DIGITAL ELEVATION MODELS FOR IDENTIFICATION OF POTENTIAL WETLANDS

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ABSTRACT

The goal of the study is to investigate the feasibility of using digital elevation models (DEMs) in establishing topographical information that can be used for identification and modelling of potential wetlands. This is done through 1) developing methods for detection of potential ponds and their drainage basins, 2) calculating the areas of the ponds and their drainage basins, and 3) comparing DEM-generated pond and drainage areas with manually determined areas based on interpretation of aerial photographs. The results show significant differences between pond areas derived from the two methods; no significant differences were found for drainage basin areas derived from the two methods. The automatic methods developed for identification and modelling of potential ponds and drainage basins, using digital elevation models, seem to be accurate and fast tools in modelling topographical conditions. It is concluded that they provide an effective approach for the evaluation of sites suitable for wetland projection and restoration.

Key words: DEM, nitrogen loading, potential wetlands, drainage basins.

1. INTRODUCTION

Due to excessive nutrient loading, the seas around Sweden are experiencing increased effects of eutrophication. The problems are particularly severe in the Laholm Bay on the Swedish west coast. Nitrogen is identified as the main nutrient causing eutrophication in the area and studies show that the nitrogen load must be reduced by at least half in order to restrain eutrophication (Rosenberg *et al.*, 1990, Enoksson *et al.*, 1990). The drainage basin is responsible for 70% of the nitrogen load to the Laholm Bay. Land use is dominated by agricultural activities, the soils nearest the coast are very porous and annual precipitation is high (800-1200 mm/year)(Fleischer *et al.*, 1989). In order to achieve the ambition of a 50% reduction in the diffuse anthropogenic nitrogen load to the Laholm Bay, it would be necessary to afforest all agricultural land (Fleischer and Stibe, 1991, Fleischer *et al.*, 1991). Since this is both practically and politically impossible to achieve, an essential component in nitrogen reduction programs has been identified as being the projection and restoration of wetlands (Fleischer *et al.*, 1989). Natural and projected wetlands are able to retain large quantities of nitrogen since they allow for the sedimentation of fine particulate material with bound nitrogen, an increased denitrification and an increased uptake of nitrogen by macrophytic vegetation; wetlands thus act as effective nitrogen filters. Small ponds have, in particular, been identified as being especially effective as they can retain great quantities of nitrogen in relation to their size. Generally speaking, a series of many small ponds distributed in a drainage basin can retain more nitrogen than a small number of larger dams.

A program for identification of sites suitable for wetland projection and restoration has been initiated for the costal zone of the Laholm Bay (Fleischer *et al.*, 1991). This program is based on determining the topographical prerequisites for wetland projection. Topographical conditions have thus far been mapped by means of manual interpretation of aerial photographs or through field work (Wessling, 1991). These methods are however time-consuming and more effective approaches are required.

The aim of the work presented in this paper is to investigate the feasibility of using digital elevation models (DEMs) in establishing topographical information that can be used for identification and modelling of potential wetlands. The work has been divided into three parts:

- To develop methods for detection of potential ponds and their drainage basins through the use of digital elevation models (DEMs).

- To calculate the areas of the ponds and their drainage basins.

- To compare DEM-generated pond areas and drainage basins with manually interpreted areas (based on aerial photographs).

2. MATERIAL AND METHODS

The study area consists of a 8.0 x 7.5 km area located north-east of the town of Falkenberg, on the Swedish west coast. The area is covered by the National Land Survey of Sweden's (LMV) topographical map sheets 5BNO and 6BSO, scale 1:50 000. Scanned elevation contours from 1:10 000 topographical maps were obtained from LMV. The equidistance of the elevation contours is 5 meters. All computer work was conducted using a DEC MicroVAX II. General statistics were calculated using MINITAB (1985). Graphical applications was performed using UNIRAS (European Software Contractors, 1985).

The scanned elevation contours were first imported into the ARC/INFO editing facility, where elevation values were assigned to their respective contours.

These elevation vectors were then used to interpolate elevation values to a gridded digital elevation model. Since more common and less time consuming interpolation algorithms (like inverse distance and Kriging) are not optimal for interpolation of iso-lines, a spline-based interpolation software package, ANUDEM (Hutchinson, 1989), was used. The resulting gridded DEM had a pixel size of 10 x 10 metres and a resolution in z (elevation) of 0.1 metre. This DEM was the basis for all subsequent analysis.

A software package developed by Pilesjö (1991) was further developed in order to identify potential ponds and their drainage basins and to estimate their areas. Alltogether, 30 wetlands (ponds and drainage basins) were modelled in the study area. For the sake of simplicity, each wetland was assumed to be a pond. Each potential wetlands' area, volume and drainage area were determined using this software. The calculation of areas and volumes was based on a one meter rise in the water-level of the stream at each wetlands' location.

2.1 Definitions of Drainage Directions

The first stage of the method of automated drainage basin detection is to determine each pixel's drainage direction in the DEM. The eight pixels surrounding each centre pixel of a three-by-three pixel window correspond with the eight cardinal points of a compass, and codes were assigned as follows: N(1), NE(2), E(3), SE(4), S(5), SW(6), W(7) and NW(8). Each number represents a drainage direction, and the value 0 is reserved for pixels with no onward drainage direction. These can either be sinks, which are defined as pixels which are lower than all of their eight pixel neighbours, or pixels located in a flat region. As an option, the program can eliminate single pixel sinks by assigning them a new elevation value, equal to the lowest elevation value of its eight neighbours.

The calculation of the drainage directions is based on the aspect value of each pixel (Pilesjö, 1991). The aspects were divided into 45° intervals, resulting in eight classes, and assigned the codes (0-8), as presented above. However, in two particular cases it is logically impossible to assign the drainage direction the rounded value of the aspect (Pilesjö, 1991):

A: If the centre pixel of the three-by-three pixel window is a sink and the elevations of the surrounding pixels results in a defined aspect.

B: If the centre pixel of the three-by-three pixel window is assigned an aspect value that gives a drainage direction to a pixel with a higher elevation.

In the first case, the problem was solved by giving all single sinks the drainage direction code 0. The second case was solved by demanding that the drainage direction always point towards a pixel with an elevation less than or equal to the centre pixel's.

The second stage of the definitions of drainage directions, after each pixel had been assigned a drainage direction code (0-8), was to solve the problem of drainage directions for flat regions. Adjacent drainage directions, both upstream and downstream from flat regions, were used as a basis for determining drainage directions for each flat region exceeding one pixel in size; these were assigned drainage direction codes 1-8. To solve the problem of assigning correct drainage direction codes to these pixels, every flat area consisting of more than one pixel was examined a second time. The position (row and column) of each 0 coded pixel in an area exceeding one pixel in size was stored during the execution of the program. Each of these pixels was then assigned the mean drainage direction of its neighbours with codes other than 0. First, all pixels with seven neighbours were assigned a new direction code, then all pixels with six neighbours were assigned a new direction code, and so on, until all the pixels had been assigned new drainage direction values.

2.2 Definition of Drainage Areas

After calculating drainage directions, automated drainage detection was performed. The coordinates (x, y) of the outflow of each potential wetland were imported to the program, and the ponds and their drainage basins were delineated.

The program starts by constructing an 'imaginary barrier', with the height of 1.0 metre, at the outflow (pixel) of each potential wetland. All pixels that supply water (drainage direction) to this pixel, and that have an elevation less than or equal to the outflow pixel plus 1.0 metre, form the pond. The area and volume of each pond was calculated according to general statistics.

Independently of elevation, all pixels that supply water (drainage direction) to the outflow pixel form the drainage basin to the pond.

2.3 Comparison of Wetland Areas

The results of the calculation of the ponds and their drainage basins were compared with the results determined by Wessling (1991), where areas of the same 30 wetlands were determined manually using aerial photographs. Assuming normally distributed data, a paired sample t-test (Williams, 1984), not assuming the same population variances, can be carried out. This was done using the area values calculated by the different methods (DEM and aerial photographs) in order to test the hypothesis that the differences in areas represent a sample drawn from a population of normally distributed differences whose mean is zero. The hypothesis was:

H_0: $\mu_{\text{aerial photographs}} = \mu_{\text{DEM}}$

versus

H_A: $\mu_{\text{aerial photographs}} \neq \mu_{\text{DEM}}$

This test was performed both for the pond areas and the areas of their drainage basins. Additionally, a simple correlaton analysis between the results derived from the different methods was performed.

3. RESULTS

The 30 ponds and their drainage basins were identified and the areas were calculated (Section 2). A section of the DEM, the ponds located within it along with their drainage basins are presented as a three-dimensional plot in Figure 1. It should be noted that a large portion of the wetlands are rather small and thus only represented by a few pixels.

3.1 Comparisons of Wetland Areas

The correlation coefficient between the 30 pond areas derived by the two methods (DEM and aerial photographs) was 0.263, with a 95% confidence interval between -0.108 and 0.569. A plot of the areas derived

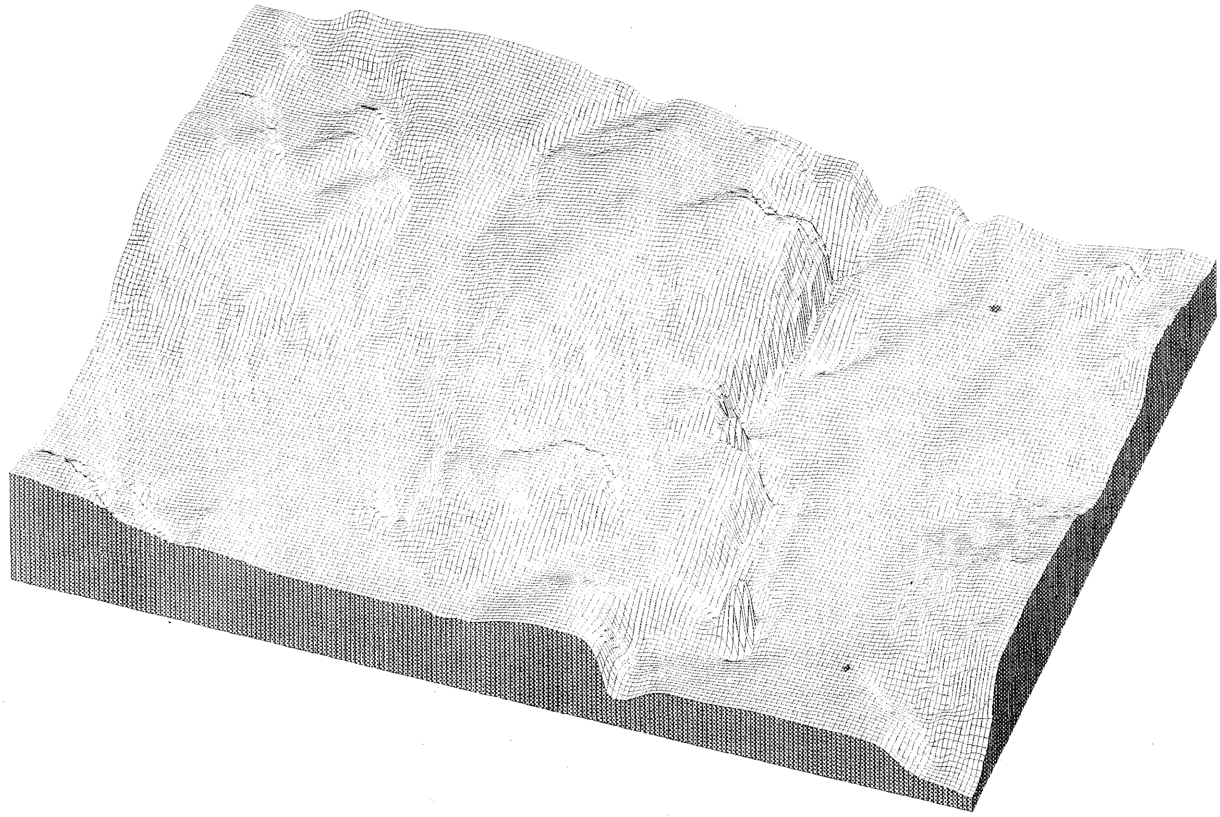

Figure 1. A three-dimensional plot presenting a section of the DEM, the ponds located within it along with their drainage basins.

by the two methods is presented in Figure 2.

In Figure 3, the differences in pond area determined using the two methods is presented.

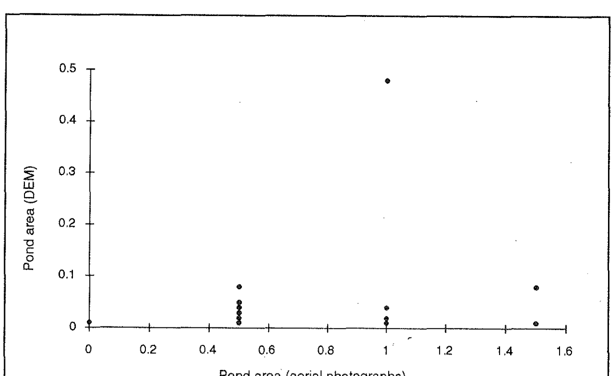

Figure 2. A plot of the pond areas (ha) derived from the two methods. n=30, r=0.263.

The influence of the method on the estimation of the areas of the ponds was analyzed using a Student's t-test. The paired sample t-test gave a t-value of 9.77, which resulted in a rejection of the H_0 hypothesis (μ aerial photographs = μ_{DEM}) at the 99% confidence level.

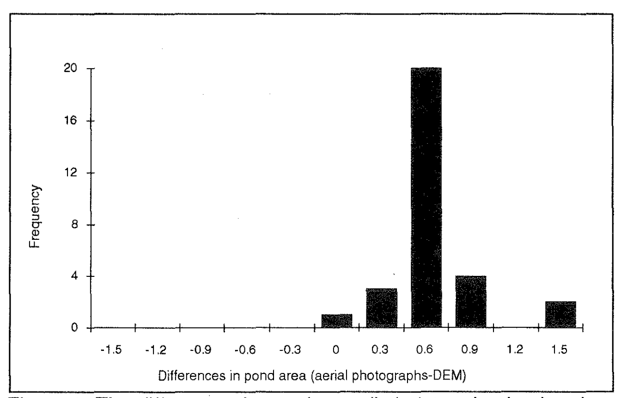

Figure 3. The differences in pond area (ha) determined using the two methods. mean=0.59, n=30.

The correlation coefficient between the areas of the 30 drainage basins to the ponds derived by the two methods (DEM and aerial photographs) was -0.059 with a 95% confidence interval between -0.410 and 0.308. A plot between the areas derived from the two methods is presented in Figure 4.

In Figure 5, the differences in drainage basin area derived from the two methods is presented.

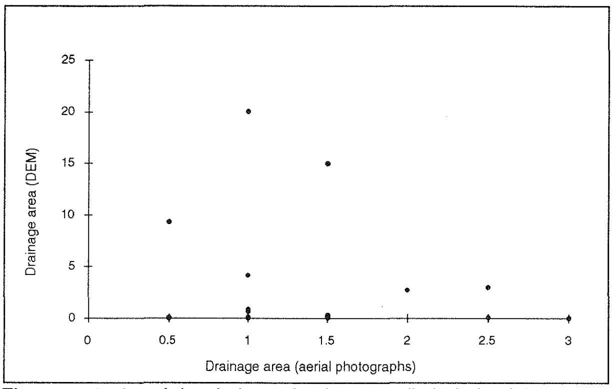

Figure 4. A plot of the drainage basin areas (ha) derived from the two methods. n=30, r=-0.059.

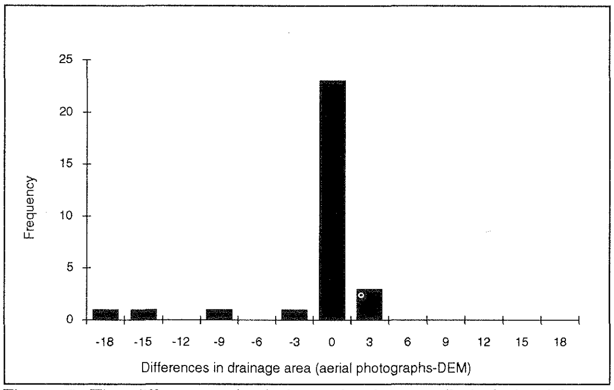

Figure 5. The differences in drainage basin area (ha) derived from the two methods. mean=-0.627, n=30.

The influence of the method on the estimation of the areas of the ponds was analyzed using a Student's t-test. The paired sample t-test gave a t-value of -0.72, which resulted in that the H_0 hypothesis ($\mu_{\text{aerial photographs}} = \mu_{\text{DEM}}$) cannot be rejected at the 99% confidence level.

4. DISCUSSION AND CONCLUSIONS

4.1 Comparison of Wetland and Drainage Areas

The results of the t-test used to compare the wetland areas derived from both automatic and manual (Wessling, 1991) methods indicates significant differences. These may be caused by the following:

- the automatic methods are properly calibrated while the manual methods provide unrealistic results.

- the automatic methods are poorly calibrated while the manual methods provide more realistic results.

- neither automatic nor manual methods provide realistic results.

There is, at present, no field data that can be used to evaluate the results generated using the two methods; it is thus difficult to quantitatively determine which method provides the most realistic results. It should, however, be stressed that the automatic methods used in this study have eliminated much source of error and, therefore, would logically seem to provide more accurate and detailed results.

Possible sources of error that may have influenced the results of the analysis of pond and catchment areas, and, consequently, the results of the t-tests as well, are:

- The pond locations determined using the manual methods were originally located on aerial photos which were not geometrically corrected to existing maps. These locations were then transferred manually to topographical maps. Some of the pond locations may have been transferred with their outflow points resultingly not being located in a stream or valley bottom.

- Since the pond coordinates used with the automatic methods consisted of digitalized outflow points from the above mentioned maps, a number of these may have been improperly located when imported to the DEM. An error of only one pixel from a stream or valley bottom can significantly alter the pond and drainage area characteristics calculated from the given outflow pixel.

- The DEM and above mentioned maps may not have been geometrically compatible, resulting in outflow pixels being improperly located. The potential of this influencing the results of the automatic analysis is seen as being minimal.

The results of the t-test used to compare the ponds' drainage areas indicate no significant differences between results derived from automatic and manual methods. Since drainage areas can be delineated fairly confidently using manual methods, it can be concluded that the automatic methods provide realistic and accurate results, provided the pixel on which all computations are based is properly located.

4.2 Conclusions

The automatic methods developed for identification and modelling of potential ponds and drainage basins, using digital elevation models, seem to be excellent tools in modelling topographical conditions. The methods are both easy to handle and fast. It is concluded that they provide an effective approach for the evaluation of sites suitable for wetland projection and restoration.

It should be noted that the results presented in this paper are preliminary and are in the process of being complemented with more exhaustive tests and evaluations using field data.

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