Long-term change of the River Liza, Wild Ennerdale, England

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Abstract

The long-term change of the River Liza in the Ennerdale valley, Cumbria, was mapped and analysed using Geographical Information System (GIS) techniques. In this paper, the focus was on the use of GIS to investigate, map and analyse the changes in the River Liza's meandering channel system. Cartographical modelling, planform morphological analysis and cross-sectional analysis were methods of analysis employed in the study. The datasets used were largely digitized River Liza's channel from the historical maps, aerial photo maps and Differential Global Positioning System (DGPS) Field Survey data. It was discovered in the study that River Liza maintained a stable pattern of movement until it became diverted at Latitude 54^{o} 30' 47.07" and Longitude 3^{o} 18' 15.05" between 1993 and 2009. However, the channel's widths and depths have been far from stable; they have been increasing as a result of constant erosion of the bank and deposition within the channel, especially since the 1970s when there have been increases in rainfall in the UK. Apart from the presence of man-made features like bridges and bulwarks, the River Liza is discovered to be one of the important features in Ennerdale Valley where natural processes have been allowed to take their course in shaping the landscape and the ecology of the valley
Keywords: long-term change, Geographical Information Systems, River Liza, channel change, Wild Ennerdale.

1 Introduction

Over the years, rivers have attracted the attention of scholars, and they have been studied at various levels, scales, and times. From the time of Biblical King

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Solomon when he wrote that "*all rivers run into the sea; yet the sea is not full; unto the place from whence the rivers come, thither they return again*" [1] to the "century of foundation" [2] which witnessed the pioneering works of W.M. Davis (1850-1922), G.K. Gilbert (1843-1918) [3] and 1859 publication of Darwin's *On The Origin of Species* [4]. There have been a lot of publications, scholarly articles and research works on rivers for over the centuries. The great attention that rivers have attracted shows the dynamic nature of this vital component of hydrological open system. The dynamic entities of rivers' characteristics vary over space and time [5]. On whatever perspective and scale at which the rivers may have been studied, whether as a resource or a hazard, they have political, social, economic as well as physical relevance [5]. Because of the dynamism of rivers, studying them cannot be exhaustive.

In any active alluvial systems like rivers, sediment is moved around by water [6]. This dynamic process is one of the causes of morphological changes in the river at both the spatial and temporal scales of water and sediment motion [6]. Various studies that have been carried out world-wide have shown that most active rivers rarely maintained the stability of their form or morphological features for a long period of time, instead they show some progressive changes and developments as the years rolled by (for example, [7–10]). River Liza, being regarded as one of the most dynamic rivers in England (Oral claim by the Wild Ennerdale Project Partners) is expected to have had high morphological changes in planform and braiding channels. Though there have been researches on the braided channels, analysis of longer-term changes [11], and channel planform changes on meandering channels in the UK [12], there have not been a research/study on the long-term changes of River Liza's morphology and planform despite the fact it is regarded as one of the dynamic rivers in England.

This paper, therefore, aims at using Geographical Information Systems (GIS)'s instrumentality to map and analyse the changes, over the years, of the meandering channel of River Liza in Ennerdale, Cumbria, England. In achieving the aim, the paper focuses on the following objectives:
- to examine and evaluate the long-term changes of River Liza's meandering channels, focusing on the patterns and directions of flow;
- to observe the previous location and channel morphology of the river;
- to examine the cross-section profile of the river; and
- to identify the possible causes of the changes in River Liza's channel (if there's any).

The scope of this study is entirely restricted to using the instrumentality of Geographical Information System (GIS) in analysing the datasets from maps and field work. The focus of the research, which is on the channel change, is based on studying the shapes and patterns of the channels as they are shown on the previous maps and the current findings- using the Environmental System Research Institute (ESRI)'s ArcGIS(c) Software tools. The paper does not focus on fluvial geomorphologic experiments or laboratory tests in identifying the morphological changes.

2 The study area

River Liza is one of the rivers in the Lake District, Cumbria, England. The Lake District, which is also called The Lakes, Lakeland [13] or the Cumbrian Lake District, is in the North West of England (see Figure 1 below). The River Liza has its source below the Windy Gap or Northern slope of the Great Gable (which is about 2,949 feet/ 899 metres above the sea level) and it flows through North-West steep-sided Ennerdale valley (regarded as one of the loneliness Cumbria valleys) running into Ennerdale Water, a natural lake located on 54°31’12”N [14]. Since the study area is entirely within the Lake District, the general geographical and geological as well as the climatic parameters of the Lake District are expected within the study area. The geographical features of the Lake District were derived from the periods of glaciations, of which the most recent one occurred about Fifteen thousand years ago [15]. The glaciations process led to the developments of valleys in the region, many of which are now filled with waters and lakes, the deepest of which is Windermere (the Largest Lake) according to Britain’s Meteorological Office [16]. The geological structure of Lake District is very distinct and complex, yet it has been widely studied [15]. The oldest rocks are the Skiddaw slate and Borrowdale Volcanic series while the highest mountain in England, the Scafell Pike (978 metres) is found in Cumbria Lake District [16]. The average annual rainfall precipitation of more than 2,000 millimetres is recorded by the Met Office but with a large variation on the different localities. The temperature variations throughout the year is moderate, may be because of the maritime climatic nature of the district. The mean temperature ranges between 3°C (37°F) in January to around 15°C (59°F) in July [17].

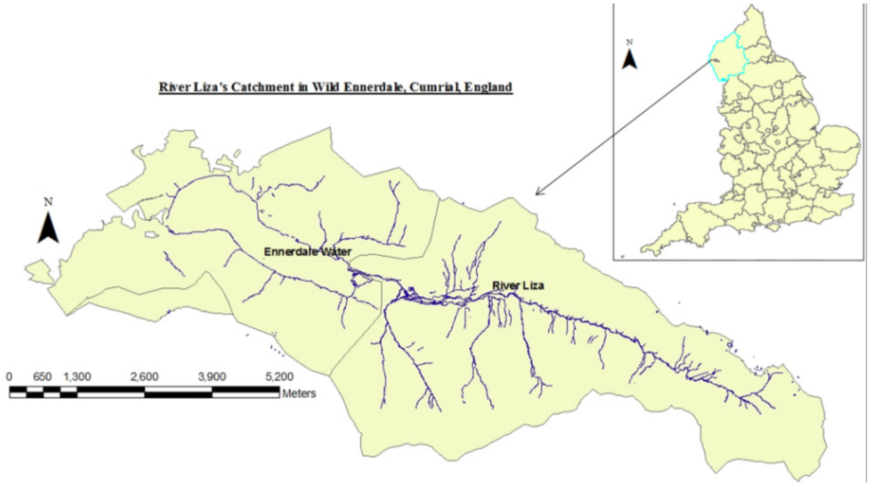

Figure 1: Location of River Liza’s catchment in Cumbria, England.

3 Research methodology

3.1 Data and data sources

Some of the data used include:
County Series 1:10560, First Edition 1846 – 1899 Historical Map published in 1867; National Grid 1:10,560, First Imperial Edition 1948 – 1976 Historical Map published in 1956; National Grid 1:10,000, First Metric Edition 1969 – 1996 Historical Map published in 1977 and National Grid 1:10,000/10,560, Latest Edition Historical Map published in 1978 – all of which were downloaded from EDINA DIGIMAP for Ennerdale Water. © Crown Copyright and Landmark Information Group Limited (2009). All rights reserved.

1985 1:10,000 Scale Black and White Aerial Photograph of 02nd June, 1985 and 1993 1:10,000 Scale Black and White Aerial Photograph of 23rd May 1993 for the River – were supplied by The Forestry Commission, North West England Forest District. NEXTMap® Britain v2.0 Digital Terrain Model (DTM) and Digital Surface Model (DSM) of 25cm Vertical Accuracy Root Mean Squared Error (RMSE) for the study area supplied by Intermap Technologies Inc.

Differential Global Positioning System (dGPS) was used to measure the very accurate positioning and altitude of the river channel on 10 June, 2009. The information collected was used to map the current location of the river for 2009 and the cross sections.

3.2 Data processing and analysis

As discussed in Heywood et al. [18], most Geographical Information Systems (GIS) applications usually adopt the layer view of the world. The different datasets which are from several sources as itemized in Section 3.1 above needed to be encoded, edited, corrected and transformed to create thematic layers to be used in the analysis. In this study, ESRI's ArcGIS 9.2© package was used. The River Liza's channels in the Historical and Aerial Photograph Maps (after geo-referencing) were digitized using the On-Screen digitizing method. The 1985 and 1993 Aerial Photo maps which had two parts were mosaic in ArcGIS after geo-referencing before being digitized. The current River Liza's bank locations which were initially surveyed through Differential Global Positioning System (DGPS) at 1cm Accuracy were downloaded and processed using the Leica SkI-Pro and Leica Geo-Office. After processing the data in the GPS Software, it was later stored in Microsoft Excel where the Latitude and Longitude coordinates in degrees/minutes/seconds were converted to decimal degrees. Then, the processed data were imported into ArcGIS using the *Add XY* tool in ArcMap. The other sections of the river channel which could not be surveyed were assumed to maintain the previous locations and occupancy. The method of analysis adopted dictated the data processing method used. In order to achieve the aims and objectives of this study, three methods of analysis were adopted, which are-Cartographic Modelling method, Planform Monitoring Analysis and Cross-Sectional Analysis Methods.

4 Result and discussion

4.1 Mapping the long-term change

The Cartographic Model is the method of analysis adopted to determine the long-term change in the River Channel migration. The datasets discussed in Section 3.1 above were *rasterised* at a common resolution of 5 metre(m) to match the NextMap data before being re-classified in such a way that the cell representing the River Channel = 1 and other cells = 0. The rasterised data layers were then overlayed in date order using a simple additive model in ArcInfo/Grid. The new layer produced shows a pattern of movement of the River Channel and the change in pattern becomes clearly obvious. The overlay methodology as described by Tomlin [19] and Burrough [20] was adopted as one of the operational language used within the Cartographical model so as to show the intersection of the river channel as observed in the maps for over the years.

The process of data integration showed a notable change along the River Channel, which is a total diversion from the normal channel trend. The point location at which the channel became diverted as identified in the analysis is at 315,130.263 and 514,008. 576 metres X,Y point location towards the downstream of the River. The Latitude and Longitude of the point of diversion is Lat 54^{o} 30’ 47.076” North and Long 3^{o} 18’ 15.056” West. The distance of the old channel to the new one is about 181.76 meters while the new channel maintaining a lateral flow length of about 1,227.48 meters before joining the old channel path at 313,506.303 and 514, 059.088 X,Y point location. The analysed data is interpolated with the map of the Study area so as to produce a concise map indicating the long-term change.

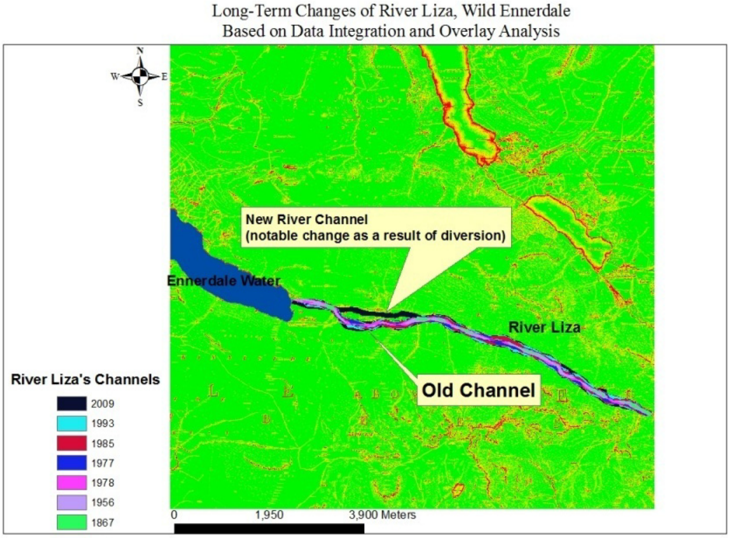

Figure 2: Map of River Liza showing the long-term change.

4.2 Channel planform change

In the study of river dynamism, one aspect of the river which has been widely studied, whenever the changes of river system are the focus, is changes in river planform [12]. From the comparison of the years of occupancy and direction of the River Liza, it is discovered that the major change in the river channel (apart from channel widening as a result of erosion and deposition) occurred between 1993 and 2009. Outside this notable change/diversion, the river maintained its occupancy/direction for a relatively long period of time. There are changes in the channel size as a result of river bank erosion and deposition within the channel. Though the sequence of movements and changes in the River Liza's channel form (Figure 3) is small, a closer look at the channel meandering shows the morphological changes which are causing bend developments and bank widening along the river. The historical sequence of the River Liza's channel planforms for the different years is presented in Figure 3 below.

The width of a section of 1867 river channel from the map, when measured was 5.87 metres while those of 1956 was 6.1m, 1977 was 7.1m, 1978 was 7.2m, and that of 1985 was 8.3m respectively. In 1993 and 2009, the width of the same section has increased to 9.8 and 10.4 meters respectively. Though the width of the channel varies along the river, the example chosen is an indication that the river channel is increasing in width while the direction remains the same, except for the diversion that was identified as discussed in Section 4.1.

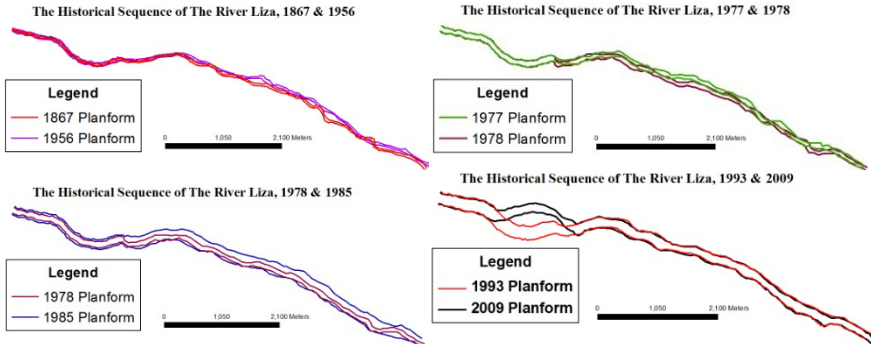

Figure 3: The historical sequence of River Liza, year by year comparison.

Figure 4 below shows examples of bank erosion and deposition within the river channel. These hydrological processes have not been massive enough to cause an intense magnitude of change in channel occupancy but the widening of the river channel.

Many mechanisms of the river bank erosion have been identified in the literatures (for example, [21–24]). Three of such mechanisms could be attributed for the causes of erosion along the River Liza's bank as observed from the field study. They are what Thorne and Osman [25] calls 'shear and toppling' failures, and trampling which is as a result of people and cattle crossing the river channel

Figure 4: Bank erosion (left) and deposition (right) within the channel.

Figure 5: Bank erosion which is likely to be as a result of either shear or toppling of the river bank.

or walking along the bank of the river channel. Example of the bank erosion which might have been as a result of shear and toppling failures is shown in figure 5 below. The depth of the erosion is around 1.82 meters.

As much as erosion activities are taking place along the bank of River Liza, much of the eroded debris/sediments are being deposited within the river (see figures 4 and 5).

4.3 Cross-sectional analysis

Thirty (30) cross sections were surveyed along River Liza, out of which 16 were found useful for the analysis. Figure 6 shows a sectional planform of River Liza where cross sections were taken in transverse to the River Liza's flow direction. Some of the cross sections details, plotted as elevation against distance, are shown in Table 1 below. Park [26] stated that "repeated surveys of river cross sections can also reveal temporal change" (page 118). The main challenge about this analysis is that there is absence of records of cross section surveys along the River Liza to compare the current survey with. What the cross sections estimate in Table 1 revealed is simply the fact that the river channels is unstable, with erosion and deposition not limited to the river banks alone but also extended to the river beds too. Since there was absence of the records of previous cross-sections, the manual overlay of historical plots became impossible. What this segment seeks to establish is to indicate the variation in channel width and depth along River Liza. The bank width and depth of the cross-section surveys were estimated in a consistent manner for each cross-section and the summary of the analysis is presented in Table 1.

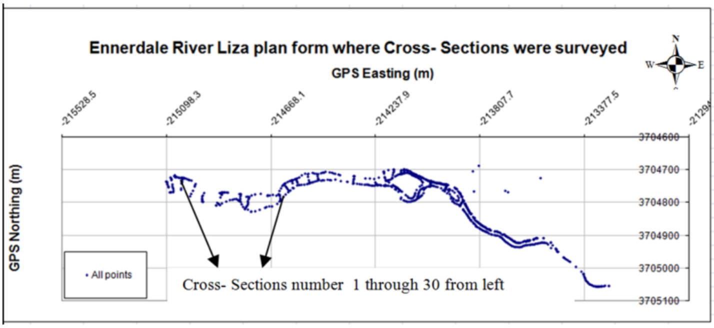

Figure 6: River Liza's Planform showing where Cross-Sections were surveyed during the Field Survey of 10 June, 2009.

Table 1: Estimate of channel form width and depth for the cross-section survey on River Liza.

Cross-Section	Channel Width (m)	Channel Depth Maximum (m)
Cross-Section 1	18m	1.5m
Cross-Section 2	28m	2.1m
Cross-Section 3	19m	1.1m
Cross-Section 6	12m	1.0m
Cross-Section 7	23m	0.7m
Cross-Section 8	35m	0.7m
Cross-Section 10	7m	1.8m
Cross-Section 11	31m	0.6m
Cross-Section 13	36m	0.9m
Cross-Section 15	7m	2.1m
Cross-Section 18	19m	1.3m
Cross-Section 19	32m	2.2m
Cross-Section 20	12m	0.4m
Cross-Section 22	31m	0.6m
Cross-Section 30	7m	0.2m

The estimates of the width ranges between 7 metres and 36 metres and the depth of 0.2 metre and 2.3 metres respectively from the cross-sections surveyed. Some of the bank depth are filled with water up to about 1m while others which are shallow are filled with boulders, debris and water of less than 0.3m deep.

4.4 The discussion and conclusion

4.4.1 On the analysis

The central focus of any study on river equilibrium is the notion of instability [21]; therefore many studies have illustrated the dynamism of active rivers than the notion of stability. The findings from the analysis carried out in this study have revealed that River Liza is a dynamic river. The instability observed that the channel width or size is increasing along the river as a result of erosion from the river bank and deposition within the river channel. The major departure from the river channel occurred between 1993 and 2009 when the river got diverted from the regular flow pattern. In other words, the river has been of a steady flow system following a regular pattern for a very long period of time. The prominent feature of old channel is the deposit of boulders and relics of rocks without any water.

4.4.2 On the causes of change

The sudden change in the River Liza's channel, which is the diversion of the River, could NOT be attributed strongly to the climatic effects ***alone.*** However, the finding from the analysis was related to the flow direction and flow accumulation as explained by Jenson and Dominigue [27], as well as to the channel slope and aspect. The analytical method for determining appropriate threshold values for stream network [28] was also considered in investigating what could have triggered the sudden diversion of the river channel as observed in figure 2. Though the surface factors and the hydrological variables as mentioned contributed greatly to the dynamism of the river, the major factor that could be held accountable for the sudden diversion or the rapid change could be a big tree that fell at the location of the diversion (see figure 7 below). The tree might have been up-rooted by the force of river channel or it could be as a result of tree-feeling activities in the valley which were once prominent in the area.

Figure 7: The point where the river became diverted, which may be as a result of the up-rooted tree.

4.4.3 River Liza and *Wild Ennerdale*

One of the objectives of re-wilding project of Ennerdale is to allow the natural processes to take its course in the valley. The natural change in channel size and pattern as discovered in this study without the interference and involvement of human is one of the contributions of River Liza in allowing the natural courses.

For example, the dynamic natural processes of erosion and deposition that are widening the width and depth of the channel are some of the fluvial processes of River Liza which shows the achievement of this objective. The mountain range, the forest and River Liza have been regarded as three of the most important features that make Ennerdale to be regarded as '*Wild Ennerdale'* [29]. This indicates that the river is a very important component of re-wilding project of the valley. However, irrespective of the above assertion, there are some human features which show a high element of human control of River Liza, thereby disrupting its natural courses or hindering the river from being regarded as a natural laboratory for fluvial/hydrologic experiments. Examples of such human features include bridges (figure 8).

Figure 8: The bridge across River Liza.

4.4.4 Recommendation

For effective and constant monitoring of the changes and dynamism of River Liza, the author would like to recommend:

- the establishment of a base station along the River Liza where the flow data, channel frequency and speed can be consistently and constantly monitored; this would provide important data depository for future researches and effective monitoring of fluvial processes within River Liza;
- the establishment of weather station in the Ennerdale valley will be a right step in studying the climatic processes that influence the re-wilding project of Ennerdale Valley, and invariably, the processes that shape the River Liza;
- constant measurement of the cross-sections and water quality of River Liza will provide a viable record in monitoring and analysing the temporal and long-term changes, not only of the river bank or bend developments but also in water quality.

5 Conclusion

GIS implementation projects are largely, if not entirely, application driven. Following closely the aim and objectives of this project, the instrumentality of GIS has been used to process the datasets. The project did not seek to provide solution to a particular environmental problem but to use the GIS technology to understand hydrological processes in the study area. It has, therefore, been discovered from the various methodologies employed that River Liza has been a very dynamic river with changes in channel occupancy, channel width and direction for over the years. The way at which River Liza is allowed to take its natural course and the natural processes in shaping its channels made it to contribute to one of the objectives of Ennerdale re-wilding project. Though there are elements of human features along the River Channel like some bridges constructed on the river and a bulwark towards the downstream of the river, the river remains active with natural processes shaping its course along major part of the channel and therefore remains a natural laboratory for fluvial processes.

References

[1] Biblical King Solomon, The Book of Ecclesiastes, Chapter one Verse Seven. *King James Version of the Holy Bible.* (No Date)

[2] Gregory, K. J., *The Nature of Physical Geography.* Edward Arnold: London, 1985

[3] Gilbert, G. K., *Report on the Geology of the Henry Mountains.* Washington, D. C.: United States Geological Survey, Rocky Mountain Region, 105, 1877

[4] Darwin, C., *On the Origin of Species by means of anural selection, or the preservation of favoured races in the struggle for life.* London: John Murray. 1st Edition, 1st Issue., 1859

[5] Knighton, D., *Fluvial Forms and Processes: A New Perspective*. London: Arnold. 1998

[6] Vriend, de H., Long-Term Morphological Prediction. In Seminara, G. and Blondeaux, P. (ed) *River, Coastal and Estuarine Morpho-dynamics.* Germany: Springer-Verlag Berlin Heidelberg. 163–190, 2001

[7] Hickin, E. J., River Channel Changes: Retrospect and Prospect. In: Collinson, J. D and Lewin, J. (ed) *Modern and Ancient Fluvial Systems.* Blackwell Oxford, 61–83, 1983

[8] Hooke, J. M., Changes in river meanders: a review of techniques and results of analysis. *Progress in Physical Geography, 8,* 473–508, 1984

[9] Sabater, S., Munoz, I., Feio, M. J., Romani, A. M., and Grasa, M. A. S, The Iberian rivers. In: Tockner, et al (ed) *Rivers of Europe.* London: Academic Press, Elsvier, 113–149, 2009

[10] Tockner, K., Robinson, C. T and Uehlinger, U (ed), *Rivers of Europe.* London: Academic Press, Elsvier, 113–149, 2009

[11] Best, J. L. and Bristow, C. S. (1993) *Braided Rivers*. Geological Society Special Publication No 75, p 416

[12] Hooke, J. M., Processes of Channel Planform Change on Meandering Channels in the UK. In: Gurnell, A. and Petts, G. (ed) *Changing River Channels*. West Sussex, England: John Wiley & Sons Ltd, 87–115, 1995.

[13] Oda, T. (ed) *Lake District Tours: A collection of travel writings and guide books in the Romantic Era*, in 6 Volumes. England: Eureka Press, 2008.

[14] Knowledge Me(URL) *River Liza* Online http://www.knowledge.me.uk/areas/lakes/river_liza.html. Accessed on 20/06/09

[15] Hollingsworth, S., The Geology of the Lake District: A Review. *Proc. Geologists Assoc., 64* (Part 4), 1964.
[16] Met Office., *England and Isle of Man: Climate***,** Online: http://www.metoffice.gov.uk/climate/uk/nw. Accessed on 17th June, 2009.
[17] Answers.com, *Lake District,* Online http://www.answers.com/topic/lake district#Climate- Accessed on 20 June, 2009.
[18] Heywood, I., Cornelius, S., and Carver, S., *An Introduction to Geographical Information Systems***.** Third Edition. Essex England: Person Education Limited., 2006
[19] Tomlin, C. D., Cartographic modelling. In: Maguire, D. J., Goodchild, M. F., Rhind, D. W. (ed) *Geographical Information Systems: Principle and Applications***.** Longman, London, Vol. 1, 361-374, 1991
[20] Burrough, P. A., *Principle of Geographical Information Systems for Land Resources Assessment***.** Oxford: Clarendon Press, 1986.
[21] Hooke, J. M., An analysis of the processes of river bank erosion. *Journal of Hydrology***,** *42,* 39–62, 1979
[22] Thorne, C. R., and Tovey, N. K., Stability of composite river banks. *Earth Surface Processes and Landforms, 6,* 469–484, 1981
[23] Lawler, D. M., Process dominance in bank erosion systems. In Carling, P. A., and Petts, G. E. (ed) *Lowland Floodplain rivers, Geomorphological Perspectives,* Chichester: Wiley, 117 – 144, 1992
[24] Nanson, G. C., Krusenstierna, A., and Bryant, E. A., Experimental measurements of river-bank erosion caused by boat-generated waves on the Gordon River, Tasmania. *Regulated Rivers: Research and Management, 9,* 1– 14, 1994
[25] Thorne, C. R., and Osman, A. M., Riverbank Stability analysis & applications. *Journal of Hydrologic Engineering,* 114(2), 151-172, 1988
[26] Park, C. C., Channel cross-sectional change. In: Gurnell, A. and Petts, G. (ed) *Changing River Channels*. West Sussex, England: John Wiley & Sons Ltd, 117–145, 1995
[27] Jenson, S. K. and Dominigue, J. O., Extracting topographic structure from Digital Elevation Data for Geographic Information System Analysis, *Photogrammetric Engineering and Remote Sensing***,** Vol. 54, No 11, November, 1988, pp 1593-1600, 1988.
[28] Tarboton, D. G., Bras, R. L., and Rodriguez-Iturbe, I. On the extraction of channel networks from Digital Elevation Data, *Hydrological Processes,* Vol. 5, pp 81–100, 1991.
[29] National Trust and Forest Enterprise, *Ennerdale West Cumbria-Historic Landscape Survey*. The National Trust and Forest Enterprise, Oxford Archaeology North, September, 2003.