POLISH ASSOCIATION FOR SPATIAL INFORMATION
ANNALS OF GEOMATICS 2008 ❍ VOLUME VI ❍ NUMBER 1

# MORPHODYNAMIC ANALYSIS OF LOWER VISTULA VALLEY USING GPS, SONAR AND AERIAL PHOTOGRAPHY

## ANALIZA MORFODYMAMIKI DOLINY DOLNEJ WISŁY Z ZASTOSOWANIEM GPS, SONARU I ZDJĘĆ LOTNICZYCH

**Michał Janusz Habel[1], Sebastian Tyszkowski[2], Tomasz Skowroński[3]**

[1]Faculty of Geography Kazimierz Wielki University in Bydgoszcz, Poland
[2]Institute of Geography Polish Academy of Science in Toruń, Poland
[3]Regional Water Management Board in Gdańsk, Poland

**Keywords: Lower Vistula Valley, morphodynamics, GPS, sonar**
Słowa kluczowe: dolina dolnej Wisły, morfodynamika, GPS, sonar

## Introduction

Dynamic environment of large river valleys undergoes constant morphological changes. The rate and direction of those processes is conditioned by both natural and human factors. Employing modern techniques of data collection, further followed by digital data processing, enables spatial analyses in order to address issues such as the development of a river valley. Electronic equipment makes it easier to catalogue the resources of the environment.

In most cases, Polish rivers are not navigable. The main obstacle is the shallowness of their watercourses (Płuciennik, Gulczyński, Najdkowski, 2007). Safe navigation along the Lower Vistula River, for instance, might be possible once a navigation map is made and the geomorphological processes in the valley floor are monitored and their further course predicted. Achievement of those goals is possible thanks to the GIS software.

On growing number of occasions, contemporary development of navigation maps is based on modern techniques for measuring depth. The acquired data make it possible to construct a digital model of the river channel, which becomes a basis for making navigation maps (Łubczonek, 2006).

Presently, bathymetric plans of inland waters based on GIS have been made for selected lakes in the Mazurian Lakeland due to safety reasons (Oszczak, Popielarczyk, Oszczak, 2005). An advantage of such plans is an instant access to information about a given object (Dost, Mannaerst, 2008).

## Aim and research methods

The paper aims at presenting contemporary research methods based on Geographical Information Systems, which may be used for analyzing morphodynamic processes (geomorphological and fluvial) of the Earth. The data were collected during field studies with the use of the GPS (the Global Positioning System) and a sonar (the Sound Navigation Ring), as well as from archival cartographic materials. Their analysis was to show the rate and the direction of the changes in the morphology of the Lower Vistula Valley, including the rate of the bed-load transport and the changes on the valley slopes. The research was undertaken in order to ease the use of the river, predominantly in terms of safe navigation.

The tool integrating the spatial data was the ArcGIS 9.0 by ESRI. All the data were transformed down to the 1992 Coordinate System which is in force in Poland. The research concentrated on the two issues. In the first one the processes in the channel of the Vistula were analysed, while in the second one the rate of the changes along the Vistula slopes was estimated (Fig. 2).

The study of the dynamics of changes in the channel was based on the Lowrance acoustic sonar (model LMS 480); its frequency was 200 kHz and the registration accuracy of the depth was 0.1 m. The sonar, equipped with a GPS receiver with an EGC-12W external antenna, received the signal from 12 satellites positioned above the horizon and worked in the WASS correction system.

In terms of the channel, the area sounded with the sonar was limited by the river bankline. The sound profiles were made across the channel as well as along the thalweg. As a result, a set of measurement points evenly distributed over the bottom of the Vistula's channel was received. They had established parameters of the distance between the water table to the bottom, i.e. the depth, and the point's geographical location. Digitalisation of the river bankline was based on the orthophotomap at the scale of 1:5000. In the process the extreme points were given the value of the water-table in metres above sea level which was recorded on the day of the measurement taking. The datum of the water table was based on the measurement of the water level taken at the gauging stations in Chełmno (806.8$^{th}$ km of the Vistula's course) and Grudziądz (834.8$^{th}$ km). The datums of the water table for each 1-km section of the Vistula River between the gauging stations were based on the average water table slope of 0.182 m/km. Each of the measurements of the depth taken for the Vistula's channel was transformed into the datum of the bottom and given in metres above sea level. Next, bathymetric maps were produced as digital elevation models (DEM), which were later used to carry out the spatial analyses.

The sonar used for the measurements is equipped with the "Grayline" option which makes it possible to distinguish between strong and weak echoes, the basic feature which diversifies the type of the deposits on the bottom. The character of the channel bottom can be told from the shades of grey (a weak signal is indicated by a darker shade, while a stronger signal is indicated by a lighter shade of grey). Soft muddy bottom or the bottom overgrown with vegetation reflects the sonar signal weakly, which on the display screen is indicated by a thin grey line or the total lack of it. Hard bottom reflects the signal strongly, which on the display screen is indicated by a wide grey ribbon (Fig. 1). This method makes it possible to create a map with spatial diversity of the sediment facies composition in the river bottom and obtain detailed information of its physical properties such as the grain size (Smith, Lazar, 2003).

The changes outside the channel of the Lower Vistula Valley, mainly referring to slopes, were based on the analyses of both archival materials and the data collected during the field work. In order to do so, archival aerial photographs and cartographical materials were collected. Similarly, a concept of using geomatics data bases to analyse the changes in the highly geodynamic zones is used for the shores of the Baltic Sea (Furmańczyk et al., 2007; Szakowski, Benedyczak, 2007). The following cartographic and photogrammetric materials were used to create the data bases system: a topographic map at a scale of 1:10 000, a historical topographic map from 1909 at a scale of 1:25 000, aerial photographs taken in 1961, 1972, 1987 and 1996 at the scales from 1:12 000 to 1:26 000, and an orthophotomap from 2005 at a scale of 1:5000, as well as other selected maps and geodesic plans. Due to both diverse reference systems and different data formats it was necessary to rectify them to the 1992 Coordinate System. The most difficult stage of the rectification was to find clear and stable ground control points in the aerial photographs.

In order to update the above materials and undertake larger studies on geodynamics of the landslides the GPS receivers were used. The methods of the GPS measurements used met the requirements of both accepted and expected measurement accuracy, the integrity of the collected data as well as the effectiveness of timing and expenses. The outline of the characteristic landforms, such as the course of the bankline and the edges of the scarps and tension cracks in colluviums and (Fig. 3), was made with the DGPS receiver (the Differential Global Positioning System). While establishing the position the measurements were averaged, the PDOP coefficient being $\leq 5$. Thanks to this the gained horizontal mean accuracy was $<0.5$ m. Besides, at one of the studied landslides a set of 5 bench marks were installed in order to monitor constantly surface displacements. Additionally, measurements for post-processing, more and more frequently used for studying mass movement, were used. The advantage of these measurements is the fact they can be done quickly and single-handedly, while the obtained data can be easily stored and compared. Once both the archival and contemporary material was collected and analysed the limits of individual stages of movements of the landslide were delimited (Fig. 2). The above stages of movements refer in fact to the dates when the aerial photographs of the area were taken.

## Testing area

In order to test the efficacy of the GIS research methods, a 6-km long section of the Lower Vistula Valley was selected as a testing area (Fig. 2). Located within the Świecie Basin, the study area includes the edge zone of the Świecie Plateau about 5 km from the town of Świecie itself. Relative heights reach almost 70 metres here. As a result, the slope inclination is significant and amounts from 15 to 35 degrees. The selected section of the valley is one of a few areas in the Lower Vistula Valley where the river directly cuts the plateau slopes. At this section the Vistula Valley is an erosive form cut down in the Tertiary deposits and filled in with an 11-step system of terraces (Kordowski, 2005). The 410-metres wide channel is a straight section due to river groynes which limit meandering. The bottom of the channel is covered with sandy deposits of riffle-pool sequence (Babiński, 1992). Mean annual channel flow at this section of the Vistula River amounts to 900–1000 $m^3/s$.

Geological structure of the area is easily studied thanks to a number of natural exposures as well as archival hydrogeological drillings of significant depth. The first two glacial till levels at the depth down to 31 metres, are separated with fluvial deposits, predominantly sands and loams, and a thin layer of silt. The tills are underlain by a 16-metre layer of fine-grained sands positioned above a 6-metre layer of varved clay. The latter sediments are underlain by the third layer of glacial till. Above the Vistula's datum of 20.5 m above sea level variously grained sands and gravels are found (Drozdowski, Kopczyński, 1992). Moreover, at this same depth the ground water table was recorded in the drillings. Along the valley slopes where impermeable sediments are exposed, such as glacial tills and silts, a few water seepages are observed.

## Dynamics of the valley slopes

High activity of mass movement in the study section of the Vistula Valley stems from the geological structure, activity of ground waters, lateral erosion of the river, and frequent oscillations of the water level. Based on mapping, a number of mass movement areas were distinguished along the 5-km edge section. One of more interesting objects is the landslide presented in Figure 4. It covers the area of 2.5 ha; it is 150 m wide and 180 m long, and its colluviums are up to 145 m long. This landslide belongs to the most active ones in the entire study area. Moreover, it is located in the close vicinity of a few times larger inactive landslide.

In the 1961 aerial photographs the landslide in question showed a low level of activity of the geodynamic processes. There were only a few small 2-m landslides observed at the top section of the slope. The central section showed indistinct traces of earth flows and surface erosion. The first mass movement appeared between 1961 and 1972 (Fig. 3). Then the eastern part of the landslide area activated, the landslide headwall moved backward by about 10 metres, while the colluviums, clearly visible in the aerial photographs, entered the channel by up to 20 metres (Fig. 4). Then one of the river groynes got damaged. The largest mass movement, however, took place between 1972 and 1987 when a deep shearing slide, which included the modern area of the landslide, moved towards the Vistula River. The then landslide area was over 1.8 ha large. In its upper part the landslide was 145 m wide, while in its bottom part it was 185 m. Colluviums observed in the 1972 aerial photographs moved further into the channel by up to 20–25 metres. Their initial limit, today impossible to be estimated, might have been much larger. In the following years the landslide area got larger and its headwall moved further back. This was because the colluvial deposits got started by the river activity such as high water stages. Such a mechanism leads to a lowered load of the bottom section of the slope and, as a result, to its instability. Since 2005 there have been no significant landslides observed in the area. The upper section of the slope experiences small falls, while in the central section creeps are recorded (Fig. 3).

Since the 1970s large damages of the hydrotechnical structure, predominantly of the river groynes, have been observed due to the landslide. Currently, due to constant activity of the slope their reconstruction is impossible, which puts a hazard to the existence of the other groynes.

## Changes in the river bed morphology

Two bathymetric maps (Fig. 5A-B), which keep the real slope of the water level, were based on the soundings of the Vistula's channel taken on 23 May 2007 and 28 April 2008. According to the comparative analysis of the bottom morphology based on both data sets, the transport of the bottom deposits takes the form of sandbar movement. In the eleven months between the measurements the position of their fronths changed by 130–310 m (Fig. 5B), which means a daily average rate of the sandbars movement of 0.95 metre. Transport of the deposits along the channel takes form of bed erosion and accumulation (Fig. 5C). As a result, the thalweg shifts. The largest changes in the channel bottom between the $815.8^{th}$ and the $816.6^{th}$ kilometre of the river thalweg can be observed where the active landslides are recorded. The material delivered from the slopes limits the cross-profile of the channel. This intensifies deep erosion and, as a result, the thalweg moves away from the active slope (Fig. 5C).

The rate of bed material transport and the movement of the sandbars' fronts shifting at the study section of the Vistula River were researched by Z. Babiński (1992). The geodesic methods used between 1981 and 1989 revealed the average daily rate of the sandbars movement to be 1.26 m. The amount and the rate of the bed material transported in rivers are closely related to the hydrological conditions in the study area during the research period of time.

The digital record of the bathymetric data of the Vistula's channel makes it possible to create cross-profiles and long profiles easily. Moreover, it enables the researchers to calculate any parameters of the bottom morphology of the Vistula River (Fig. 5A-B) as well as their statistical analyses.

## Summary

Using the GIS for studying morphodynamic processes in the Lower Vistula Valley has already given results. Modern methods of the field data collecting (GPS and sonar) and their further processing (GIS software) have enabled the authors to precisely evaluate the dynamics of the environment of the valley floor. Establishing the following was most important:

- precise location and parameters of the active zones along the river slopes, i.e. the places where the delivery of colluvial deposits from the landslides of the slopes to the channel is either already under way or might take place soon,
- dynamics of the past mass movement within the active sections of the slopes,
- the rate of the sandbars movement along the channel, i.e. the amount of the dragged waste and the rate at which it is transported.

The above studies are the key issues if the channel together with the groynes is to be maintained and safely navigated. Further collection of the data referring to the depth of the channel along a longer section of the Vistula River might lead to a creation of a digital navigation map. In accordance with the directive of the European Union, inland digital maps should be created for all waterways concordant with the Inland ECDIS Standards (Stateczny, 2006).

One of the problems the creators of such a navigation map for the Lower Vistula would have to face, however, is the need for frequent update. This is connected with the dynamics of the morphological processes in the valley floor. In order to avoid time-consuming field data collection followed by their analysis the morphodynamic model based on the data included in this paper should be used.

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***Abstract***

*The paper discusses modern research methods based on the GIS which were used to estimate the dynamics of geomorphological and fluvial processes of the Lower Vistula Valley. The study area included a 6-km stretch of the valley about 5 km to the east from the town of Świecie. During the field studies sonar and the GPS were used to collect the data on the morphology of the channel, while the GPS and the DGPS were used to measure the parameters of the slope zone at the direct contact with the Vistula's channel. Moreover, archival cartographic data were collected. The tool used to integrate the spatial data is the ArcGIS 9.0 by ESRI. All the data were transformed in accordance with the 1992 Coordinate System which is in force in Poland. As a result of the studies a detailed location of the active slopes of the valley was established. These are the places where the material is delivered to the channel. Moreover, the rate at which the bed material is transported was estimated on the basis of the sandbar dynamics. These researches are essential for both maintenance of the channel, including the hydrotechnical structures such as groynes, and safety navigation.*

***Streszczenie***

*W pracy omówiono nowoczesne metody badawcze oparte o systemy geoinformacyjne, które zastosowano w celu określenia dynamiki procesów geomorfologicznych i fluwialnych doliny dolnej Wisły. Obszar badań stanowił około 6 kilometrowy fragment doliny około 5 kilometrów na wschód od miejscowości Świecie. W terenie zebrano dane dotyczące morfologii koryta i parametrów strefy zboczy kontaktujących się bezpośrednio z korytem Wisły. Zebrano również archiwalne materiały kartograficzne. Narzędziem integrującym dane przestrzenne był program ArcGIS 9.0 firmy ESRI. Wszystkie dane zostały poddane transformacji do obowiązującego w Polsce układu współrzędnych „1992”. Rezultatem badań były m.in. dokładna lokalizacja aktywnych stref zboczy, czyli miejsc dostawy materiału do koryta oraz określenie prędkość transportu rumowiska w postaci dynamiki łach. Prowadzone badania są istotne z punktu widzenia utrzymania koryta, w tym budowli regulacyjnych oraz prowadzenia bezpiecznej żeglugi.*

mgr Michał Janusz Habel
hydro.habel@gmail.com

mgr Sebastian Tyszkowski
sebtys@wp.pl

mgr inż. Tomasz Skowroński
tomekskowronski@wp.pl

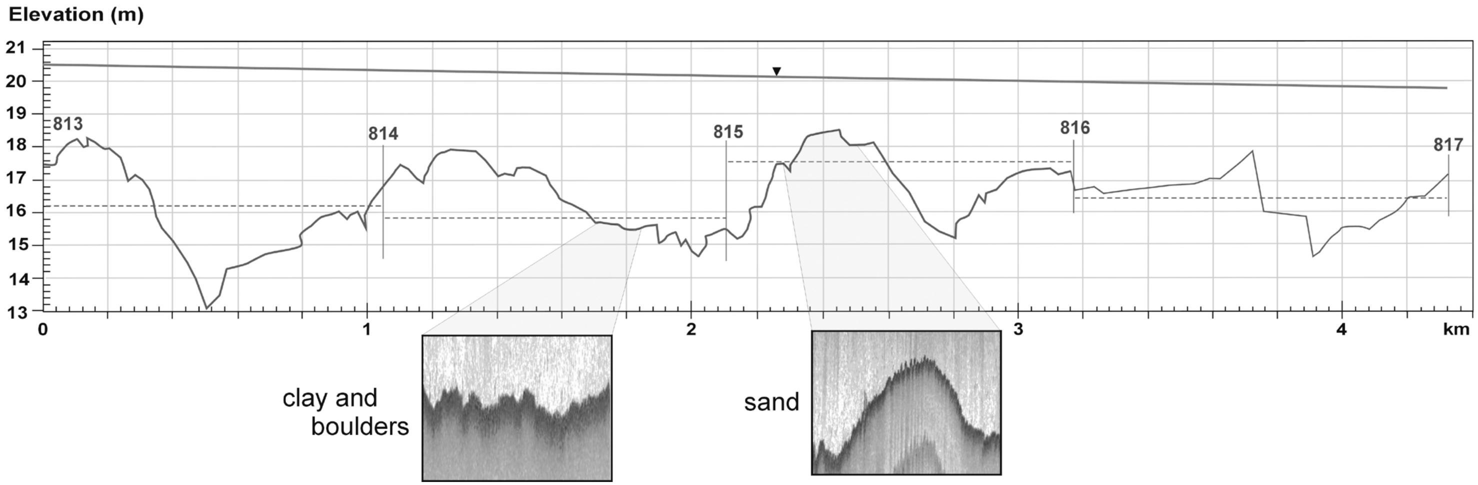


**Figure 1.** Long profile of the studied channel section of the Vistula based on the data collected on 23 May 2007 including examples of diverse types of bottom deposits. The dashed line marks the average depth of the channel at a given 1-km section

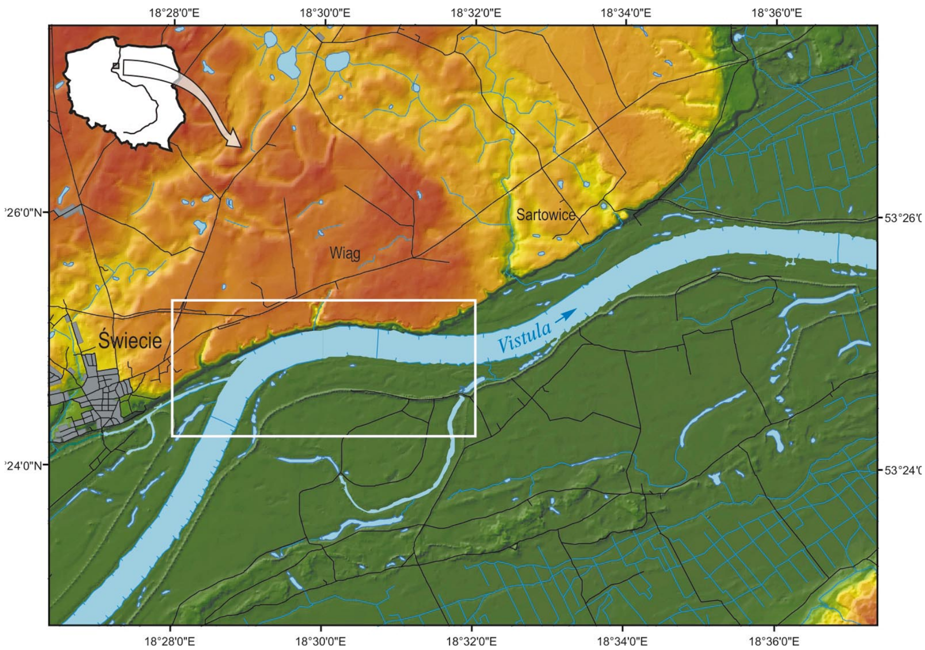


**Figure 2.** Location of study area near Swiecie

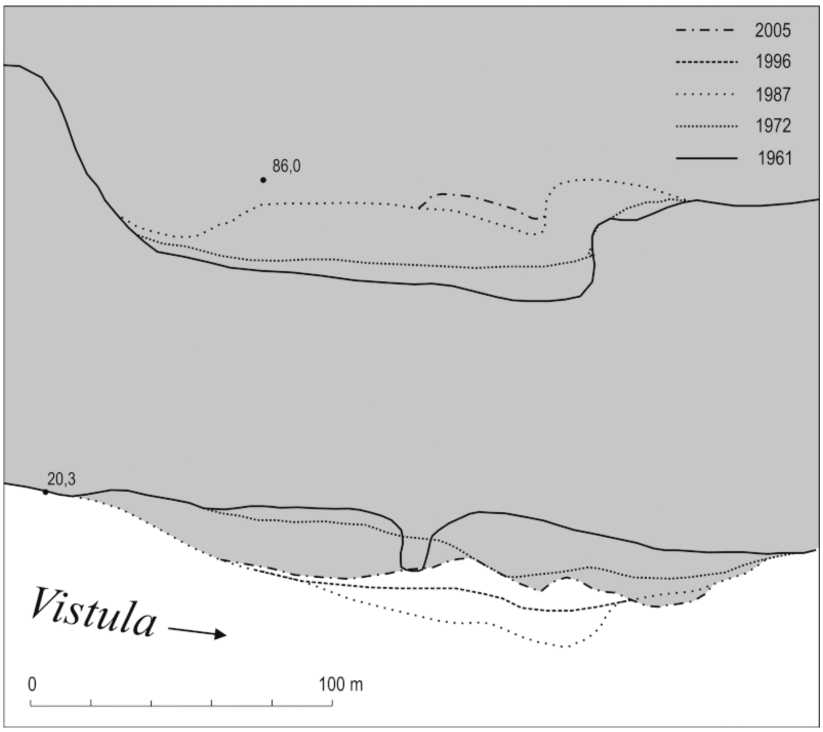


**Figure 3.** Phases of mass movements marked by the aerial photographs from 1961, 1972, 1987, 1996, 2005 year in Wiag landslide

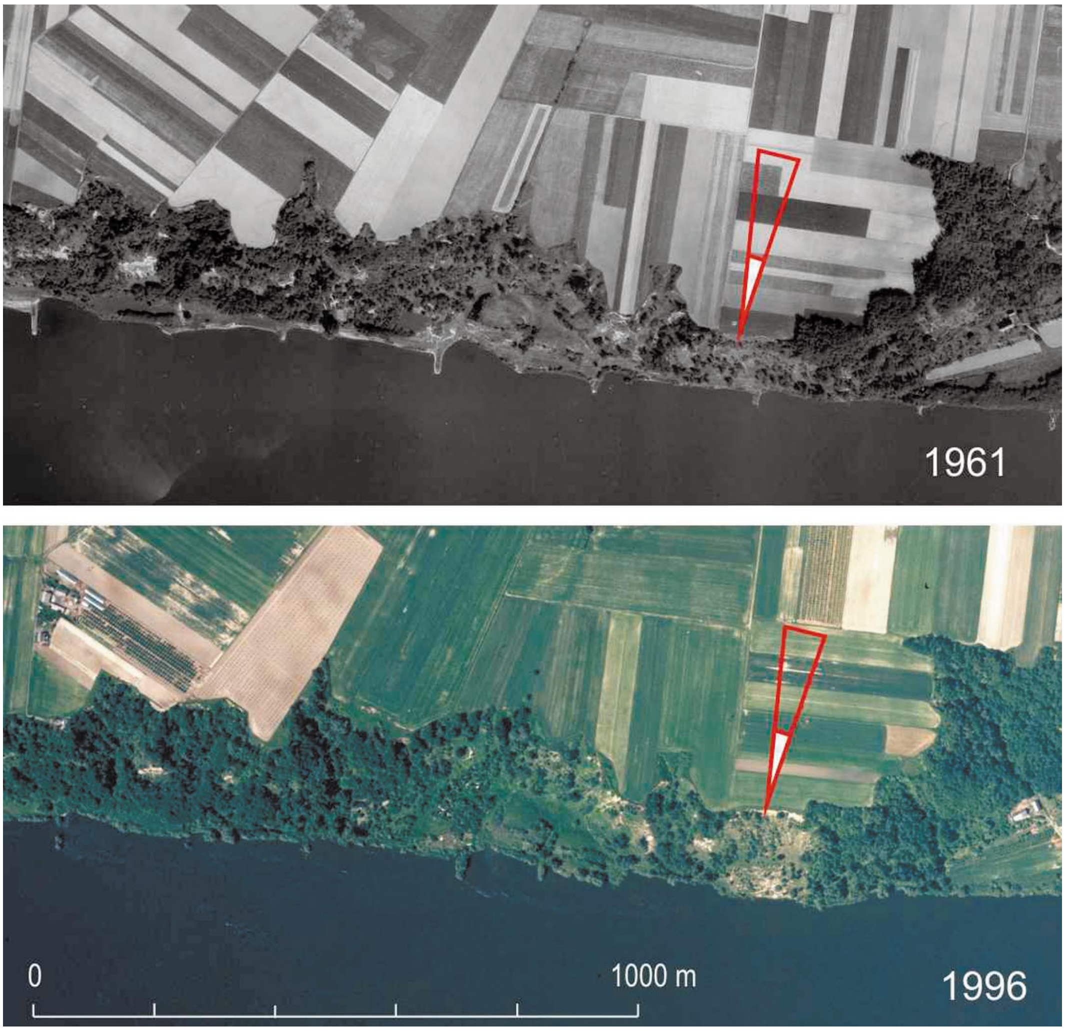


**Figure 4.** Changes on landslide slope near Wiag. In the centre old, not active landslide, current active slope marked by red arrow

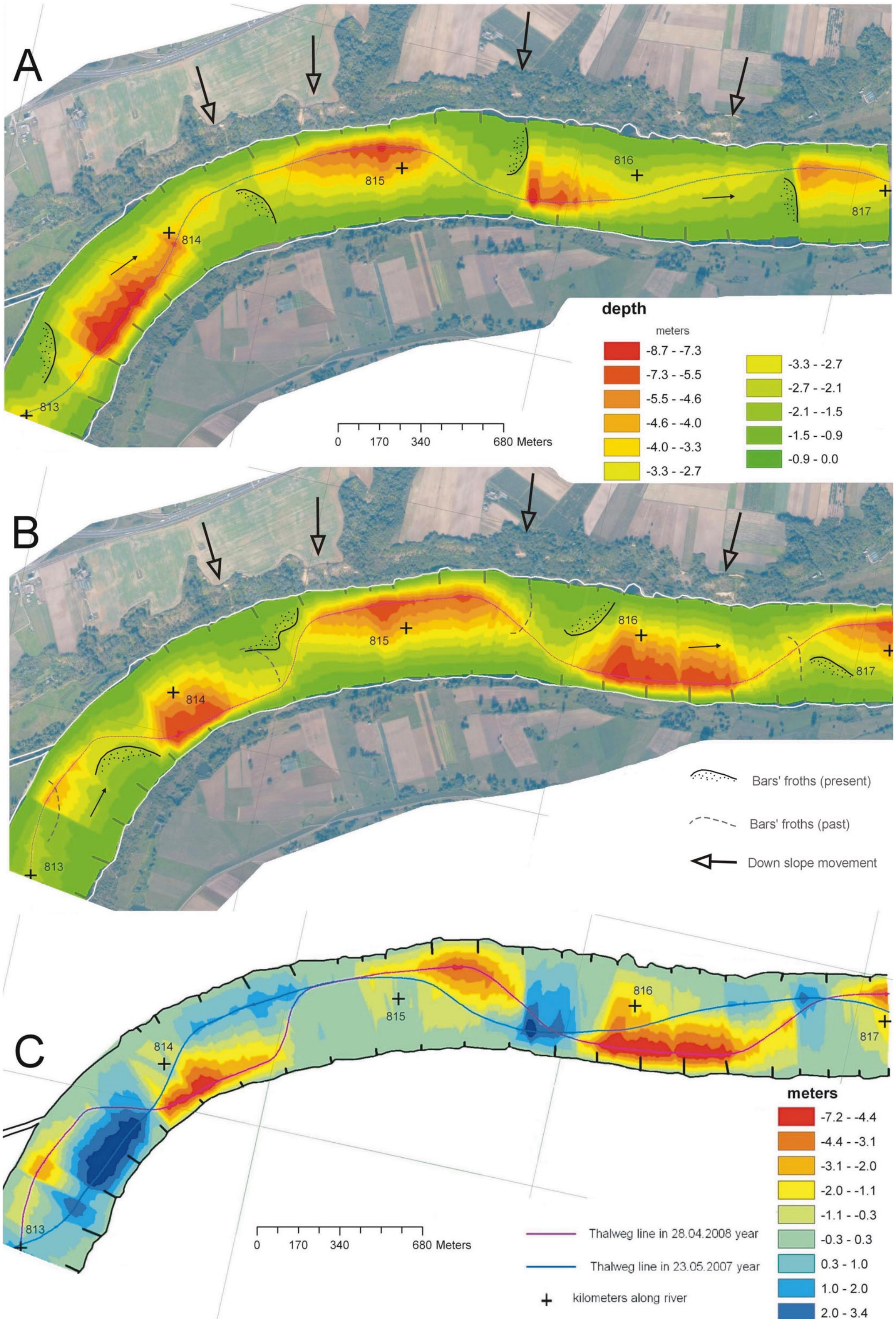


**Figure 5.** Dynamics of the changes along the channel of the Lower Vistula: A – bathymetric map based on the channel sounding taken on 23 May 2007, B – bathymetric map based on the data collected on 28 April 2008, C – digital map of the morphological dynamics of the Vistula's channel bottom