REMOTE SENSING LIMITATION IN FLOOD MODELLING VERIFICATION IN WETLANDS. THE LOWER BIEBRZA BASIN

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Abstract: In this paper applying of Remote Sensing technique in wetland area for verification 1D numerical model of river flow is discussed. The Lower Biebrza Basin, the river-marginal peatland, located in the northern-south Poland was selected as a research area. The flood phenomenon occurs regularly in this river system and is not constrained by any man-made structures. The river and the floodplain are modeled as a 1D system, in which water in the floodplain takes part in the total water transport. A flow hydrograph forms the upstream boundary conditions, rating curve is used at outlet. The Digital Elevation Model of the floodplain constructed in GIS was coupled with river flow model for spatial flood extent simulation in the valley. Result was verified with help of the previously processed Landsat satellite image. The success was obtained in northern part of the valley, although a big difference was found in southern part of the valley. The inundation water chemistry was measured in selected transects for water source identification, which showed that the big part of the inundated area on the south should be described as a snow-melt "in situ" source. These results agreed with flood spatial extent calculated by hydraulic model and GIS.

INTRODUCTION

A characteristic feature of the Biebrza River is flooding, which occurs almost every year. The origin of floods is mostly a spring thaw (Byczkowski and Kiciński, 1984). Water which inflows into the Biebrza valley is accumulated here due to the small longitudinal slopes of the basins. The high water level continues for a long time, especially in the southern part of the valley (the Lower Basin) due to the fact that here a syncline like widening of the valley is closed downstream by a morainic formation and an alluvial cone deposited by the Narew River (Żurek, 1984). This most natural part of the Biebrza Wetlands is very interesting from the flooding point of view. It plays the role of a natural temporary reservoir of the surface water, which is accumulated there and takes part in the process of filling this area with water. This function is especially important for flows at or below the 40 year returned period (Bhowmik and Demissie, 1982). Another important role of flooding in the

Lower Basin is an ecological one. The ecological aspect of flood is formulated as a concept of flood pulse (Junk et al., 1989; Junk, 1996; Bayley, 1991; Junk, 1996), which provides a floodplain with mineral substances and algae ovules. This inflow creates conditions for development of fluviogenous ecosystems in the part of the floodplain. The seasonal flooding promotes the exchange of materials and organisms among the mosaic of habitats and plays the key role in determining the level of biological productivity and diversity (Bayley, 1995). The development of the accurate and reliable numerical river flow model, named in this paper hydraulic model which well describes surface flow on floodplain can be use as a tool of water management for analysis both flood aspects in wetland: hydrological and ecological. The main problem which appears during calibration and verification of numerical model for natural valley is obtaining proper verification dataset from field measurements due to natural obstacles of such a valley with numerous oxbows, organic saturated soils and natural vegetation. Recently, the spatial model verification has often been undertaken, in which the calculated flood extent was compared with satellite images (Bates et al., 1997; De Roo et all, 1999, Świątek et al, 2002). In this paper, a possibility of the remote sensing method applies for the spatial extent of river flood verification calculated by hydraulic model coupled with GIS in natural river valley is discussed.

RESEARCH AREA

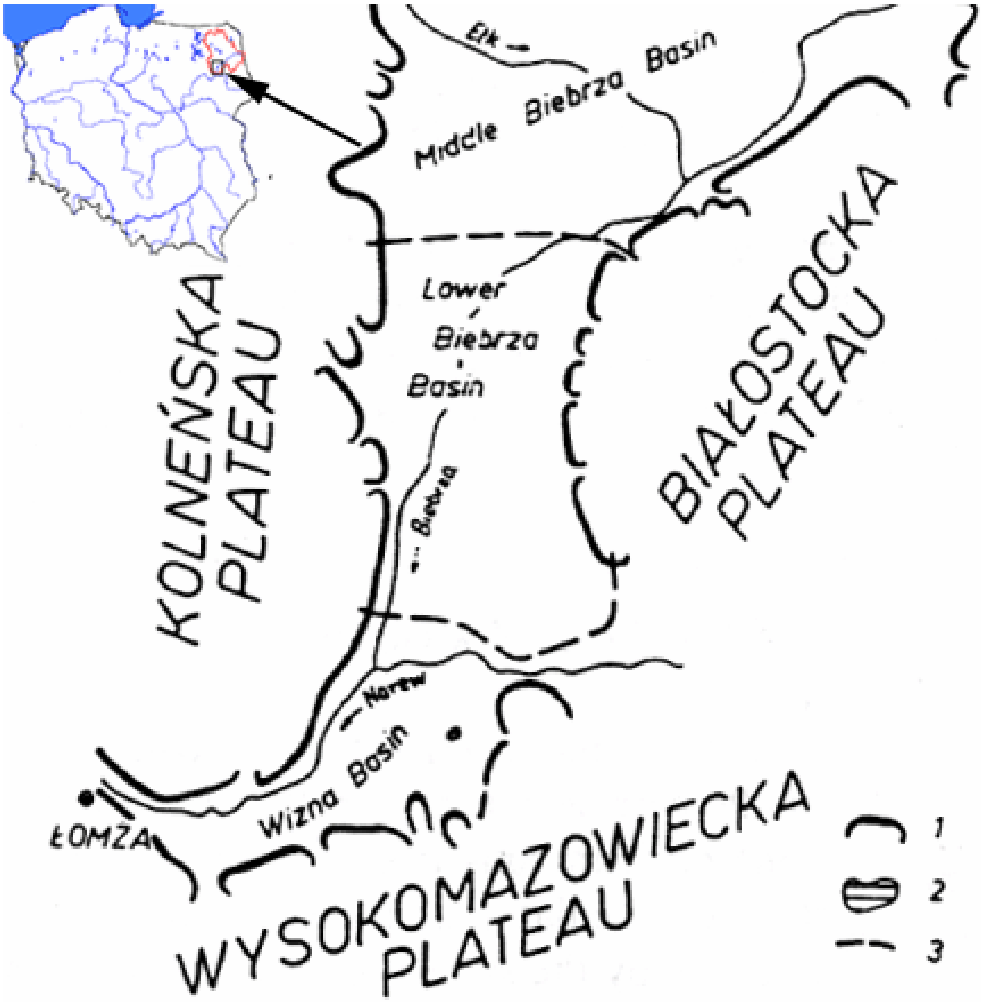

Fig. 1**.** The Lower Basin area on site sketch of the Biebrza ice-marginal valley (after Żurek, 1984). Legend: *1*- plateau edge, *2*- lakes *3*- border of basins

The Biebrza Lower Basin is located in the Northeastern Poland, in the macroregion of Północnopodlaskie Lowlands, mezzoregion of Biebrza valley. It forms a meridional channel which is 30 km long and 12-15 km wide. The Lower Basin is an ice-marginal valley, surrounded from the east and west by morainic plateaus of the last but one glaciation: Białostocka and Kolneńska Plateau (Żurek, 1984). In the north and south it borders large peat basins: the Middle Biebrza and Wizna basins (Fig. 1).

The Biebrza River is the main channel of the hydrographic network of the Lower Basin. The river course is winding and forms many meanders, side streams and old riverbeds, which are included in the surface water systems only during period of high water flows. The width of the river channel varies from 10 to 34 m, and its average depth is 1.8 m (Mioduszewski and Querner, 2002). Water level slopes vary from 0.5 ‰ to 0.23 ‰. A remarkable feature of the Biebrza Lower Basin is the asymmetric position of the river: it courses the valley from east to west in the final 20 km, and then, follows its course of the west side, right adjoined to the valley margin. The Biebrza River valley's wide is varied from 4 km in the northern part, to 8 km in central part and 15 km in southern part. Hydrological feeding in the Lower Basin may be generally described as fluviogenous along the river, and soligenous in the areas beyond the fluviogenous zone. The soligenous feeding is predominat in the southeastern basin.

MEASUREMENTS

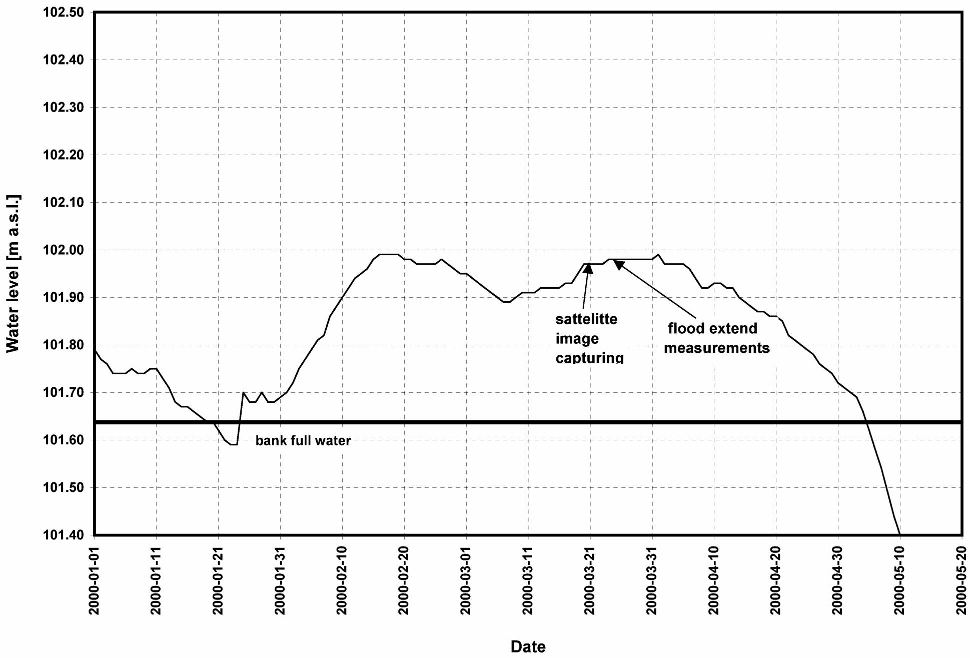

Fig. 2. The water level observed in Burzyn gauge during the flood in 2000

The daily water level observations in the Lower Basin are permanently performed on two river gauges situated in Osowiec and Burzyn. Fig. 2 shows dynamics of the surface water level observed in Burzyn gauge. During three months the water stage was higher than the bank full level in Brzyn gauge. The maximum water stages close to 315 cm (about 102 m.a.s.l.) were continued from 15th February to 5th April (Fig 2). The satellite image was captured in 20th March. All field measurements were taken from 22nd to 24th March, exactly at the time of the maximum water level observed in the Burzyn gauge (Fig 2).

DEM OF THE LOWER BASIN

On the floodplain, which is a relatively flat area, the effect of topographic representation on the inundation extent calculation is significant and noticed in several papers (Marks and Bates, 2000; Bates and De Roo, 2000). Water levels data are calculated in numerous cross-sections by hydrologic or hydraulic models and, then, the GIS is used as a post processor for determine which areas will be inundated. The Digital Elevation Model (DEM) is a principal condition of applying the GIS method for flood assessment. The DEM of the Lower Basin was generated by the ArcInfo TOPOGRID method during an interpolation process. The main data source for the model generation was a set of contour lines elaborated in the digital form. These data was partly captured from air-photo stereo-pairs, with an accuracy of 1:25 000 scale topographic maps, and partly obtained from existing scanned topographic maps by “on screen” digitizing of contour lines from topographic maps in the scale of 1:25 000. Additionally, the all-existing point altitude information was incorporated into the source database for DEM generation. The point elevation data was digitized from the topographic maps (all elevation points marked and labeled on topographic maps) or measured in the field. However, this dataset was found as still not sufficient, because of the fact that a large part of the Lower Basin consists of relatively flat floodplains (with only few contour lines) compared to the areas close to the moraine edges, which posed problems during interpolation of the DEM. Another problem in the Lower Basin is the presence of river dunes close to the main river channel, which are rather not represented on topographic maps. In order to create a dataset resembling as much as possible reality and for improving the interpolation process the DEM source dataset was extended by the construction of additional valley cross-sections. The cross-sections were partly obtained by measurements, and were partly based on map analysis. This was done as follows. Close to the river, the cross-sections were measured in the field by coupling the traditional leveling survey with Differential GPS (DGPS) techniques. The DGPS was found as a very useful and time saving method for coordinates and altitude measurements, and were often the only possible method in such a remote area (Chormański et al., 2000a) with dense vegetation, numerous oxbows, and limited a number of reference points. The 15 places located on the riverbank were selected at the distance of 2-4 km from each other along the river, from Osowiec downstream to Sierbuczyn. Then, the reference points - one for each cross-section - were measured by the DGPS technique. At these points the levelling was done giving the shape of the valley close to the river on both sides of the river channel. The measured part of cross-sections varied from 50 to 500 meters depending on the height and density of floodplain vegetation. Then, the cross-sections were extended to the edge of the valley by capturing elevation every 100 meters from topographic maps (Fig. 1). The DEM was generated by the ArcInfo 7.2 TOPOGRID command. This method, originally developed to interpolate DEM for hydrologic modeling purposes, was also

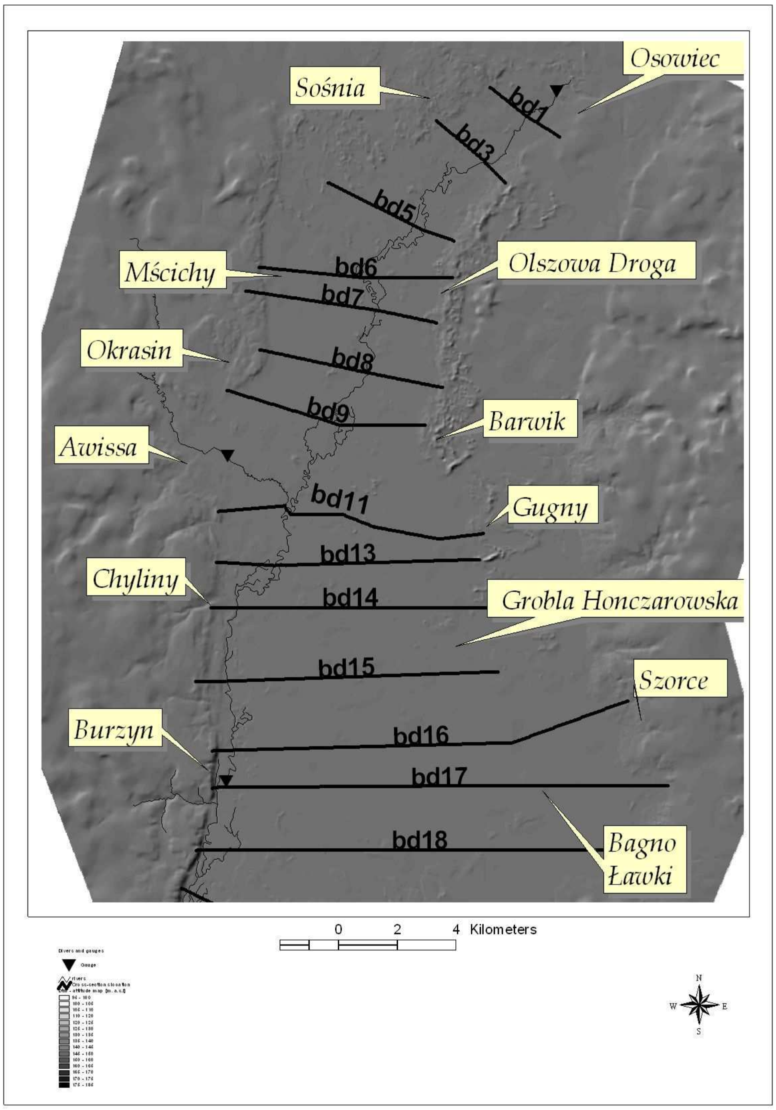

Fig. 3 The Digital Elevation Model of the Lower Basin. Location of the cross-sections used for development of the DEM and Hydraulic model.

several times successfully used to construct a model of floodplain topography (Cera et al., 1996; Townsend and Walsh, 1998). The TOPOGRID is an interpolation method specifically designed for the creation of a hydrologically correct digital elevation model. It is based upon the ANUDEM program developed by Hutchinson (1996) and, generally speaking, it 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 has been designed to take advantage of the types of input data commonly available, and the known characteristics of the elevation surface. This method uses an iterative finite difference interpolation technique. It is essentially a discretised thin plate spline technique, where 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) evaluated the TOPOGRID routine as one of the best available algorithm for DEM generation. The DEM of the Lower Basin was created as a raster network with a cell resolution of 25 meters using the procedures explained above (Fig. 1). The disadvantage of TOPOGRID interpolation algorithm was noticed - it has problems modeling the junction of the steep valley sides and flat valley floors. A similar disadvantage of TOPOGRID is noticed by Townsend and Walsh (1998) and Wise (2000). To correct this problem, supplemental contour lines were added at the bottom of the slopes. The supplementary lines used the same values as the lowest value on the slopes. According to the verification results, it is concluded that after correction of errors, the constructed DEM seems to be good enough for flood mapping. The created DEM was verified on the basis of a field survey. The three valley cross-sections were measured in the Lower Basin for the purpose of determining the final model accuracy and model verification.

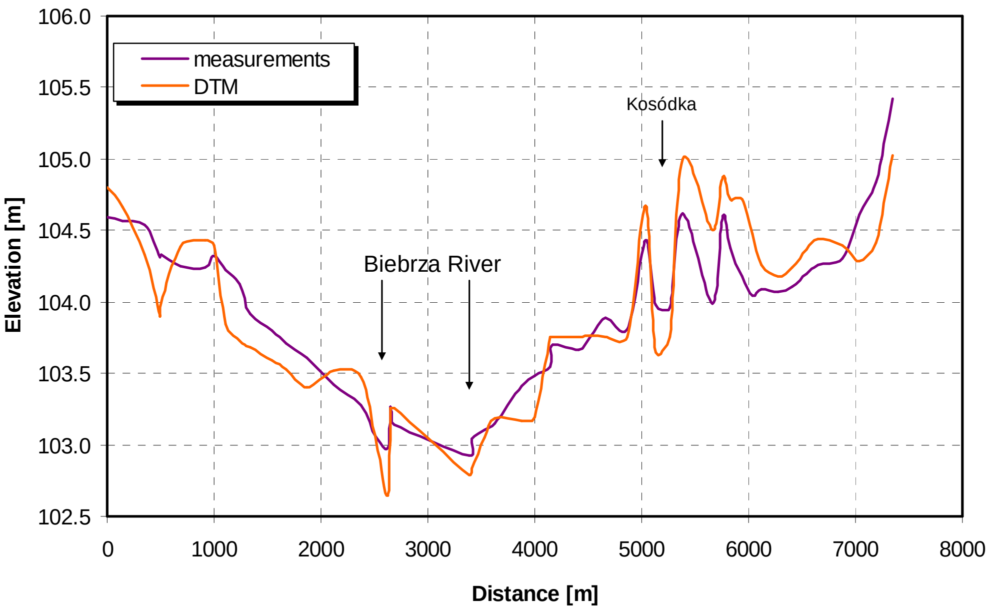

Fig. 4. One of the three verification transects courses from Awissa to Barwik

The cross-section locations were selected so as to include different types of valley morphology: moraine, moraine sides, and river formed dunes close to river channel, bigger wind dunes lying far from the river and flat organic parts of the valley. The survey compared with DEM gave the root mean square error (RMSE) of 0.35 m.

LOWER BIEBRZA RIVER UNET APPLICATION

In this work in order to simulate flood flow in the lower Biebrza Basin, UNET (One-Dimensional Unsteady Flow Through a Full Network of Open Channels) was applied [*HEC, 2001*]. This program is a component of computer software HEC-RAS (River Analysis System, distributed by Hydrologic Engineering Center - HEC) [*HEC, 2000*] and is numerical realization of the mathematical model of river water flow, which is formalized in the equations of unsteady one dimensional open channel flow, based of the St. Venant hypotheses.

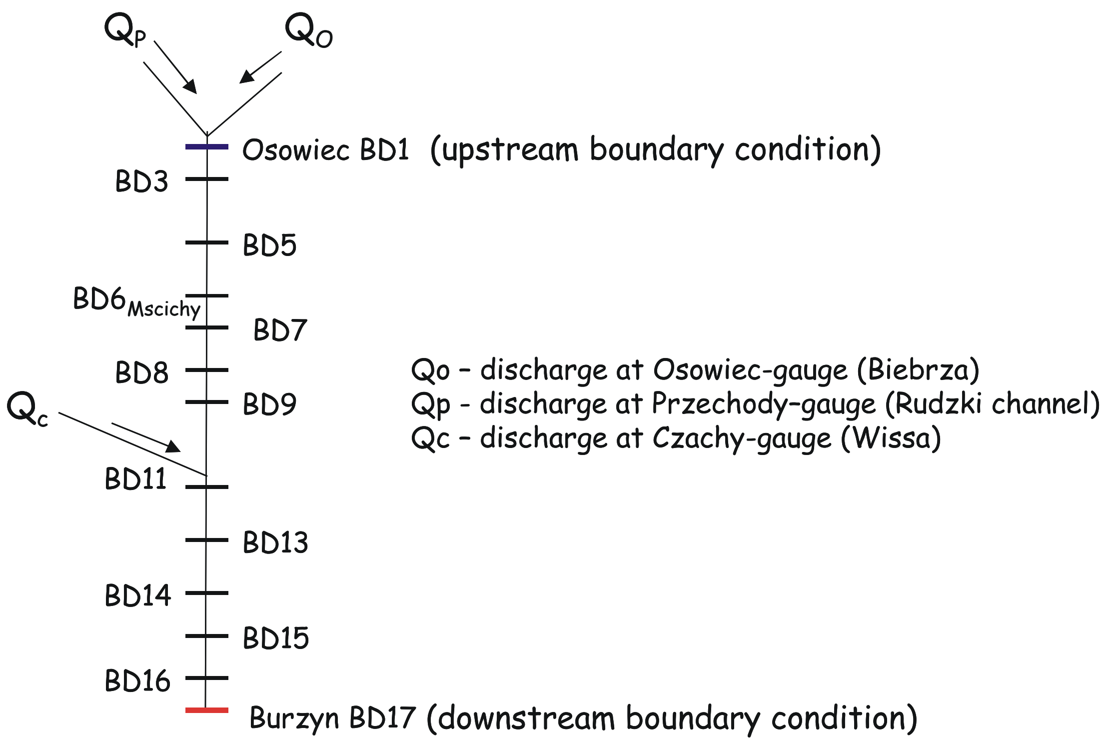

Fig.5. Topological model representation

In the topological discretization scheme of flow, the Lower Biebrza River and floodplain (Fig.3) is represented as an one-dimensional. Only the channel area (defined by left and right bank stations) is used in the computations, unless the water surface elevation exceeds the elevations of the bank stations. In the natural situation overland floodplain flow is far more complex and difficult to describe. As the river stage is rising, water disperses laterally from the channel, inundating the floodplain and filling storage areas. As the water depth on floodplain increases, the valley begins to convey water downstream, generally along a shorter path than that of the main channel. When the river stage is falling, the water moves toward the channel from the overbank storage, supplementing the flow in the main channel. This “two-dimensional flow regime” is approximated by a one-dimensional representation. This simplification is possible because the primary direction of flow is oriented along the channel. This channel/floodplain problem has been addressed in many different ways [*Liggett and Cnuge. 1975*]. Fig. 5 shows the scheme of topological discretization and locations of cross-sections along the river and floodplain. The model simulates the Lower Biebrza River as a single channel starting from Osowiec Gauge (BD1) and terminating at Burzyn gauge – BD17 (Tab.1)). Drainage ditches network, old rivers-beds and spreads existing in this area were not taken into account, due to lack of their geometric and topographic data. The Wissa River is treated as a point lateral inflow located at 8 km upstream of Burzyn and is described by flow hydrograph in Czachy gauge (Q_C) (Fig.6). The geometry of river channel and floodplain is established by an elevation and station of each point in a cross section used to describe the ground profile. The river bed were measured by manual sounding, the neighbourhood of river banks was leveled and points situated in floodplain were calculated from Digital Elevation Model and topographic maps. Automatically interpolated by UNET cross-sections are added to the system for stability solution. The distance between interpolated cross-sections is 500 m.

Table 1 Channel and floodplain distance between cross-sections

Number	Cross-section name	Distance along channel [km]	Channel distance between cross-section [km]	Right floodplain distance between cross-sections [km]	Left floodplain distance between cross-sections [km]
1	BD1	0.00			
2	BD3	2.38	2.38	2.04	2.17
3	BD5	7.36	4.98	3.35	2.98
4	BD6	11.62	4.25	2.45	1.59
5	BD7	14.38	2.76	1.03	1.32
6	BD8	17.45	3.07	2.04	2.10
7	BD9	19.99	2.54	1.83	1.85
8	BD11	26.74	6.75	3.60	3.12
9	BD13	29.95	3.21	1.80	1.69

10	BD14	33.24	3.29	1.56	1.40
11	BD15	36.13	2.89	2.50	2.44
12	BD16	38.88	2.75	2.34	2.34
13	BD17	41.24	2.36	1.27	1.27

A flow hydrograph forms the upstream boundary condition. It is located at cross-section BD1 (Fig.5) and it is a sum of discharges at Przechody (Q_P) and Osowiec (Q_O) gauges (Fig.7) The rating curve is used as a downstream boundary condition at Burzyn gauge (Fig 8.). There is a significant difference in discharge rates between BD1 and Burzyn cross-sections (Fig.9). This is mainly due to the large lateral inflow from subcatchment during the flood event. The uniform lateral inflow is imposed along the river section as $Q_{u\_lateral}(t)=Q_{Burzyn}(t)- Q_{Upstream}(t)-Q_{Wissa}(t)$. This solution is obviously a rough approximation of the actual situation, as it does not account for the temporal and spatial variation of the lateral inflow. A more realistic approach on this issue needs to be elaborated in further study and should be based at a hydrological model of subcatchment inflow.

Table 2 Variation of Manning's *n* with river conditions

	without vegetation	with vegetation
channel	0.025 0.028	0.030 0.033
floodplain	0.07	0.09

Hydraulic roughness, described by Manninng's coefficient (*n* value), is a major source of uncertainty in a water surface profile calculations required. The variation of water surface elevation along a river is largely a function of the boundary roughness and the stream energy to overcome friction losses. Manning's coefficient varies with stage, flow, temperature and vegetation cover. Selection of the proper value of the friction coefficient is very crucial for the accuracy of the computed profiles. When discharges corresponding to observed water-surface profiles are know, coefficient *n* can be calculated from Manning's equation. Because for Lower Biebrza River these data are not available, coefficient *n* was estimated using tables [*Chow 1959*] and *n* values were selected during calibration process of model.

CALIBRATION OF THE MODEL

The Lower Biebrza River model was calibrated for both steady and unsteady flow. At steady state water stages in cross-sections were measurement on 11.07.2000.

In this case the upstream flow at BD1 was 8.2 m^3/s and inflow from tributary Wissa 0.88 m^3/s. Fig. 10 compares calculated water surface profile with measurements. The maximum error is 7.2% at cross-section BD9 and probably was induced by large distance between BD9 and BD11 (about 6.7 km) and different hydraulic property of cross-section. The model error for steady state is presented in Fig. 11. In steady state conditions Manning's *n* value for particular reaches of river was estimated numerically.

The model for unsteady flow was calibrated for hydrologic data of flood event in time period 01.01.2000-31.05.2000. From the hydrologic data only discharges and stages are available in Burzyn gauge. Therefore during the calibration and verification of the model

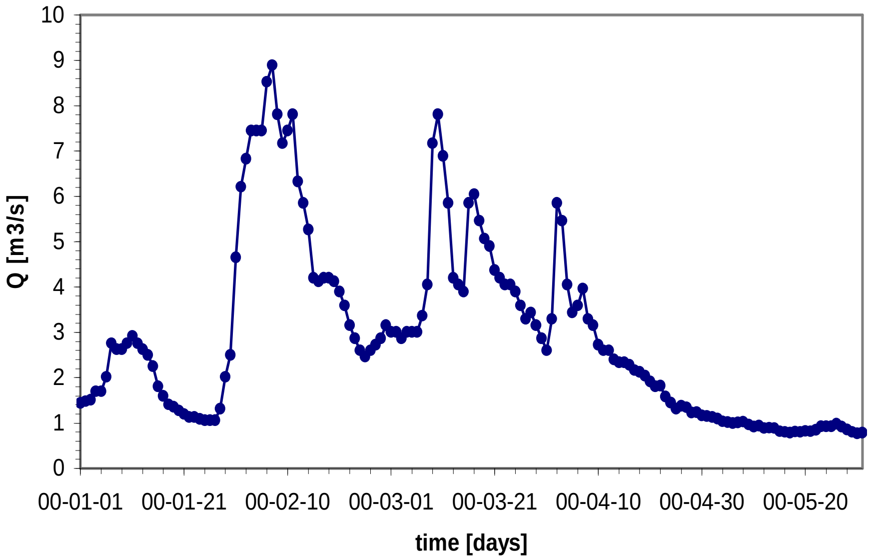

Fig.6. Discharge hydrograph at Czachy gauge-point lateral inflow.

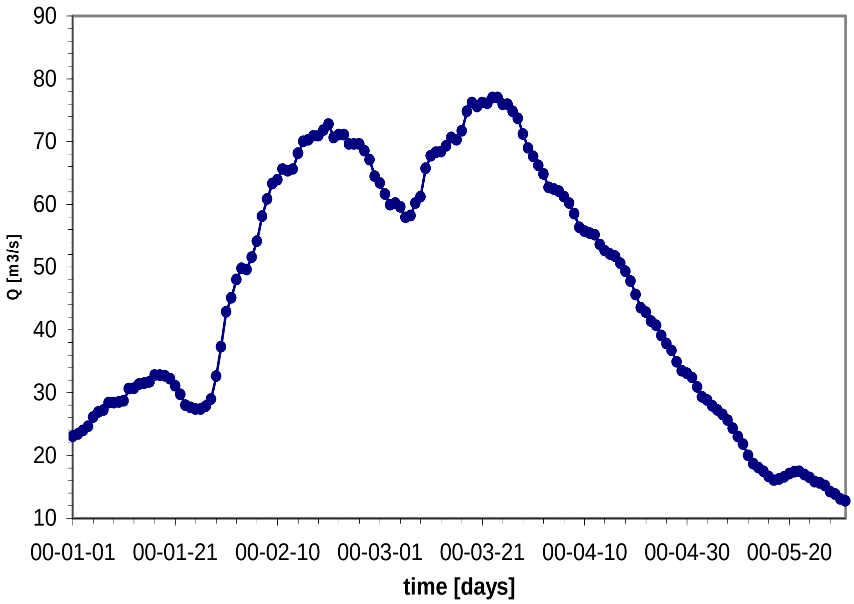

Fig.7. Upstream boundary condition – discharge hydrograph (QOsowiec+QPrzechody)

the calculated and measured discharges and stages in this gauge cross-section were compared. The model parameters (Manning's *n* value) were specified for different river conditions (vegetation, vertical variation with depth) as a result of numerical experiments (Tab.2). In Fig.12, the stages hydrograph calculated and measured at the Burzyn cross-section (BD17) are shown. The maximum difference between model stages and measurements is 18.5 cm in 17.05.99 during a fall of a flood wave. The reason of this situation is two dimensional character of flow between floodplain and main channel which is not taken into account in used one dimensional model.

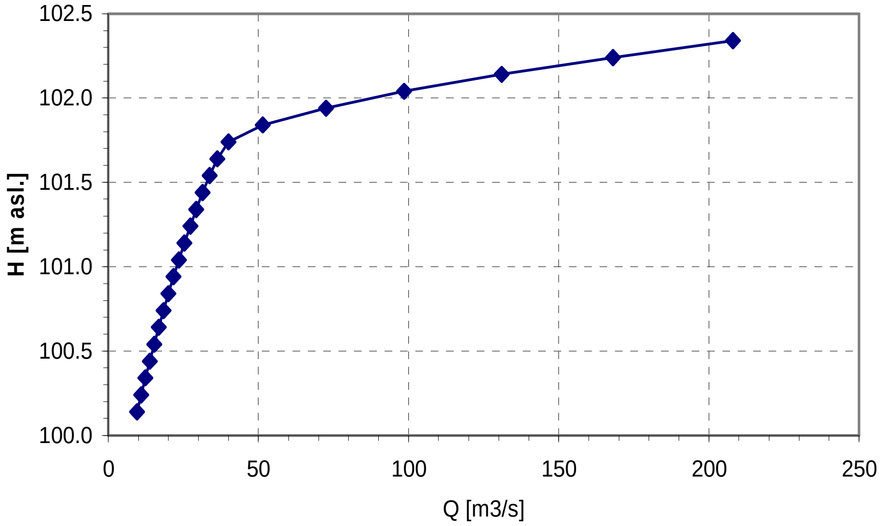

Fig.8. Downstream boundary condition – rating curve at Burzyn gauge.

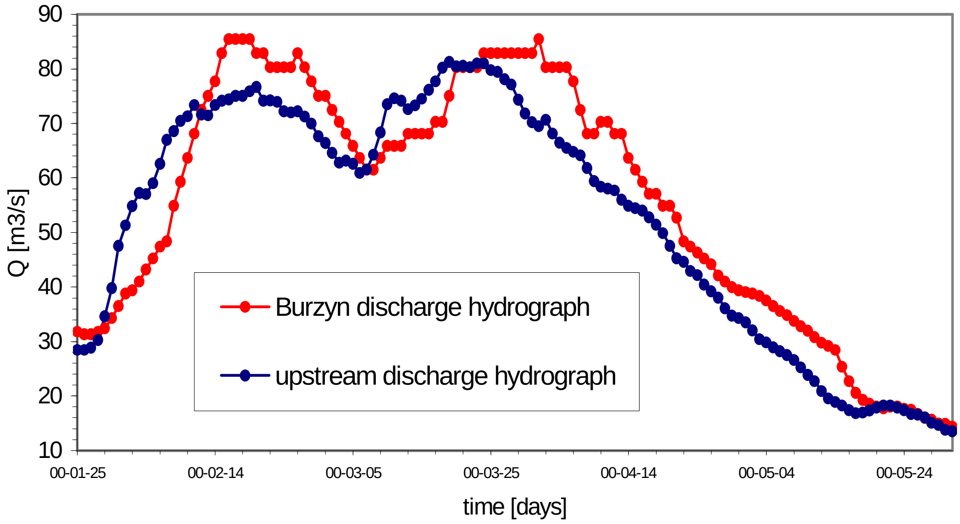

Fig.9. The comparison inflow with outflow for Biebrza River lower basin

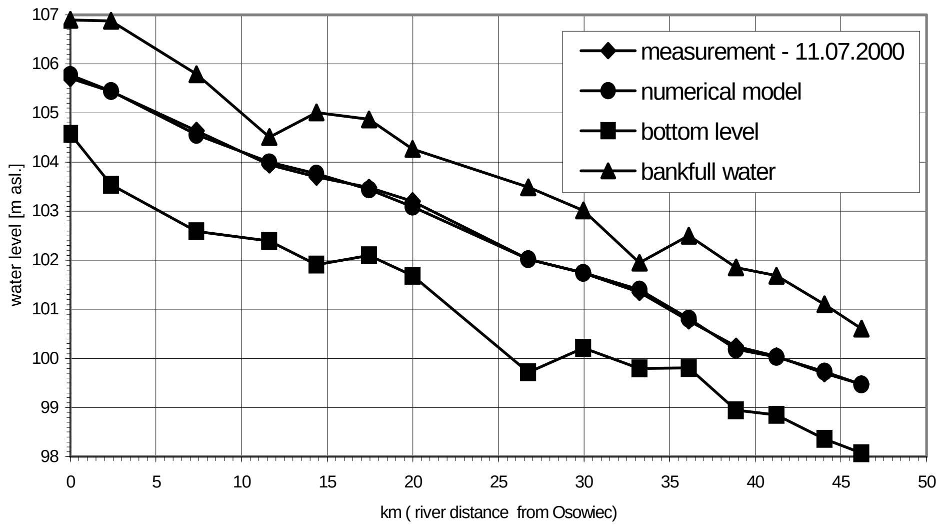

Fig.10. Calculated water stage profile (steady state 11.07.2000)

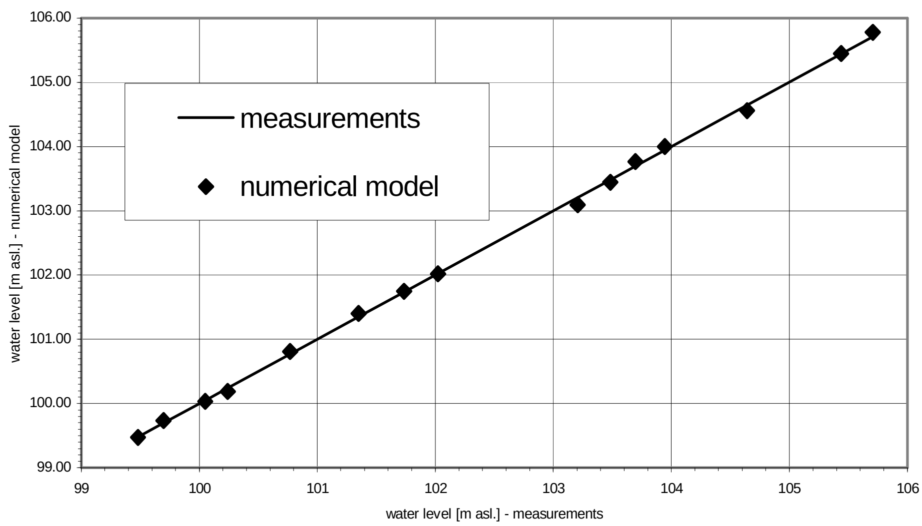

Fig.11 Model error (steady state 11.072000)

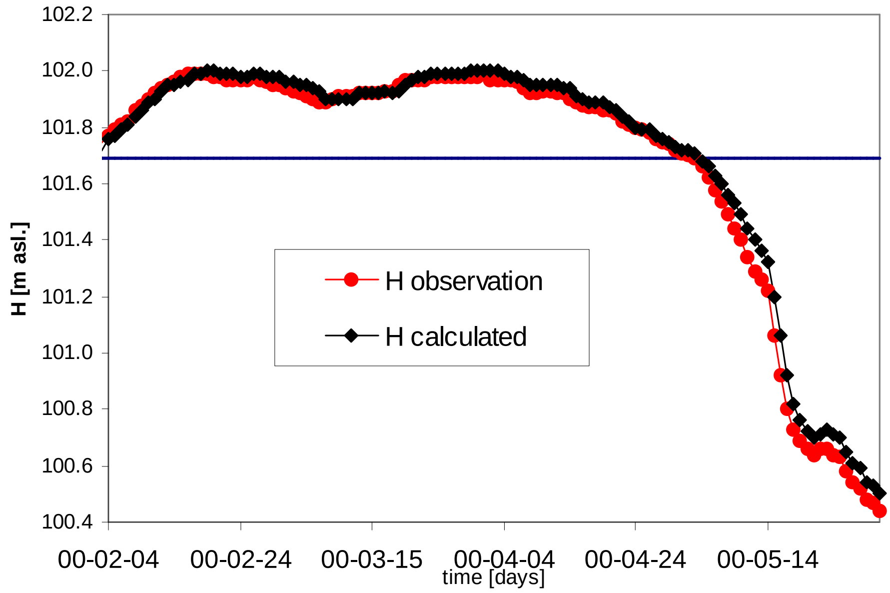

Fig.12. Numerical simulation results (stage hydrograph 01.01.2000-31.05.2000 cross-section Burzyn gauge)

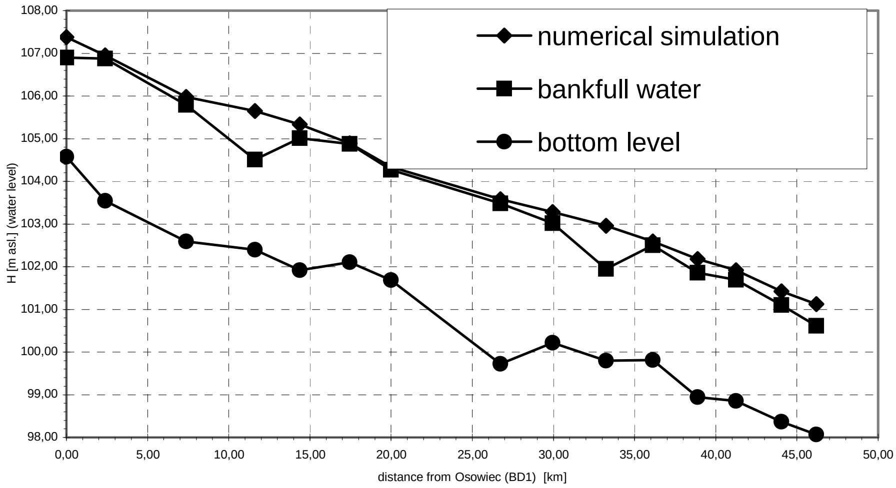

Fig.13. Calculated water surface profile (2000.03.21)

THE REMOTE SENSING METHOD

The Landsat TM was chosen to be a data source for inundation area determination due to the following reasons:

- images were available for the day of measurements and close to the flood peak time;
- fortunately, the weather was good during flood peak-time (no clouds, no rain), there was an acceptable degree of cloudiness in 2000;
- advantage of multispectral data in the detection of water and flooded vegetation: especially the near and middle infrared spectrum of radiometry wave (Lilesand and Kiefer, 2000);
- good results were obtained by using such images for flooded area determination in wetlands and forested areas during the spring time when leaves were not fully grown (Profetti and Mcintosh, 1996; Townsend and Walsh, 1998);
- sufficient resolution of the image (30 meters);
- low price compared to radar satellite data.

The satellite images of the Landsat 7 ETM+ 188/24 (Lilesand and Kiefer, 2000, http://www.eurimage.com), was captured during a maximum stage of the flood in 2000. The image was imported to the data format acceptable by ER Mapper software and stored as multi-spectral – multi-image datasets limited to the Lower Basin area, and next, has been geometrically corrected by a first order polynomial transformation method, on the basis of 19 ground control points (GCP). The GCP were selected as the well-recognized details on both satellite images and topographic maps in a scale of 1:25000. The images were rectified to the Polish topographical coordinate system of 1965. The Root Mean Square Error (RMSE), a standard technique of the geometric accuracy assessment (Wilkie and Finn, 1996), noticed about 8 m. Next, the image was resampled to 25-metre pixel size using the nearest neighbour resampling technique (Lilesand and Kiefer, 2000).

The manipulation of the spectral information represented by colour or tonal differences was undertaken for help our visual ability to detect and separate the discrete spectral features within the image A few methods of image visualisation and processing were tested, selected, and applied for the inundated areas detection, such as RGB false colour composite, rationing, vegetation components, and orthogonal transformation (Chormanski at al., 2002b; Chormanski, 2003). A selected ratios and transformations were applied on the Landsat dataset: ratio 7/4, NDVI and PC1. The results of these analysis were stored in new bands, and then, were used for classes determination and training regions development. Finally, the supervised classification by maximum likelihood method was performed for mapping the inundated areas on these new developed image bands. During the spring period, the wetland vegetation is not developed yet, and different communities are very difficult to recognize. Taking this into consideration, 14 generalized classes, containing different landuse types, were developed on the basis of field observation and references to the vegetation map of Lower Basin (Palczyński, 1984). The homogenous training regions of various land-cover types have been collected on the basis of field observation and GPS measurements as well as topographic map analysing. In general, the distinguished classes could be divided into two groups: the "inundated" classes: deep water, shallow water, inundated tall sedges and reeds, flooded alder forest, flooded meadow, alder birch forests, reeds and shrubs, sedges, shrubs and sedges, moss-sedge communities, and "dry" classes containing: coniferous forest, leafy forest, grasslands, and bare soils. The new transformed bands were visualised as RGB composition containing: PC1 band as Red, NDVI band as Green and ratio 7/4 band as Blue, respectively. The ratio 7/4 is a simple division of band 7 by band 4 (TM 7/4). The second, more complex ratio, was the Normalized Difference Vegetation Index (NDVI), which is computed by dividing the difference of the near-IR (band 4) and visible red (band 3) by the sum of them. The above-mentioned ratio was successfully tested by Townsend and Walsh (1998) for inundation discrimination in the marsh area. The use of the decorrelation properties of principal component analysis (PCA) indicates the difference between land cover types as well as divides water content reflectance from soil and vegetation background (Profeti and Macintosh, 1997). The orthogonal axes are created from the often highly intercorrelated bands within multispectral imagery. PCA compresses the variance into a multispectral image (using linear transformations) in such a way that the first three bands in a PCA image contain over 95% of the information (variance) previously contained in the original n-band image (Wilkie and Finn, 1996). The first component (PC1) contained about 90 % spectral information of the image (Szporak and Chormanski, 2004), was selected as the third one, which would be used for the inundation mapping. The maximum likelihood classification method uses spectral band covariances of the training sets to determine orientation and relative elongation of the p-dimensional probability distribution around the mean of class. The a posteriori probability, $P(i/x)$, is the likelihood that a pixel with brightness value vector x composed of p elements (bands) is a member of class i. This membership is calculated for each class from the determinant of the class variance-covariance matrix, and the Mahalanobis distance (the pixel-to-class centroid distance corrected for the variance and covariance of the class i). The classified image was next reclassified for two groups: the "inundated" and "dry" classes (according to). In regards with the assumption, which has been made in the beginning of the classification process, the classified images were reclassified into two classes "inundated" and "dry" (Chormański et al., 2000), which procedure conducted determination of the inundation map. The calculated inundated area for the maximum of flood in 2000 was equal to 192.7 sq km. The obtained inundation map was verified only on the basis of points collected during field measurements, which focused only on the inundation border. These points collected by GPS shows that inundation border in most cases agree with the border of “inundated” class.

RS USED FOR MODEL VERIFICATION

The result of remote sensing analysis was used for verification of the spatial extent of river flood generated by model for the flood maximum stage. Calculated water stages by hydraulic model in cross-sections were mapped in whole floodplain using the DEM in GIS software *ArcView GIS*. The processed image (captured 20 March

2000) was used for verification of the spatial extent of maximum river flood (21 March 2000) generated by hydraulic model (Fig.13). Comparison of the inundated area generated by hydraulic model coupled with DEM and obtained by remote sensing method shows good quality of the model in upper part (RS method = 59.7 km^2; HM-GIS = 49,5 km^2) and gave unsatisfactory results in the lower part of valley (RS method = 153.1 km^2; HM-GIS = 51.9 km^2) (Fig 14).

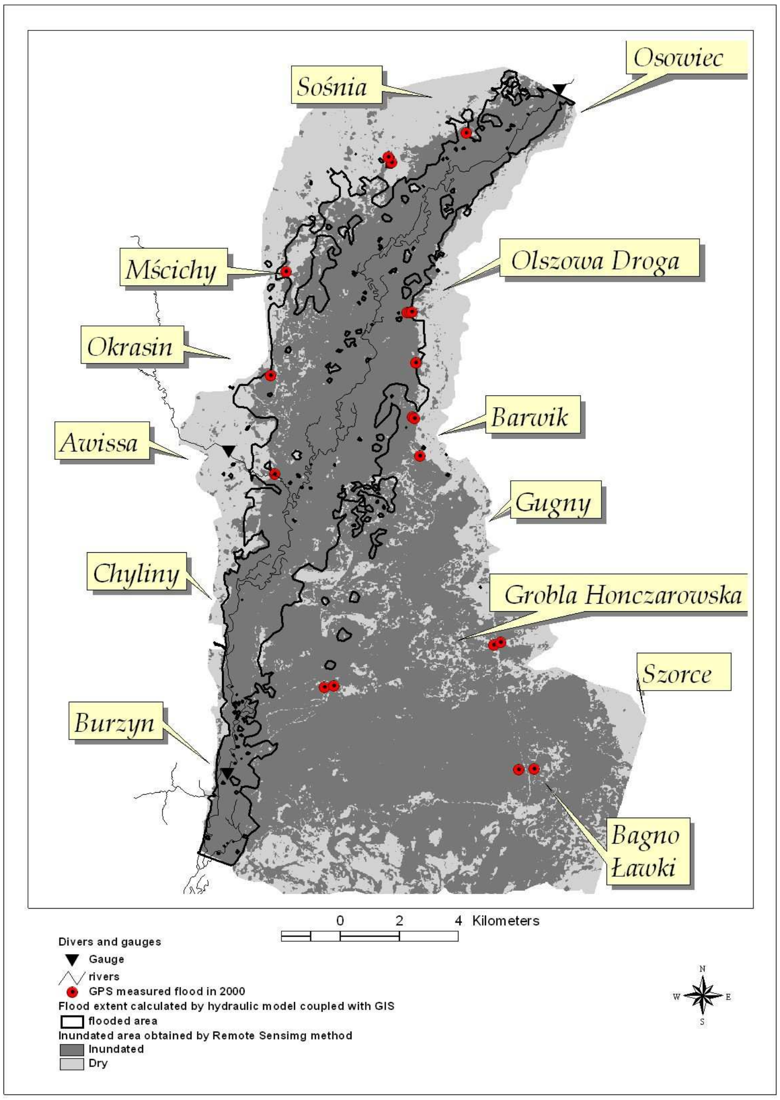

Fig. 14. The inundation map of the Lower Basin obtained by supervised classification of the Landsat image for the flood in 2000.

WATER CHEMISTRY

A big differences between flood extent calculated by the model and inundated areas obtained from analysis of the satellite image, give an effort to develop a method for determination of the water source of inundation. Consider that, an attempt of integrating GPS measurements, Remote Sensing and water chemistry measurements was performed. Two transects on areas accessible by foot in the inundated area were measured, namely, Transect "a" Barwik and Transect "b" - Grobla Honczarowska (Fig. 15). Transect "a" was located on area where results obtained from both HM and RS methods were similar, and, transect "b" on south part of valley, where the biggest difference was obtained. Along selected transects simple water properties were measured in the field (Electroconductivity – EC_{25}; acidity - pH) or determined within 8 hours after sampling in the field laboratory (dissolved oxygen - O_2; total inorganic carbon, which consisted in this thesis case of HCO_3^- only). The sampling was done each few hundred meters. These water characteristics were selected, because they were easy to measure, and were possible indicators of water types (Wassen 1995). EC was considered the most useful parameter for identifying water types. Also the immediate measurement in the field was a reason for choosing this parameter. This usefulness of EC was also noticed by Wassen (1996).

The values of EC from samples collected in transects were analysed and compared to river EC, which during the flood was measured in several places. The EC of the samples collected from river water varied between 420-460 µS/cm . In the Barwik transect (a on Fig. 15) the EC values were relatively higher in the flooded part, which probably resulted from extra water inflow from the Biebrza tributaries the Kosódka River and the Wissa River. On the floodplain, on the left bank of the river, the EC values varied between 324-435 µS/cm and could be interpreted as river water. The next identification for river water was observation of visible water flow on the floodplain in a direction parallel to the river. The analysis of EC values measured in the "Grobla Honczarowska" transect (transect b on Fig. 8.1) gave different and interesting results. At a distance of ca. 2.5 km from the moraine edge the values were around 200 µS/cm (171 –223). In two samples, localized close to the river, values increased to 295 and 368 µS/cm, respectively. This area was interpreted as the mixing zone of two different types of water: river water and water pounding on the swamp, whose source was snow melting. Low values of EC indicate that the origin of the water is predominantly rainwater, which is poor in dissolved substances (Van Wirdum, 1984). It was concluded that this analysis allowed determining the water predominantly consisting of rainwater, which is the border of zone where river water predominates (Fig 15). Take this into consideration; the south part of the valley is a mixed-source wetland (Okruszko H., 1990), where during a spring flood period a significant area is influenced by snow-melt water.

CONCLUSIONS

Remote sensing methods can be used for hydraulic model verification in many river valleys and, but in natural river valley where different types of wetlands exists, it cannot be applied in fully automatic way. The Biebrza river wetland case shows that, differences in geomorphologic pattern of the north and south part of the valley resulted in the differences in water-source of inundated areas. In mixed-source wetlands, the remote sensing analysis which shows inundated area without focusing on water source, not agree with hydraulic model output, which concentrates on river water flood extent. In such a case, the remote sensing method used alone for verification of the flood extent calculated by hydraulic model gives not sufficient results. In the opinion of the authors of this paper, flood water properties - including a water chemistry analysis, could help in distinguishing flooded area from inundated by other water sources, and, should be included in procedure of verification hydraulic models.

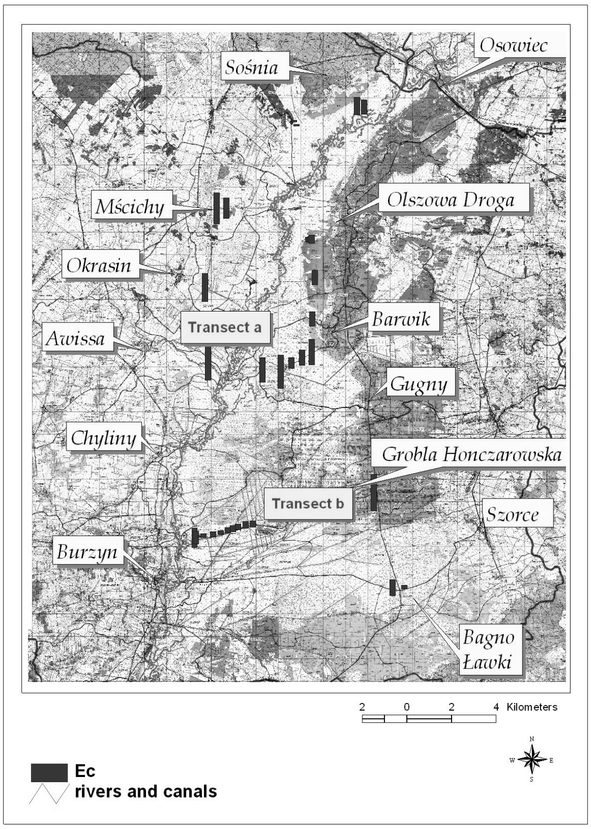

Fig. 15 Measured Electro-conductivity (EC) values of surface water in the Lower Biebrza basin during the flood in 2000

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