ECONOMIC AND ENVIRONMENTAL STUDIES No. 8 OPOLE 2006

Jarosław CHORMAŃSKI and Kinga ZAKRZEWSKA
Warsaw Agricultural University (Poland)

APPLICATION OF GIS TECHNIQUES AND FLOOD MODELING AS A TOOL FOR SUPPORTING SUSTAINABLE AGRICULTURE

1. Introduction

Implementing sustainable agriculture is decreasing the negative influence of agriculture on the environment. This issue has become of great importance for protected areas such as the Biebrza National Park. It is the biggest national park in Poland, which protects riparian wetland ecosystems, a unique ecosystem and the most extensive wetland system in Central and Western Europe. Interestingly enough, over 40% of its area is privately owned by cultivators. In the Lower Biebrza valley, they use their land for grazing cattle, or as grasslands and pastures. These areas are subject to annual flooding, which sometimes lasts up to 200 days. The floodplain is a nesting area for various birds, which very often build their nests on high and dry ground, thus their eggs are at risk of being destroyed by grazing cattle. During the period of flooding the pasture area becomes radically smaller and the dense cattle grazing poses a danger to these birds' nests. To fulfill the conditions for sustainable agriculture, the size of pasture land on the flood-land of the Biebrza valley should be limited according to pasturage norms in force for areas of nature preservation.

2. Research area

The section of the Biebrza river floodplain between Chyliny and Mocarze was selected for detailed research [Fig. 1]. It is 4.5 km long and

Fig. 1. The research area. The section of the Biebrza River floodplain between Chyliny and Mocarze
Source: Authors' own research.

1 km wide; a relatively low lying and flat area. The height above sea level is in the range from 99.9 m to 103.5 m, while the average height is equal to 101.5 m. The whole research area is located in the Biebrza National Park and used by birds for nesting. It belongs to private farmers and is used as pastures for cattle grazing.

3. Method

The GIS method of flood area determination was adopted from Chormanski [2003], applying the procedure described below:

1. Development of a Digital Elevation Model
   a. Data collection and preparation,
   b. DEM generation.

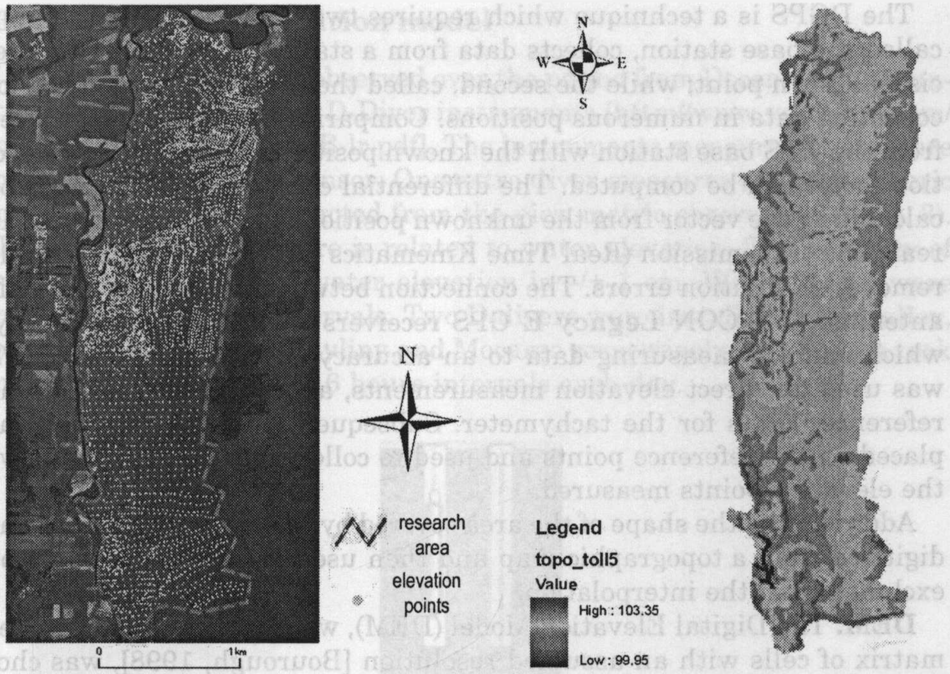

Fig. 2. Development of the Digital Elevation Model: a) elevation points measured, b) the DEM

Source: Authors' own research.

2. Development of a model of water table elevation
   a. Construction of a network of water level gauges and hydrological data collection,
   b. Construction of surface water isohypses using cross-sections,
   c. Interpolation of the model of water table elevation by interpolating between cross-sections.

Determination of flooded areas – combination of DEM and the model of water table elevation using GIS raster overlay analysis

3.1. Digital Elevation Model

Data collection and preparation. The data used to determine the model were elevation points measured directly in the field. All measurements were performed during two visits in November 2004 and September 2005. The aim of the measurement work was to obtain knowledge regarding the relief of the floodplain surface. These measurements were determined by coupling the Differential GPS (DGFPS) technique with classical topographical surveying.

The DGPS is a technique which requires two GPS receivers: the first, called the base station, collects data from a stationary position at a precisely known point; while the second, called the rover receiver is used for collecting data in numerous positions. Comparing the location measured from the GPS base station with the known position of this point, a correction factor can be computed. The differential correction is performed by calculating the vector from the unknown position to the known position in real-time transmission (Real Time Kinematics – **RTK**) and consequently removes all location errors. The connection between receivers is via radio antennae. TOPCON **Legacy E** GPS receivers were used in this study, which enabled measuring data to an accuracy of within 1.5 cm. DGPS was used for direct elevation measurements, as well as for establishing reference points for the tachymeter. Subsequently the tachymeter was placed on the reference points and used to collect data. Figure 2a shows the elevation points measured.

Additionally, the shape of the area covered by the river and oxbows was digitised from a topographic map and then used to indicate areas to be excluded from the interpolation.

DEM. The Digital Elevation Model (DEM), whose structure is a raster matrix of cells with an assumed resolution [Bourough, 1998], was chosen to digitally represent the floodplain topography. The DEM of the research area was created with a cell resolution of 5 meters (Figure 2b) using the ArcGIS 9.0 *TOPO to Raster* command, also known as the *TOPOGRID* routine available in the ArcInfo 7.1 software. This method has been successfully applied several times to construct a model of the topography of a floodplain [Cera et al., 1996; Townsend and Walsh, 1998; Chormanski, 2003]. The *TOPO to Raster* command is an interpolation method specifically designed for the creation of a hydrologically correct digital elevation model. It is based on the ANUDEM program developed by Hutchinson [1996] and, generally speaking, is a very useful tool for reliable generation and error correction of a DEM with limited elevation data based on contours and/or point elevation information. The interpolation procedure is designed to take advantage of the types of input data commonly available and the known characteristics of the surface. This method uses an iterative finite difference interpolation technique [ESRI, 1997]. It is essentially a discretised thin plate spline technique, in which the roughness penalty has been modified to allow the fitted DEM to follow abrupt changes in the terrain, such as streams and ridges. Wise [2000] assessed the *TOPOGRID* routine to be one of the best available algorithms for DEM generation, while Chormanski [2003] considered the DEM created by *TOPOGRID* as good enough for flood mapping.

3.2. Water table elevation model

The water levels were observed over the period from December 2004 until September 2005 using D-Diver instruments [http://www.vanessen.com/pdf/en/products/CTD04GB-lr.pdf]. The instruments measure the pressure of the water above the sensor. One extra diver measures the atmospheric pressure, which is subtracted from the piezometric observations (Fig. 3). The difference in pressure is related to water elevation. The accuracy of such measurements of water elevation is –/+ 1 cm. Water tables were measured at 6 hours intervals. Two D-divers were installed in the valley, close to the river near Chyliny and Mocarze respectively. The Divers took height measurements at 6 hours intervals each day.

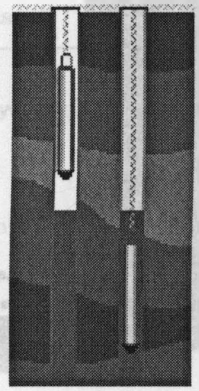

Fig. 3. D-Divers [Van Essen, 2000]

Subsequently, the surface water isohypses are indicated by curves which represent positions of equal water elevation. These are perpendicular to the main direction of the river course. The first cross-section of the terrain was located near the village of Chyliny, at the northern boundary of the research area (Line number 1 on Fig. 4a). The second cross-section was situated near the village of Mocarze, at the southern boundary of the research area. The third cross-section was placed near the village of Brzostowo, midway between the other two divers. Here, the water level was not measured by a diver, but estimated as an average from the calculations of the first two divers, due to the accuracy of the interpolation process. Next, the observed and estimated elevations of the floodwater were related to the isohypses. Figure 4a shows the location of the three cross-sections taken within the research area.

Based on this, the model of water table elevation as a continuous raster layer was interpolated using the *TOPO to Raster* method between these lines. The model obtained represents the flood water level for both readings. Figure 4b illustrates the model of water table elevation interpolated for the selected day from the period investigated.

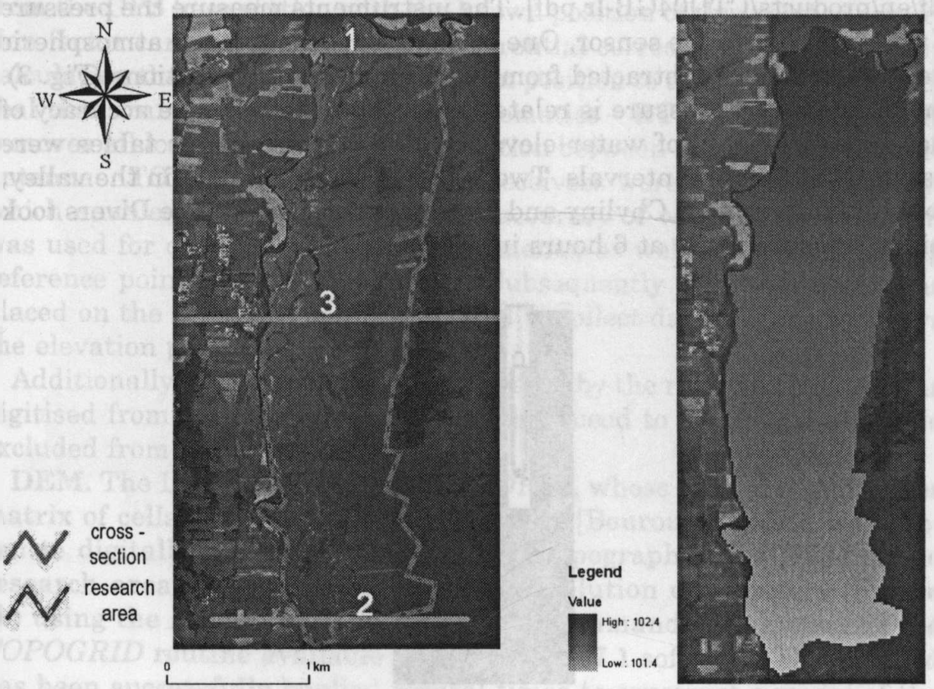

Fig. 4. Development of the water table model: a) location of cross sections, b) model of water table elevation

Source: Authors' own research.

3.3. Determination of the extent of flooding by GIS analysis

The GIS analysis was carried out using a map overlay in a raster environment. A simple GIS function-map combination, used to evaluate the DEM and water table elevation resulted in a flood map: A cell in the raster database is regarded as flooded when the **water table elevation layer** *is higher than the* **DEM**.

4. Relation between the concentration of livestock and flooded area

During the period of flooding the pasture area diminishes significantly and concentrated cattle grazing endanger birds' nests. Regulations based on the principles of sustainable agriculture define appropriate norms for livestock grazing on protected areas. One of these norms is based on the Livestock Unit (LU). The Livestock Unit is a standard unit to describe livestock numbers of various species as a single figure that expresses the total amount of livestock present. According to Polish norms 1 LU amounts to 500 kg which corresponds to one adult cow. LUs are approximate, since different breeds vary greatly in size and consumption. Table 1 shows the conversion rate for the real number of livestock to LU in Poland.

Table 1. Conversion rate for the real number of livestock to LU for different animals

Animals	Conversion rate: No of LU per individual
Stallions	1.20
Horses above 2 years old	1.00
Bulls	1.40
Cows	1.00
Calves up to 6 months old	0.15
Boars	0.30
Sows	0.30

Source: Authors' own research

Concentration of livestock on the grassland of the National Park of the Biebrza amounts to 0.5 to 1 LU/ha depending on the type of pasture. On the pastureland in the research area the concentration was equal to 0.5 LU/ha.

5. Results

The application of the raster GIS analysis allowed us to determine the flooded area for every day of period analyzed from December 2004 until September 2005. The flood peak was observed on the morning of the 1st of April, when the water level in Mocarze was 102.68m a.s.l. This water level meant that the whole pasture area was flooded. From the 1st of April until the 9th of June the water level decreased by 60cm. The water still covered about 376 ha and only 22 ha of the pasture land had emerged. Maximal flooding occurred between April and May, when all the pasture area was under water, which resulted in no cattle being grazed.

A significant change occurred in June and July, when the pasturage accessible to cattle increased from 35ha to 385 ha (the number of livestock increased from 17 to 182). The whole of the grazing land was accessible from the 11th of July until August. Given the size of the research area (395ha) farmers can graze an maximum of approximately 200 livestock. From August onwards, the water level again began to rise. This process is illustrated in Figure 5 and Table 2.

Table 2. Area flooded, area of available pastureland and related number of livestock calculated for selected days.

Numer of day	Date	Water level	Area Flooded area [ha]	Area for pasture [ha]	Number of livestock
D113	1/4/2005	102.68	398.2	0	0
D157	15/5/2005	102.13	381.8	16	8
D182	9/6/2005	102.07	376.1	22	11
D184	11/6/2005	102.05	372.4	26	13
D188	15/6/2005	101.95	354.8	43	22
D190	17/6/2005	101.94	349.1	49	25
D194	21/6/2005	101.84	326.3	72	36
D196	23/6/2005	101.78	312.6	86	43
D198	25/6/2005	101.71	289.9	108	54
D200	27/6/2005	101.62	258.2	140	70
D201	28/6/2005	101.56	238.0	160	80
D202	29/6/2005	101.49	208.5	190	95
D203	30/6/2005	101.31	141.7	256	128
D205	2/7/2005	101.22	93.7	304	152
D206	3/7/2005	101.20	79.2	319	159
D208	5/7/2005	101.04	47.3	351	175
D210	7/7/2005	100.91	29.0	369	185
D214	11/7/2005	100.76	15.4	383	191
D249	15/8/2005	100.93	25.5	373	186

Source: Authors' own research

Consequently, the relationship between the areas flooded and the water level, and a similar relationship between the water level and number of livestock were developed. Figures 6 and 7 show these relationships calculated according to the time series of observations of the water level in Chyliny. This relationship may also be expressed by a polynomial equa-

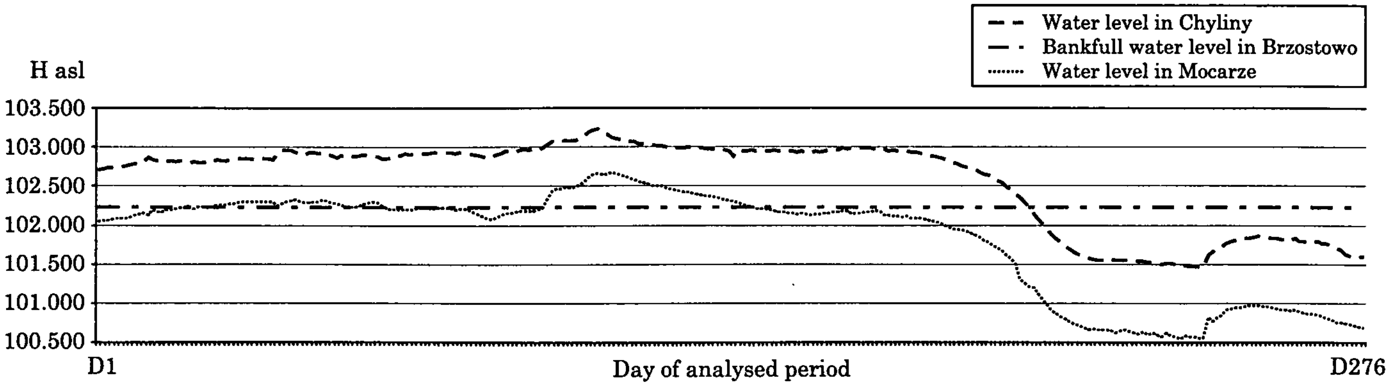

Fig. 5. Water level observed by divers installed in Chyliny and Mocarze during the period analysed (from December 2004 until September 2005)

Source: Authors' own research.

tion. The equation for the relationship between the water level and the area flooded has the following form:

$$\text{Flooded Area} = 438.41x^5 - 224459x^4 + 5E{+}07x^3 - 5E{+}09x^2 + 2E{+}11x - 5E{+}12$$

where x is the water level in Chyliny. The high value of $R^2 = 0.9982$ indicates that the model is very accurate. Knowing the water level, we can calculate the area available for grazing and number of livestock.

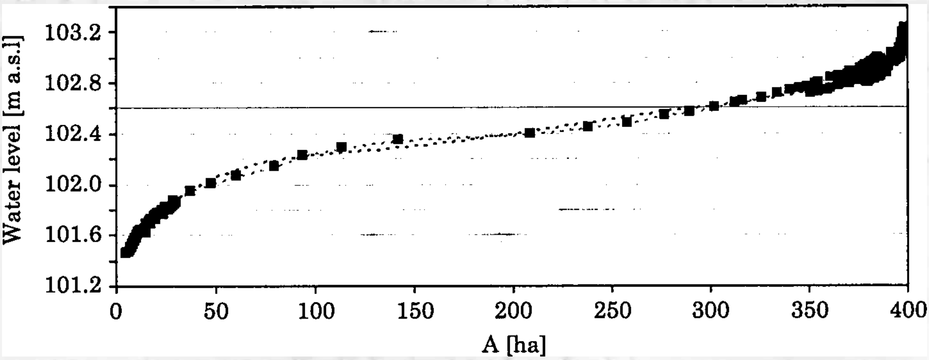

Fig. 6. Relationship between water level and the area of flooded ground, which is calculated according to the water level observed in Chyliny

Source: Authors' own research.

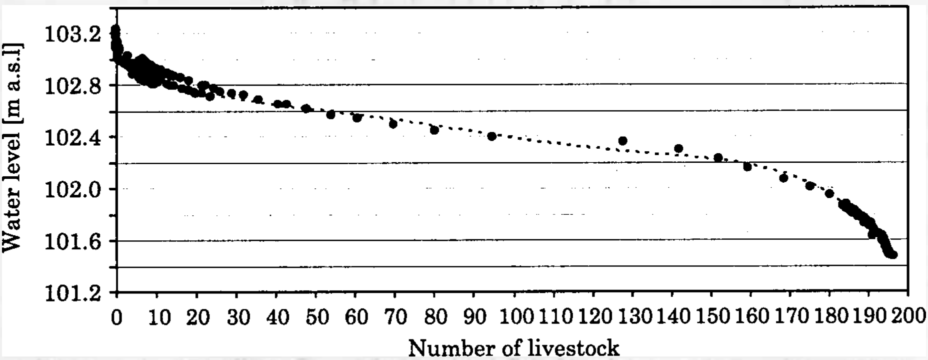

Fig. 7. Relationship between water level and the number of grazing livestock calculated according to the water level observed in Chyliny

Source: Authors' own research.

Figure 8 shows a simulation of the area of flooded ground which was calculated for selected days and presented in Table 2. This illustrates how fast the area of flooded ground decreases when water level falls. An accurate Digital Elevation Model gives us the possibility of observing which

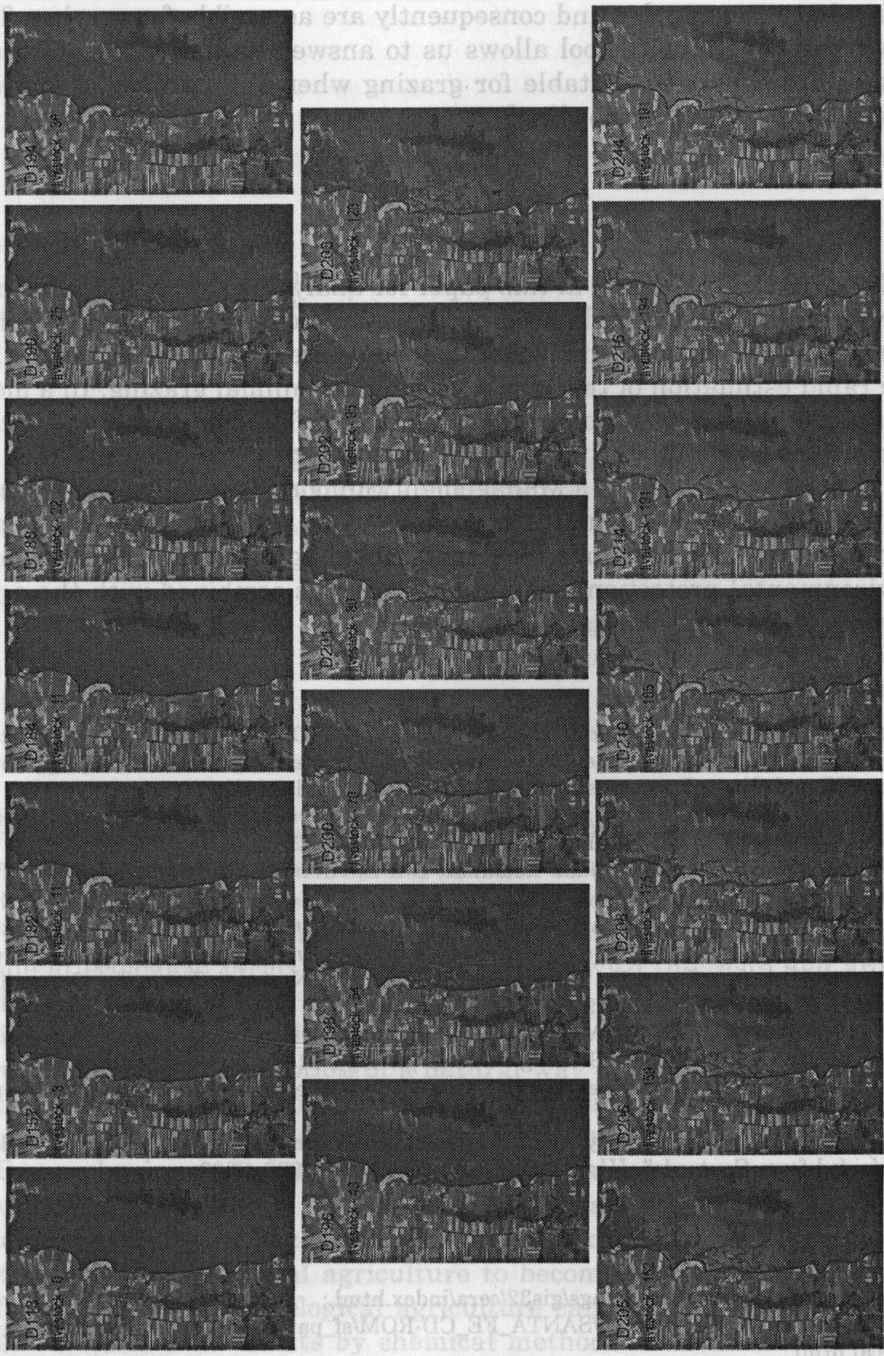

Fig. 8. Area Flooded according to the model on selected days of the analysed period

Source: Authors' own research.

areas have become dry and consequently are accessible for grazing. The advantage of this GIS tool allows us to answer the following question: *Where* are the areas suitable for grazing when the number of grazing livestock is limited by flooding?

6. Conclusions

The GIS tool described in this paper for analyzing the area flooded has been successfully verified based on the example of the Biebrza National Park. This GIS based flood model may be treated as a simple method for the rapid estimation of the area accessible for animal grazing. In a more advanced version it becomes a valuable tool for identifying and localizing areas available for grazing. In this variant it could be included as an important element of a Management Support System for the Biebrza National Park. In particular, the model may be recommended as a useful and practical tool for supporting sustainable agriculture in areas where environmental protection in a natural valley is combined with the agricultural use of grasslands.

Literature

Cera, T.B., Tremwel, T.K., Burleson, R.W., "Use Arc/INFO, EPA-SWMM, and UNIX text processing tools to determine flood extend", Online proceedings of "AWRA Symposioum on GIS and Water Resources", Sept 22–26, FT. Lauderdale, FL, 1996.

Chormański, J., *Methodology for the Flood Extent Determination in the Lower Biebrza Basin.* Warsaw: Agricultural University, Ph.D. Thesis, 2003.

ESRI,– ArcInfo 7.12 User Manual. Redlands, CA: Environmental Systems Research Instiutute, 1997

Hutchinson, M.F., "A Locally Adaptive Approach to the Interpolation of Digital Elevation Model:", in: *Third International Conference/Workshop on Integrating GIS and Environmental Modeling.* Santa Fe, NM. Santa Barbara, CA: National Center for Geographic Information and Analysis, 1996.

Townsend, P.A., Walsh, S.J., "Modeling Floodplain Inundation using Integrated GIS with Radar and Optical Remote Sensing", *Geomorphology*, 21(2), pp. 95–312, 1998.

Van Essen, *Diver-HL327v2 User Manual.* Delft, The Netherland: Van Essen Instruments 2000.

Wise, S., "Assessing the Quality for Hydrological Applications of Digital Elevation Models Derived from Contours", *Hydrol. Process*, 14, pp.1909–1929, 2000.

Websites

http://www.awra.org/ proceedings/gis32/cera/index.html,;

http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/hutchinson_michael_dem/local.html,

http://www.vanessen.com/pdf/en/products/CTD04GB-lr.pdf