where there is no access to the areas of interest, LIDAR is an ideal technology for inventorying the land. The possibility exists for creating DTMs, models of the vegetation, predicting the stand characteristics, and delineating roads all from the same data. LIDAR is an excellent method of delineating maintained roads, based on the comparison of digitized suspected roads and the 1-meter digital orthophoto. Maintained roads were identified in all three study areas, with all levels of shot density. These can be identified by visual interpretation of the TIN of the LIDAR and were extracted quite well with the linear feature extraction process. These roads need to be capable of the passage of logging trucks and equipment. As a result, they produce enough of a break in the canopy that is represented quite clearly in the LIDAR data. The identification of legacy roads is not as easy a task as that of maintained roads

The importance of knowing the exact location of roads and legacy features is important in the mitigation of mass wasting. While the knowledge of these road locations will not prevent landslides from occurring, it will help in the identification of areas of focus where engineering efforts can be concentrated in order to insure that these roads are at least not the primary cause of slope failure. It seems promising that LIDAR can be used to effectively identify and inventory both major and minor roads. The identification of mass wasting incidences is also a tool that could have a number of uses in forest management with a focus on riparian areas.

As with all analysis that uses a GIS, the model or analysis is only as good as the worst data that is used. This is evident when seeing how the quality of the analysis decreased as the shot density decreased. In order for thorough analysis to be done in areas with extremely accurate results, the quality of the data is going to have to increase as well. The DTMs that are being produced from LIDAR data are the most accurate available commercially, but when created in a forest environment are not to the level that exists in other areas. As the price of this technology comes down and computer processing becomes more powerful, it will become possible to obtain the data at a shot density where high quality analysis can be performed with adequate results. The state that commercial LIDAR is in at the moment would not make it possible for this type of project to be performed over a large area.

Further research should be concentrated on dealing with this technology on a much smaller scale as the quality of LIDAR increases and the cost decreases. The methods used in this project are basics for what could be done on a very large study area. Automating the process would be very beneficial for inventorying the existing roads, but with the state that the LIDAR data is now, an overwhelming amount of manual inspection would be required to detect the majority of 'legacy' features. It is possible to complete a thorough inventory of an area with the current technology, but the benefits do not appear to outweigh the costs at this time.

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