

THE USE OF PHOTOGRAMMETRY AND LIDAR FOR LANDSCAPE ROUGHNESS ESTIMATION IN HYDRODYNAMIC STUDIES

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ABSTRACT:

Flooding is a major problem for many countries causing damage to the environment and pressures on human activity. Engineers use Manning's coefficient of roughness to determine water flow over floodplains which is a vital parameter in hydrodynamic studies. The coefficient is mainly a property of the ground surface texture and the changes in water surface elevation. The traditional method of determining the coefficient requires experience and often demands field visits. Airborne remote sensing provides an opportunity to produce good representations of the ground surface and therefore an easier and more efficient method of determining the coefficient.

Digital surface model's (DSM's) are standard products from aerial photography and photogrammetry. The introduction of LiDAR technology has provided an alternative method for producing high quality DSM's. One of the main aims of this research was to assess the potential of using LiDAR and aerial photography/photogrammetry in analysing the landscape for the estimation of the coefficient of roughness.

A test site with an excellent variety of features has been established close to Nottingham, UK and DSM's have been created from LiDAR data and photogrammetry. Analysis of the DSM's for different types of landscapes has been undertaken. 'Automated' techniques for the estimation of the coefficient of roughness have been investigated. Maps of the estimated values of the coefficient for different landscapes have been generated and compared with traditionally derived values for the test site.

The research shows that airborne remote sensing has the potential to provide new methods for estimating Manning's coefficient of roughness ('n').

1. INTRODUCTION

River flooding is a major problem which faces many countries. Heavy rainfall in river catchments can accumulate large amounts of water which flow through the river system producing a rapid rising in the river water level and causing strong currents and wave actions. When the flow rate exceeds the discharging capacity of the river, water overflows the banks of the river to the surrounding land causing damage to the embankments, property and hazards to the environment. It can be disastrous to human and animal lives as well as creating health problems when sewers overflow. The infrastructure including electric power-lines, telephone cables, water networks and sewerage systems can be extensively damaged. Generally speaking, the flood can affect the infrastructure, threaten the population and create social problems (Environment Agency, 2001).

Studying the hydraulic properties of the flood surges helps develop an understanding of the factors controlling the behaviour of the water. Many different factors control the flow of water: the flow rate, the topography of the area, the cross sectional area of the water boundary, the wetted perimeter of the boundary layer and the coefficient of roughness. The coefficient of roughness 'n' represents the hydraulic roughness

and is known as Manning's coefficient of roughness or Manning's 'n' (Chow, 1973). The hydraulic roughness develops resistance to the water flow through creating a retarding force.

To determine the coefficient of roughness is an important step in the hydrodynamic modelling process. To obtain reliable estimates of the roughness has always been a difficult task often relying on experience and subjective judgement. A number of techniques have been implemented for determining the coefficient of roughness with some being dependent on applying field measurements of the flow parameters, others being based on studying the coefficient on hydrodynamic scale models or comparison with landscapes of 'known' Manning's n. Most of the methods require the collection of information from the site of interest regarding topography, texture (ground features) and vegetation cover (French, 1994, Chanson, 2001). This task is a critical part of determining the coefficient of roughness and collecting reliable information can take a long time.

Airborne and space borne remote sensing techniques can provide reliable information about the Earth's surface. This can be for planimetric interpretation and measurement as well as for height determination. So it can be considered as a potential tool

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for assisting with determining Manning's 'n' values. Airborne remote sensing techniques normally provide better accuracy in elevation measurements and more detailed analysis of the surface compared to satellite remote sensing methods. There are a number of airborne remote sensing techniques that can be considered including aerial photography and photogrammetry, LiDAR (airborne laser scanning), Synthetic Aperture Radar (SAR) and multi-spectral line scanning.

Digital surface models (DSM's) are standard products from aerial photography using analytical and digital photogrammetric techniques. Analytical photogrammetry is a well-established mapping technique and can provide reliable and accurate measurements (Elfick *et al.* 1994). However, the measuring technique is a manual process which requires skills and experience of putting the measuring mark on the stereo model surface with every new measurement. This is a very slow operation so obtaining a DSM is usually a time consuming and very costly process. Digital photogrammetry employs image-matching techniques to compute elevation measurements from stereo pairs of digital (softcopy) aerial photographs. Then creating DSM's can be automatically performed which makes the process much faster and very cost effective compared to the analytical technique. Unfortunately, the quality of these automatically-generated DSMs may not be as high when compared with a DSM from analytical techniques. LiDAR is a relatively new technology that can provide accurate DSM's, with a suggested accuracy of between ± 10 cm to ± 20 cm, in a relatively short time (Baltasvics, 1999).

The accuracy of a DSM or a digital terrain model (DTM) can be critical in flood risk management in the cases of flat or gentle sloping floodplains. Fowler, (2000) suggests that contour line maps of the floodplain at one-foot (~30 cm) interval should be available for a flooding study.

This paper presents the results from research in to the use of photogrammetry and LiDAR techniques to provide high quality DSM's and estimations of Manning's 'n' values. The paper outlines the aims, an introduction to hydrodynamic studies, and the results from a test site. Further information can be obtained from Asal (2003).

1.1 Aims, Objectives and Methodology

Aims:

1. Investigate the use of airborne remote sensing techniques for creating DSM's.
2. Assess the potential of using airborne remote sensing techniques including laser scanning systems and aerial photography in modelling the landscape in particular for the estimation of Manning's coefficient of roughness.

Objectives:

1. Create and evaluate DSM's from airborne laser scanning and aerial photography.
2. Apply comparative analysis of the surface models generated from aerial photography and LiDAR to assess the potential of each technique in analysing the landscape.
3. Investigate automatic method(s) for the estimation of the coefficient of roughness in large areas such as floodplains.

Methodology:

1. To undertake the practical trials a test site has been established at Newark-on-Trent to the east of Nottingham, UK. LiDAR data was obtained from the Environment

Agency of England and Wales and the aerial photographs were obtained from the National Remote Sensing Centre (NRSC) at two common scales, 1:10,000 and 1:25,000. These photo scales were chosen as they are commonly flown scales in the UK and are readily available from archives. This ensures this research has the widest potential use.

2. The ground control points for the aerial photography and field ground truth elevations were measured using Global Positioning System (GPS) techniques.
3. Digital photogrammetry was undertaken using ERDAS IMAGINE OrthoMAX.
4. Analytical photogrammetry was undertaken using a Leica SD2000 analytical plotter.
5. Visual and quantitative analysis of the surface models, and the investigations into automatic techniques for estimating the coefficient of roughness were investigated using ERDAS IMAGINE digital image processing system and ArcView GIS.

2. HYDRODYNAMIC STUDIES

2.1 Manning's Coefficient of Roughness

Many equations have been developed for the purpose of studying open channel flow, Manning's equation being one of the most widely used in this analysis. It is a semi-empirical equation and was developed in the 19th century by Manning in order to simulate open channel water flow. It was first designed for the purposes of studying uniform steady state flows of constant discharge, constant velocity and constant channel dimensions with time. However, practical experience proved that this equation can be successfully applied on gradually varied flow, which is the common natural flow. It 'is also used' in defining the water flow over floodplains (LMNO, 2000). Manning's equation takes the following form (Jain, 2001):

$$v = (1/n)(R^{2/3}S^{1/2}) \quad (1)$$

where:

v = the mean velocity through the channel in metres per second.

n = Manning's coefficient of roughness.

S = the channel bed slope in metres per metre.

R = the channel hydraulic radius calculated from:

$$R = A/WP \quad (2)$$

where:

A = the cross sectional area of the channel.

WP = the wetted-perimeter of the channel.

2.2 Factors that Determine Manning's 'n'

Kay (1998) states that n depends on the building material of the channel and the channel vegetation texture, which impose difficulty in estimating it with any degree of accuracy. Furthermore, the value of n is not constant with time in the same channel due to weed growth and variations of flow conditions over time. This can be explained as in case of small flow rate grass and weeds tend to be upright which brings about bigger resistance to the flow and leads to a bigger value of n . The situation is different with high discharges in the same channel due to grass and weeds being unable to continue standing in high velocity. This leads to their flattening which results in smaller resistance to the flow and smaller n value. From this it can be seen that n is a variable quantity where

estimation of its value leads to the determination of flow resistance. This is not an easy task which may need extensive studies of different circumstances and factors that have a direct effect on Manning's n value.

Chow, (1973) and French (1994) described factors controlling the value of n as follows: surface roughness: this factor is directly related to the building material of the channel bed, whether it is gravel, sand, silt, clay, or any other material. It is not enough to estimate the surface roughness as grain size and shape although they affect the magnitude of the resistance force to the flow. Chow, (1973) states that, commonly fine grain materials provide smooth channel and low value of n while coarse grain materials give high resistance to the flow and relatively higher values of n . LMNO (2000) and Henderson (1966) introduce estimations of the values of n for some materials.

3. AERIAL PHOTOGRAPHY AND LIDAR FOR CREATING DIGITAL SURFACE MODELS

Both aerial photography and LiDAR have been used extensively for digital surface modelling of the landscape. Aerial photography and photogrammetry have had a long history of producing DSM's through analogue, analytical and digital methods (Mikhail *et al.*, 2001). The more recent digital techniques have enabled very rapid DSM to be produced through automated image matching techniques and the quality of these have been assessed by a number of researchers (Smith, 1996). One of the fundamental differences between LiDAR and photogrammetry is that LiDAR is based on a range measurement to a point from a single airborne position. Photogrammetry however, is based on stereo matching of images from two airborne positions. The stereo matching process requires the matching of a 'patch' of pixels covering a small area rather than a discrete point (footprint) as with LiDAR. In addition, often the algorithms used in the photogrammetry solution have been designed for smooth landscape modelling rather than the rapidly changing elevations of buildings in an urban environment. With both technologies there is the question of what surface is being measured? An analysis of these technologies is given in Smith *et al.* (2000) and in Asal (2003). Before the methodology for producing coefficients of roughness could be investigated it was considered useful to try and visualise the DSM for different land uses. This would help to appreciate, from the information that is available from a DSM, the nature of the texture of the landscape. So, an analysis to see whether the different DSM's show different textural characteristics was undertaken. A full analysis is given in Asal (2003).

3.1 The Test Site

The area covered by the test site at Newark-on-Trent includes a variety of landscapes. Primarily it is on the flood plain of the River Trent but one side of the river rises rapidly to the old town of Newark. Typical of many old town centres, it has narrow winding streets where it is difficult to see on to the ground level from the air. This is particularly difficult for photogrammetry as it requires too be able to see the ground from two positions for stereo analysis. Along side the old town is an industrial area and a relatively new residential area. To the north bank of the river and beyond some mixed development is a rural flood plan area of mainly hedged agricultural fields, small woodlands and a ring road on top of an

embankment. Aerial photography at 1:25000 scale covers a much greater area than the 1:10000 scale but common areas covered by the photography and LiDAR could be found. DSM's were created at 2m postings. Unfortunately it was not possible to obtain the different photography and the LiDAR at the same time.

3.2 Analysis and Comparison of Digital Surface Models

Figures 1, 2 and 3 show typical results obtained. (Red lower, green and mauve higher)

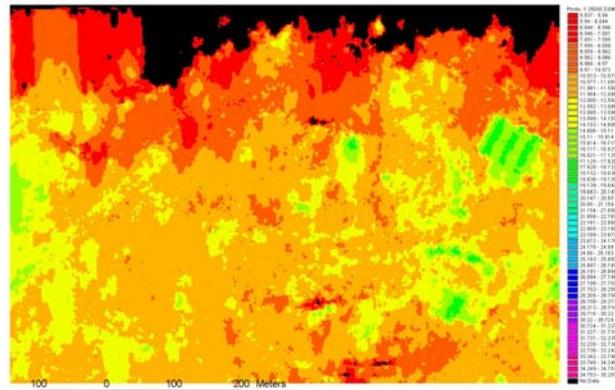


Figure 1: DSM from 1:25,000 aerial photography in a rural area

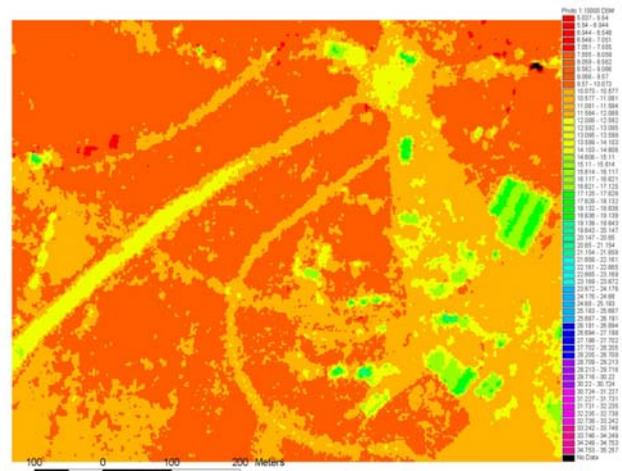


Figure 2: DSM from 1:10,000 aerial photography in a rural area.

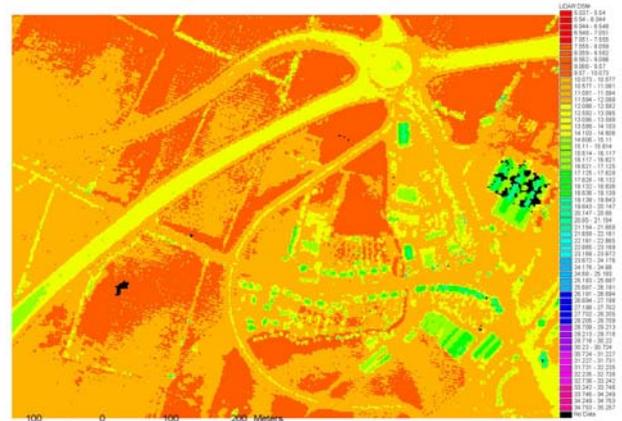


Figure 3: LiDAR DSM in a rural area.

Three dimensional visualisation was also used and figures 4 and 5 are typical examples of the results obtained. Detailed investigations were undertaken by producing cross sections through some of the areas of interest and similarly showed the digital photogrammetric techniques are smoothing the surface models.

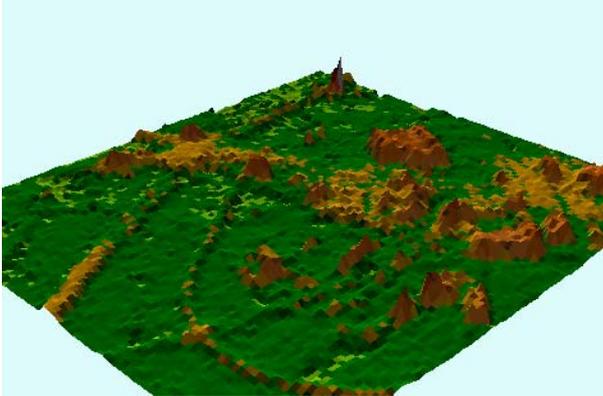


Figure 4: 3D model created from 1:10,000 photogrammetry DSM in industrial area.



Figure 5: 3D model created from LiDAR DSM industrial area

Further analysis can be found in Asal (2003). The conclusion drawn from this is that the DSM's are giving good indications of landscape texture. The digital photogrammetric DSM's are, as expected, smoothing where the analytical photogrammetry and the LiDAR techniques produce a sharper result. The differences between the DSM's needs careful analysis as there are a number of reasons why differences occur which are not related to the measurement process itself for example, vehicles on the roads and changes in seasonal vegetation cover.

4. DETERMINATION OF THE COEFFICIENT OF ROUGHNESS

4.1 Introduction

The coefficient of roughness aims to define the resistance to water flow and this can be broken in to two components. The first is the variation in elevation of the ground surface, often defined as a Digital Terrain Model (DTM). The second component is dependent on the characteristics of the ground surface texture which is related to what is on the DTM. The

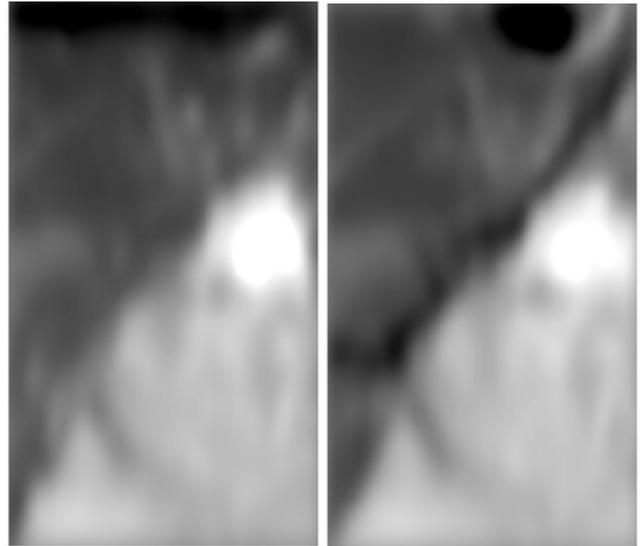


Figure 6: Left, a DTM layer created from 1:10,000 photogrammetry DSM; right, a DTM layer created from LiDAR DSM. Both images used a Fourier transform Gaussian filter.

DSM obtained by photogrammetry measures to the surface visible to the sky as it is an optical sensing device for example, roof tops, the top of crops and road surfaces. Since LiDAR sends out a laser pulse it measures to where ever it gets a return pulse from. This could be on top of a tree or, if it penetrates through the vegetation, ground elevation. If a DTM is determined and subtracted from the DSM, a feature layer is produced. A number of data filtering processes were considered to produce the DTM. These filters are based on image filtering techniques where different 'grey scale' values can be analysed. The removal of the surface information from a DSM can be obtained by undertaking a low pass filtering which emphasises low frequency features and de-emphasises the high spatial frequency features (Lillsand *et al.*, 2000). This has the effect of smoothing or removing detail.



Figure 7: Left, feature layer created from 1:10,000 photogrammetry DSM; right, feature layer created from LiDAR DSM. Both images used a Fourier transform Gaussian low pass filter.



Figure 8: Left, focally analysed layer generated from 1:10,000 photogrammetry DSM using SD function and a 3x3 kernel; right, focally analysed layer generated from LiDAR DSM using SD function and a 3x3 kernel

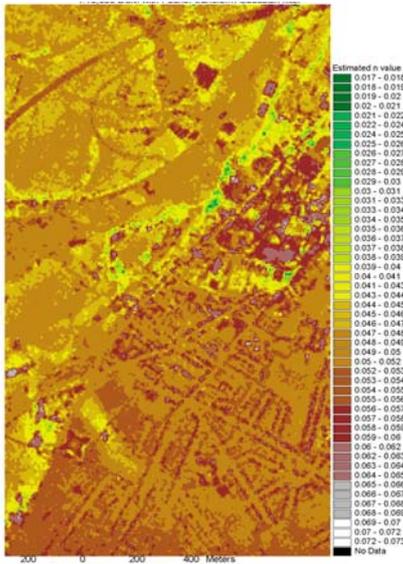


Figure 9: Estimated Manning's n map from a feature layer created from Fourier transform of 1:10,000 photogrammetry DSM using Gaussian low pass filter

4.2 Filtering Using Image Processing Techniques

An analysis of a variety of low pass filters were implemented and figure 6 Left and Right show the DTM layer and figures 7 Left and Right show the feature layer (DSM - DTM). This is the result from using a Fourier transform Gaussian low pass filter. Note how well the surface features have been stripped. A focal analysis processing was also implemented and of particular interest was the standard deviation focal analysis. It would be expected that a large standard deviation from a group of pixels (points) would indicate a rough surface and a low standard deviation a smooth surface. This suggests another potential measure of roughness which might relate to Manning's coefficient of roughness see figures 8 Left and Right.

4.3 Values of Manning's 'n' Coefficient of Roughness

Values for Manning's 'n' for the test site were obtained from a consultant flood modeller: water surface $n = 0.010$, rural landscape $n = 0.035$, urban landscape $n = 0.100$. This is a very coarse level of differentiation and what is proposed in this research is not just automation of the determination of Manning's 'n' but also providing it at a much higher level of detail. This increase in level of detail will mean extra information for the hydraulic engineers and potentially an increase in accuracy.

Chow (1973) presents one of several equations available which relates Manning's n to the theoretical roughness of the water boundary (3). It is arguable which is the best; this one has been chosen for illustrative purposes.

$$\phi\left(\frac{R}{k}\right) = \frac{(R/k)^{1/6}}{21.9 \log(12.2R/k)} \quad (3)$$

where: n = the coefficient of roughness
 ϕ = the slope angle of the sides of the water boundary
 R = the hydraulic radius of the cross section of the water boundary (ft)
 k = the height of the roughness (in feet)

Chow (1973) further states that experimental studies showed that the variation in the term $\phi(R/k)$ is very small in a wide range of variation of R/k . So, as an approximation the term $\phi(R/k)$ is considered as a constant with an average value of $\phi(R/k) = 0.0342$ where the units are in the 'foot-pound-second' system. Therefore, equation (4) takes the form:

$$n = \phi\left(\frac{R}{k}\right) k^{1/6} \quad (4)$$

Digital surface models from airborne remote sensing can provide a good estimation of k for small areas of interest.

4.4 Manning's 'n' from DSMs

Using the spatial modelling technique available in ERDAS IMAGINE 8.3, ArcView and equation (5) with the Gaussian filter feature layer, maps of Manning's 'n' were produced from both photogrammetry with 1:10000 scale photographs (see figure 9 and LiDAR data).

$$n = 0.0342 k^{1/6} \quad (5)$$

4.5 Manning's 'n' using the Focal Analysis and Standard Deviation Process

Considering the focal analysis of the DSM's using the standard deviation function with the kernel size of 25x25 (pixels) it was found there was a need to introduce a multiplying factor to scale the values. The scaling factor was produced by standardisation against the rural landscape values. As can be seen in figures 10 and 11 the values in the urban area are rather high.

5. CONCLUSIONS

The determination of Manning's 'n' is at present largely based on subjective judgement and is therefore influenced by all the 'personal' variation in the judgement that can occur. This

research has aimed to produce values based on more scientific

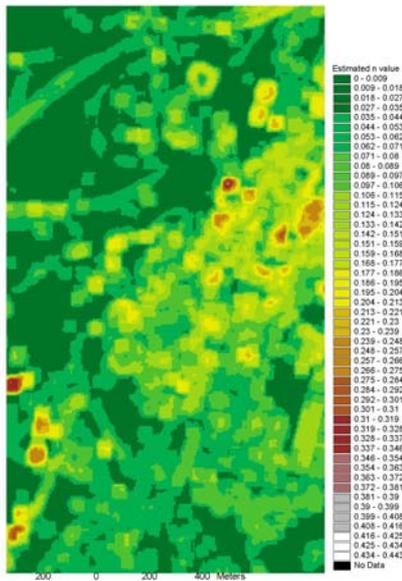


Figure 10: Estimated Manning's n map from focal processing of 1:10,000 photogrammetry DSM using a standard deviation function and a 25 x 25 window

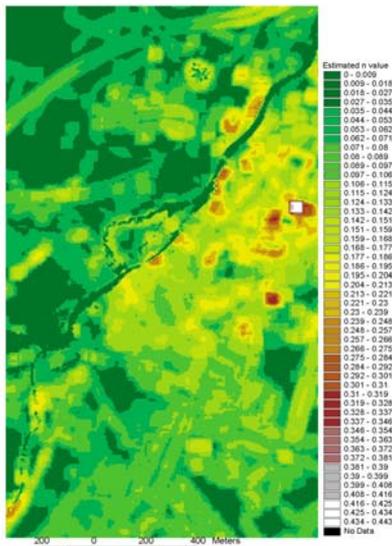


Figure 11: Estimated Manning's n map from focal processing of LiDAR DSM using a standard deviation function and a 25 x 25 window

grounds. The use of different technologies and processing strategies has shown potential solutions to automating and increasing the density of the values. This research has shown a variation in the DSM produced from the different technologies and photograph scales. From visual assessment and from statistical analysis the DSM's give an indication of surface texture. Digital image processing techniques such as the use of Fourier Transform filters and Focal Analysis have shown potential in determining values of Manning's 'n'. Further research is required to improve the values over larger flood plain areas and in the application of the values in the hydrodynamic modelling process.

5.1 References

References from Journals

Baltsavias, E. P., (1999). A comparison between photogrammetry and laser scanning, *ISPRS Journal of Photogrammetry & Remote Sensing*, 54 (1999), pp. 83–94.

References from Books

Chanson, H., 2001. *The Hydraulics of Open Channel Flow: An Introduction, Basic Principles, Sediment Motion, Hydraulic Modelling, Design of Hydraulic Structures*. Butterworth-Heinemann, Oxford.

Chow, V. T., 1973. *Open-Channel Hydraulics*. McGraw-Hill, New York.

Elfick, M., Fryer, J., Brinker, R. and Wolf, P., 1994. *Elementary Surveying* (Eighth Edition, S. I. Adaptation). Harper-Collins, London.

French, R. H., 1994. *Open-Channel Hydraulics*. McGraw-Hill, New York.

Henderson, F. M., 1966. *Open Channel Flow*. Macmillan Publishing Co., Inc., New York.

Jain, C. S., 2001. *Open-Channel Flow*. John Wiley & Sons, Inc., New York.

Kay, M., 1998. *Practical Hydraulics*. TJ International Ltd, Padstow, Cornwall, UK.

Lillesand, T. M. and Kiefer, R. W., 2000. *Remote Sensing and Image Interpretation*, Fourth Edition. John Wiley & Sons, Inc., New York.

Mikhail, E. M., Bethel, J. S. and McGlone, C. J., 2001. *Introduction To Modern Photogrammetry*. John Wiley & Sons, Inc., New York.

References from Other Literature:

Asal, F. F. F., 2003. Airborne remote sensing for landscape modelling. PhD thesis, The University of Nottingham, UK, p. 317.

Environment Agency, 2001. *Lessons Learned: Autumn 2000 Floods: A report by the Environment Agency of England and Wales*. HMSO Publishing, London.

Smith, D. G., 1997. Digital photogrammetry for elevation modelling. PhD thesis, The University of Nottingham, UK, p. 242.

Smith, M. J., Priestnall, G., Asal, F., 2000. Combining LiDAR and photogrammetry for urban and rural landscape studies. In: *Proceedings of the XIXth Congress of the International Society for photogrammetry and remote sensing (ISPRS)*, Amsterdam, 16–23 July 2000.

References from websites

Fowler, R. A., 2000. LiDAR For Flood Mapping. *Earth Observation Magazine*, July 2000. <http://www.eonline.com>.

LMNO Engineering, Research, and Software, Ltd., 2000. *The Fluid Flow Calculations Website*. <http://www.lmnoeng.com/>

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