Erosion Analysis for Archaeological Purposes using LiDAR

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Abstract: The purpose of this paper is to report the findings of an investigation (using GIS techniques) into whether erosion in the uplands of North Yorkshire, England, poses an immediate threat to the existing Archaeology in the area. Water runoff and increased user pressure have been noted as the two main dangers to the landscape in this study. But the primary erosion factor that affects upland archaeology is related to human activity, which can be documented quite accurately using LiDAR technology.

Keywords: erosion, GIS, archaeology, uplands, LiDAR, Digital Surface Model (DSM), Digital Terrain Model (DTM)

1. Introduction
The purpose of this paper is to report the findings of an investigation into whether erosion in the uplands of North Yorkshire, England, poses an immediate threat to the existing Archaeology in the area. Water runoff and increased user pressure have been noted as the two main dangers to the landscape. Upland habitats in England are generally considered to be land above 300 meters. They comprise most of the various habitats located above the upper reaches of enclosed farmland. Dominant habitats in these areas are dry and wet dwarf-shrub heaths, bogs, and rough grasslands. There are also considerable expanses of rocky and alpine habitats. About 12% of England’s land surface consists of upland habitats [1]. These areas interface in significant ways with other habitats in the English landscape such as freshwaters and native woodlands. They support a wide variety of rare plant, bird, and animal life. This makes upland habitats very important from a nature conservation perspective. Another aspect of upland habitats needs to be addressed. Because they are located above areas of arable agriculture and urban development one can often encounter a rich cultural heritage. This is usually in the form of buried archaeology, earthworks, rock art, and historical buildings. Protection and sustainable management of these habitats is essential. Fortunately, most upland environments are contained within the borders of established National Parks. They are regulated on five-year plans generated by the individual National Parks. These plans may differ between parks but they must respect two of the National Parks system’s basic principles:

1) To promote opportunities for the understanding and enjo

2) To conserve and enhance the natural and cultural heritage [2].

Further, many of these areas are located within Areas of Outstanding Natural Beauty (AONB) [3]. AONBs are different from National Parks in that there is less opportunity for outdoor recreation. Natural England describes AONBs as areas of high scenic value which deserve statutory protection. This statutory protection is designated by Natural England. The responsibility for the management and preservation of AONBs lies with the local authorities [3].

Additionally, almost a fourth of the English uplands have been designated as Sites of Special Scientific Interest (SSSI) [2]. Natural England describes SSISIs as some of England’s best wildlife and geological sites. Much of upland England has been designated as SSSI [4].

Despite existing regulations upland habitats are extremely fragile and threatened. A large portion of these environments is in a degraded condition. Primarily as a result of heavy grazing and poorly planned burning of upland moors, the uplands have experienced enormous losses of many habitats [5]. Human derived threats to upland habitats can be relegated to two large categories: inconsiderate land-use practices and indirect effects brought about by pollution in the atmosphere and climate change. The biosphere of upland environments is determined by harsh climates, thin soils, and short growing seasons. Soil erosion, which is the result of heavy rainfall and the natural processes of freezing and thawing, can be exacerbated by the added effect of pollution and climate change. The dominant form of land-use in the uplands is agriculture, particularly livestock grazing. Poorly managed agricultural activities such as over-grazing and improper burning of moors can have a significantly detrimental effect on upland areas. Another issue related to agriculture is the growing reliance on All Terrain Vehicles (ATVs) as a means of transportation in the uplands [2].
The issue of recreational use of the uplands needs to be addressed. The uplands offer visitors the sensation of being in a vast, open wilderness. Therefore, it is easy to understand why the uplands are a much sought after location for outdoor recreational activity. As mentioned earlier, the upland areas in England are mostly within National Parks. This has generated somewhat of a philosophical clash. On the one hand, the National Parks are charged with maintaining the conservation of natural areas. But on the other hand, the Parks are supposed to encourage their recreational use. Presently, the National Parks are actively encouraging the recreational use of upland areas and the number of visitors does seem to be quite significant.

The issue of access to these lands is also fundamental to this discussion. In 2000, the Countryside and Rights of Way Act (CROW) was established [6]. This Act has three fundamental parts [7]. Part I has “provisions to introduce a new statutory right of access for open-air recreation to mountain, moor, heath, down and registered common land.” Part II makes changes and improvements to laws governing the rights of way system. Part III establishes improved administration and protection of SSSIs. The effects of this legislation are still not entirely clear. One concern is that recreational use pressure could impact previously unvisited areas negatively. Another possibility is a reduction of recreational traffic in already established routes [2].

Increased access to the uplands is linked to the erosion of footpaths in these areas. When footpaths have good vegetation cover the roots will bind the soil together. With significant use, though, the soil is compacted making it more difficult for the roots to establish themselves and gullies begin to appear. Gullies act as channels for water running off the uplands. This causes more vegetation and soil to be lost. Often the gullies contain standing water and mud creating unpleasant places to walk. When faced with these obstacles walkers often choose to go around these areas. By doing so the grass on the sides of the paths is trampled and the paths are unnecessarily widened [8].

In National Parks authorities recognize the possibility of extensive erosion due to climatic conditions, land-use policies and recreational use. Occasionally, in order to assess the condition of the walking areas footpath surveys are conducted. These surveys are usually conducted on foot with the surveyors checking such things as path width, depth of gullying and drainage capabilities. This type of information assists in the decision-making process of whether to intervene in some situations and initiate path repair. The main drawback to these types of surveys is the amount of time needed. Now that people have access to additional recreational space the need to assess more paths may create an unmanageable situation [2].

Because of the amount of time needed to conduct surveys on foot other potential tools are being considered. This study discusses the use of LiDAR data in a Geographic Information System (GIS) as a surveying tool. LiDAR analysis will be conducted to assess the impact of erosion on existing archaeological features. If LiDAR data for a given area is available, producing a GIS analysis of the data could provide a rapid, efficient and highly accurate survey, thus, off-setting the need for extensive man-hours to conduct an effective land survey.

1.1 What is LiDAR and how is it used in Archaeology

LiDAR (Light Detection and Ranging) refers to a remote sensing technique for light detection and ranging to determine three-dimensional data points through the application of laser beams [9]. LiDAR is a recent (mid 1990s) technological development in the field of Earth Science [16]. It has revolutionized the field of topographic surveying and is recognized as an excellent technique for measuring terrain elevations. It uses consistent pulses of laser light along with accurate locations of kinematic points to generate highly precise elevation measurements that reflect both horizontal and vertical qualities [17]. Extremely accurate three dimensional images of the earth’s surface can be generated by using LiDAR [14].

Hardware which is needed to capture LiDAR data includes a vehicle, either an airplane or a helicopter, a laser scanning system, a GPS system, and an INS (Inertial Navigation System). The roll, pitch, and heading of the aircraft can affect the LiDAR data. The INS measures these effects and compensates for them. Multiple laser beams per second, usually at rates greater than 30 MHz, are transmitted toward the target area as the vehicles move through specified survey routes [17]. When the light is reflected back it is captured and analyzed by the LiDAR sensor. The exact amount of time needed for the laser beam to travel from the aircraft to the surface and back to the LiDAR sensor in the aircraft is calculated for each of the multiple light beams. These calculations are used to generate three dimensional points which accurately represent both surface and actual terrain features. These multiple point calculations are known as point clouds. Point clouds are later processed and assigned accurately georeferenced x, y, z coordinates which allow them to be used in the GIS to create Digital Surface Models (DSM) or after filtering to create Digital Terrain Models (DTM) [15].

The distinction between DSMs and DTMs is essential for understanding how to appropriately use the data. A Digital Surface Model (DSM) is a full surface model. A DSM includes buildings and vegetation. This offers very realistic information about what is actually on the surface. Normally, when a laser pulse is dispatched multiple returns are commonly recorded. One can have what is known as a first-pulse (FP) and a last-pulse (LP) as well as pulses in between. This can be described by considering the density of a forest canopy. When a laser pulse is dispatched it first encounters the upper portion of the canopy. It reflects back from a semi-opaque surface and continues downward with progressively decreasing levels of reflective intensity until reaching the actual opaque land surface for the final return [17]. These data will give a very clear picture of what resides on the surface. For the study of archaeological structures this approach can be useful.

On the other hand, a Digital Terrain Model (DTM) offers an accurate geometric description of the actual terrain to-
Erosion Analysis for Archaeological Purposes using LiDAR

Crutchley states, “LiDAR data can be immensely useful and has unrivalled capabilities for mapping in certain environments, such as within particular types of woodland” [10]. LiDAR has the ability to probe through dense forest canopies. A DTM is a recording of the last pulse sent back from the multiple laser pulses. It is a reflection of the actual land surface. For archaeologists this is very beneficial because with the capability to penetrate heavy canopies it becomes possible to visualize earthworks and other indications of archaeological remains existing under the vegetation [16].

This paper discusses the use of LiDAR to conduct an erosion impact survey but LiDAR data has also been used in a variety of studies to assist in archaeological investigations. Crow and Benham discuss the application of LiDAR analysis to expose previously hidden evidence of archaeology beneath a forest canopy [18]. Challis and Kincey discuss how the use of LiDAR can enhance already existing historic environmental records [19]. Full-waveform laser scanning is now being studied as a means of further penetrating heavy forest canopies in the search for archaeological evidence [20]. New analytical techniques are being developed, such as applying the slope contrast (sharp unnatural changes in elevation) method to identify archaeological features in irrigated agricultural landscapes [21]. In an attempt to investigate late glacial and early holocene landscapes in Belgium LiDAR was used to map palaeochannels (early river channels) to determine their flow characteristics in order to give a picture of the landscape of the late palaeolithic and early mesolithic [22]. Challis, Carey and Kincey have compared LiDAR data to simultaneously collected terrestrial records of sediment, organic content, moisture and stratigraphy with potentially favorable results, although, this does remain somewhat unpredictable [23]. One of the more famous uses of LiDAR is the mapping of the World Heritage site of Stonehenge. Indications of vast fieldworks around the site were imaged [24]. Using LiDAR in archaeological investigations offers the potential for gaining substantial information regarding specific sites. This paper will focus on one method for obtaining this information.

2. Methodology

2.1 Study Area

The study area is an extensive tract of land in North Yorkshire. Two LiDAR data strips were used to illustrate the surface to assess the area for the effects of erosion. The data areas extend from east to west (Fig. 1). Bolton Abbey, a 12th-century monastery is located at the center of the two strips. The Yorkshire Dales National Park is a large park centered on the Pennines in the counties of North Yorkshire and Cumbria. It covers 1,762 square kilometers. Many people take advantage of the parks numerous footpaths to enjoy the scenic beauty of the area [11]. The southern boundaries of the park extend into and cover a large portion of the upland habitats in the study area. To the south one encounters a progressively more residential environment, with towns such as Skipton, Addingham, Ilkley, and Otley. Further to the south are larger cities like Manchester, Leeds and Bradford. An SSSI shapefile for the Yorkshire area was downloaded and it demonstrates that much of the uplands in the study area have been included in the extensive series of SSSIs which extend into the vast upland area north of the study area (Fig. 2).

Being situated both in a National Park and in an area having SSSI designation most of the upland habitats in the study area have statutory regulations and guidance for maintenance. Having statutory regulations makes it easier to arrive at solutions in areas where the effect of erosion has developed into a serious problem. The Yorkshire Dales National Park Authority is an independent body and functions as the local planning authority and has the responsibility for the maintenance of rights of way throughout the park. If lines of communication were kept open studies such as this could prove to be of benefit to the park. If it can be shown that this technique has both economic and speed-related benefits it may create incentive to further utilize the technique for investigating erosion throughout the park.

These upland areas have many cairnfields (locations with conical heaps of stones built as monuments or landmarks) and are scattered throughout with Cup and Ring rock carvings (Fig. 3). Cup and Ring carvings describe petroglyphs found mostly in Scotland and Northern England. Their ages are generally estimated at 4000 – 5000 years. This would place them in the Neolithic and Bronze Ages. These petroglyphs appear as circular extractions in the surface of the rock [12].

These cupmarks can be seen singly or in clusters. Another common motif is a cupmark encircled by a circular channel (cup and ring mark). These can be found as single or multiple rings surrounding the cup. These motifs can also appear as more convoluted designs integrating cups and rings, cups and grooved channels which link different parts of the overall design. Although many theories have been put forth, presently, the true meaning of these symbols remains unknown [12].

The study’s primary requirement is to assess the potential for erosion related effects on existing archaeology in the study area. In order to locate the archaeology a Scheduled Monuments shapefile from North Yorkshire was loaded into the GIS (Fig. 4). This helped associate existing archaeology with the study area. The western LiDAR strip was not directly associated with any significant archaeology in the upland areas and therefore will not be considered further in this study. The eastern data strip, particularly the upland areas east of the River Wharfe, shown here as the red line, displayed significant archaeology (Fig. 5).

All throughout this upland area, especially in the area north of Ilkley and the Ilkley Moor, which are famous for their many examples of prehistoric rock art [13], a large number of engraved rocks and cairnfields (??????) have been documented. This area will be the main focus of this study.

2.2 Libar Analysis

For this study, ArcGIS 10 from ESRI was used to analyze the LiDAR data. LiDAR data is recorded in millimeters but ArcGIS needs to have data recognition in meters. It is first necessary to change the data reading from millimeters to meters. The DTMs that were used in this study were generated in a grayscale color configuration by default. Using a gray-scale configuration often gives some ambiguity when trying to distinguish surface detail. If the configuration is changed to color it becomes easier to distinguish terrain detail. For this study a Blue to Brown color scheme was adopted. Blue signifies higher elevations and Brown indicates lower elevations (Fig. 6 and Fig. 7) from ESRI.

The DTM is now ready to be analyzed. The nature of the DTM, though, makes it difficult to accurately distinguish features on the ground. The gradual change of color representing elevation does not allow the eye to see small changes. It appears more to be an amorphous mass of color. This can be alleviated by employing a simple solar shading technique. In ArcGIS, and most GIS software, this technique is known as hill-shading. Hill-shading illuminates the surface from a user defined false source of illumination. (This means) The user is able to change the azimuth?? degree as well as the elevation of the illumination source. Using a hill-shade with the DTM emphasizes minute topographic changes that are indicated by the elevation points. This offers the user a very precise and accurate rendering of the surface (Fig. 8).

Several alterations needed to be done in order to achieve maximum clarity. First, the Stretch Type in the Symbol properties needed to be set to Standard Deviation. This gives more clarity to continuous data strips such as the two used for this study. The Resample selection in the Display properties tab needed to be set at Bilinear Interpolation. Bilinear Interpolation gives a much smoother look to continuous data than selecting Nearest Neighbor. The hill-shade
was created by default opaque. In order for the color coded DTM to be seen a hill-shade transparency value of 70% was assigned (Fig. 9).

As mentioned above the hill-shade azimuth and illumination elevation can be altered. This proves to be a very useful function. Experience shows that if only one illumination location is used there will be some features which are not visible within the parameters of that particular exposure. It is necessary to use several different illumination angles for correct image interpretation. Using this technique eliminates the likelihood that some features associated with only one source of illumination will be over-looked. For the purposes of this paper four separate hill-shades were created at 90 degree intervals – 90°, 180°, 270°, 360 degrees.

The hill-shades offered very clear and precise visualization but at times it was not entirely evident what was being viewed. For example, field boundaries, were sometimes difficult to distinguish from footpaths. The location of forested lands was difficult to determine, as was the actual location of established footpaths. If identifying these features were not possible it would prove to be very difficult to accurately determine what was or was not erosion (Fig. 10).

To alleviate this situation two Ordnance Survey raster maps of the study area were downloaded. The OS maps were overlaid upon the existing data and a transparency value of 60% was established. This allowed the hill-shades to be viewed with indications of what was actually on the ground. Field boundaries, footpaths, forested areas, and rivers were now clearly defined and the ability to distinguish these features from areas of actual erosion was greatly enhanced (Fig. 11).

The main focus of this paper was to identify man-made areas of erosion in the landscape. To do this it was necessary to distinguish human generated from natural forms of erosion. Most natural erosion is the result of the downhill flow of water. A practical way of explaining the difference between these two forms is that human activity will tend to stay, within generalized elevation contours, simply because it is the easiest way to go. Water, controlled by the law of gravity, tends to seek out slopes for its journey to the bottom. Because of this difference a Slope Raster was created from the DTM and given a green color coding. This makes identification of areas of natural erosion much easier (Fig. 12).

In order to document these two types of erosion two polyline shapefiles were created. The intent was to identify and trace areas of erosion, and then to include them in either a man-made shapefile or a natural erosion shapefile. Using all four degrees of illumination, the surface was investigated and suspected areas of erosion were assigned to one of the two shapefiles.

3. Results

As mentioned above two separate shapefiles were created to represent natural and man-made erosive features. By using multiple elevation degrees of illumination most erosive features were identified. Analysis of the LiDAR data which referenced potential natural erosion features showed clearly that the majority of these features were in fact part of the natural landscape. Rivers or streams did appear to function
Figure 11: Ordinance Survey Maps Entered

Figure 12: Slope Raster, Natural Erosion

Figure 13: Slope Severity Raster

as channels for water moving to the rivers at times of heavy precipitation. The channeling can be better visualized by looking at the polylines superimposed over a slope severity raster.

The raster was color coded from green to yellow to pink with nine slope values. The greens represented the least slope, the yellows medium and the pinks represented severe slope. When observing this, one can see that most of the natural erosive features were associated with an increase in slope severity. At times these features were quite pronounced, probably indicating many years of erosion activity. As most of these features can be considered natural geologic activity it is not surprising that they do not impact significantly the existing archaeology. Most probably, because this was the result of natural geologic activity the people who lived there were aware of the potential for adverse consequences. Probably they did not put anything of value there or, if they did, it no longer exists.

The erosion recorded on the man-made erosion polyline is significant, pointing to a variety of potential complications (Fig. 14). The erosive damage appears on approved footpaths found on Ordnance Survey maps and newly created unapproved footpaths as well. As seen when looking at the Ordnance Survey maps man-made erosion is mostly associated with proximity to the established footpaths. A large portion of the disturbance to the landscape appears to be small linear erosion features which run parallel to the established footpaths, especially when one approaches bends in the path. Additionally, often when a footpath bends sharply, many unauthorized alternative tracks appear to be short-cuts, demonstrating that walkers do not wish to follow the more circuitous path. Track braiding is a common problem in recreational walking locations. Track braiding usually takes place near footpath intersections. It seems as if the most extensive footpath related erosion can generally be seen near these path intersections. The severity of path erosion also changes throughout the landscape, showing the level of concentration of recreational walkers in specific areas. There are also areas which appear to have been impacted by the illegal use of motor vehicles. Whether these vehicles are two wheeled dirt-bike type motorcycles or four wheeled All-Terrain Vehicles (ATVs) is really not the point. The most important thing to understand is that the illegal use of vehicles can be highly damaging to the fragile environment of the uplands.

The GIS analysis showed clearly that most examples of erosion in the study area occurred near the authorized footpaths. If one looks at the region near Long Ridge on the Middleton Moor one can see many examples of off-trail walking (Fig. 15 and Fig. 16).

There is an established footpath that follows the ridge line. There are multiple examples on the DTM showing divergences from the main trail and even the creation of parallel footpaths. Near the ridge footpath there are two separate intersections with other established routes. Near where these routes converge are multiple examples of path braiding as walkers sought out short-cuts. South of Lone Ridge on the Middleton Moor there are further examples of newly created paths independent of the authorized routes.

Looking at the area called Hollingley Intake near Denton Moor (Fig. 17 and Fig. 18), it is evident that walkers are creating a whole series of new paths. New paths are being created between the main established footpaths. A larger problem can be seen in the vicinity of the inverted U-shaped forested area on the Ordnance Survey map. This forested area...
area appears to encourage walkers to leave the established path leading to the creation of new trails heading in the direction of the forest. When the walkers have finished with the forest they continue walking straight on newly formed paths. These new paths and the established path form a series of unnecessary long extended paths.

The area between Dunkirk and Brick House Farm on Askwith Moor offer examples of erosion other than just walker induced erosion. (Fig. 19 and Fig. 20). There are two roadways in the area. Originating from the sides of these roadways one sees many examples of very straight and direct, some side by side, paths of erosion. One can speculate that this area has become popular for the illegal use of off-road motorized vehicles. Four areas of access to the uplands from the roadways are visible. Elevation profiles were extracted from the GIS in an attempt to understand the nature of this erosion (Fig. 21 and Fig. 22). These profiles show the changing elevation across the eroded area and occasionally are able to demonstrate the likely cause of the erosion. While somewhat difficult to read, the second image does have a slight increase in elevation in the middle of the large depression. This may be the signature of four wheeled ATV use.

Erosion damage in the study area could have an impact on existing archaeological features. On Middleton Moor as shown in Fig. 23, one can find a round barrow and many cup and ring stone carvings symbolized by the beige color spots in the image. The areas of erosion in this location seem directly associated with these carvings. The carvings are probably the incentive for people to leave the established pathways. This situation appears quite serious and palliative measures should be considered. Fig. 24 also shows where erosive action could have serious implications for the existing archaeology. A cup and ring sculpture is located near one of the eroded paths in Fig. 25. If one looks further to the north, slightly beyond the study area, it becomes apparent that the three, long, straight paths, which may be associated with motor vehicles, pass directly beside two cup and ring stones.

4. Conclusion

Archaeological features face many threats but in the uplands erosion is the main complication. Both natural and
man-made erosion factor into this. But the primary erosion factor that affects upland archaeology is related to human activity. This can be documented quite accurately using LiDAR technology. One problem with LiDAR, though, is that the data is not universally available. For example: While the Brecon Beacons National Park has 73% LiDAR coverage, only 4% of the North Yorkshire Moors has been covered [2]. Also, most LiDAR coverage focuses on river valleys and locations that flood. The Environment Agency focuses their coverage on these areas trying to predict flooding.

Despite these issues, LiDAR will likely become an invaluable resource in archaeological terrain analysis. It offers rapid and accurate analysis of potential erosion damage. It is cost-effective and very helpful in assessing erosion. It has the potential to inform and coordinate what were before expensive and time-consuming surveys in the field. A further advantage of analyzing erosion in a GIS is that the data can be connected to a number of associated numerical and
textual pieces of data; these include grid references and feature dimensions. Accepting the fact that LiDAR data can’t offer a complete set of evaluation data such as on land cover, standing water, vegetation, it can offer a very accurate and precise view of the terrain when combined with other technologies.

When considering the effects of erosion on archaeological features it will be very important in the future to contemplate the influence that LiDAR analysis can have in evaluating not only erosion but other landscape related issues.

References


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