

Waterway of the Middle Vistula (Wisła) and the Bug

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ABSTRACT

In this paper was characterized the fragment of the east-west waterway from Płock to Terespol, composed of the section of the Vistula measured from 633rd kilometer (the backwater end of Włocławek Reservoir) to 520th km (Warsaw), Żerań Canal including a fragment of Zegrze Reservoir and the lower part of the Bug up to 282nd km (Terespol). Hydrological and geomorphologic conditions of both sections of the river-beds and the state of their regulation infrastructure were presented in the aspect of existing navigation conditions and causes of their limitations. It was stated that both the river-beds, i.e. of the Vistula and the Bug over their analyzed sections, have not fulfilled the requirements determined by the waterway classification standards.

Keywords : shipping, inland waterways

GENERAL CHARACTERISTICS

The waterway of the Middle Vistula and the Bug is composed of the section of the Vistula from Płock (633rd kilometer at the backwater end of Włocławek Reservoir) to Warsaw (520th km), next Żerań Canal including a fragment of Zegrze Reservoir, and further – the Bug from its estuary (0th km) up to Terespol (282nd km). From Niemirów (224th km) to Terespol the Bug is a border river.

From hydro-morphologic point of view the sections of both rivers have a lowland character. However they differ to each other by a character of the upper part of river basin. The Bug has, in its basin, many marshes and old drainage areas filled with water, whereas most tributaries of the Vistula bring water from higher located terrains of low retention – uplands and mountains. From that result the differences in flow rates and variations of water level in the stream-ways of both the rivers (Tab. 1 and 2).

Tab. 1. Characteristic flow rates calculated for the period of 1961-1983 year, acc. [Report 2006] .

No.	River	River gauge	km	Drainage area – km ²	For hydrological year of the 1961-1983 - year period [m ³ /s]					For shipping season of the 1961-1983 - year period [m ³ /s]				
					NNQ	SNQ	SSQ	SWQ	WWQ	NNQ _z	SNQ _z	SSQ _z	SWQ _z	WWQ _z
1	Bug	Włodawa	378.3	14410	8	18	63	320	750	9	23	50	125	312
2	Bug	Frankopol	163.2	31336	21	43	134	546	1410	21	53	104	258	534
3	Bug	Wyszków	34.8	39119	19	55	178	777	2400	29	67	134	353	753
4	Wisła	Warszawa	513.3	84857	102	217	619	2755	5470	169	280	574	2156	5470
5	Wisła	Kępa Polska	606.5	168957	102	340	1014	3893	6730	249	426	877	261	6730

NNQ – the smallest flow rate recorded during an observation period
 SNQ – mean flow rate calculated from the yearly lowest records during an observation period
 SSQ – mean flow rate for an observation period
 SWQ – mean flow rate calculated from the yearly highest records during an observation period
 WWQ – the largest flow rate recorded during an observation period

The above given symbols but having the index „z” stand for the respective values reduced (related) to the yearly navigation period.

Tab. 2. Water level variations acc. [IMGW 1997] .

No.	River	River gauge	Warning state (SO)	SSH state	State variation amplitude	Difference between SO and SSH	Difference between SSH and SNH
1	Bug	Włodawa	250	163	4.4	1.0	0.7
2	Bug	Frankopol	250	154	4.9	1.0	0.8
3	Bug	Wyszków	400	262	5.1	1.4	0.9
4	Wisła	Warszawa	600	243	8.0	2.8	1.0
5	Wisła	Kępa Polska	420	268	5.4	1.5	1.0

SO – the water state established by the administration, exceedance of which triggers procedures of readiness for anti-flooding protection; it generally corresponds with bank-full stage.
 SSH – mean state for an observation period
 SNH – mean state calculated from the yearly lowest records during an observation period

GEOMORPHOLOGY OF THE RIVER-BEDS

Between Dęblin and Włocławek the Vistula flows through the terrains belonging to Mazowsze Lowland. The Lowland's though is filled with Tertiary formations covered by boulder clays and glacial gravels as well as Pleistocene marginal-lake silts. The formations are highly disturbed. Alluvial formations of the today Vistula are not very thick hence on the river-bed almost non-washable strata may appear. In the work [Hydroprojekt 1982] the following regions of possible appearance of non-washable thresholds are specified : 515th km ÷ 519th km, 522nd km ÷ 523.5th km, 562nd km ÷ 567th km, 575th km ÷ 577th km, 583rd km ÷ 589th km, 595.5th km ÷ 598th km, 617th km ÷ 620.5th km, 622nd km ÷ 626.5th km. In Warsaw, in the region of the inlet to Żerań Canal the alluvial formations were completely washed out due to excessively large narrowing the high-water stream-way, dense regulation infrastructure as well as excessive sand mining for building industry purposes. At the mean-low water states paving stones protrude water level in the middle part of the stream-way.

From some research it results that over 300 years ago the Vistula river-bed down Warsaw was much more compact. Changes in developing the river basin made surface and ground retention decreasing. It led to an increased rubble flow from drainage area and starting the process of river-bed wild running which has been continued till today [Falkowski 1989, Monograph 1982]. In many places the Vistula flows around large islands on which farm buildings are located [Przewodnik 1967]. A part of the islands were cut off the main river-bed by means of embankments. The rest of farm buildings remaining within the embankments were moved outside them.

In the region of Warsaw from 501st km to 522nd km the Vistula is completely regulated on both banks. Whereas down the river up to Włocławek Reservoir the regulation infrastructure appears only in the region of bridges, as well as in order to limit bank erosion developing. It is generally one - bank strengthening or local one along short sections of both banks of the river, which often are substantially damaged.

Lack of funds for systematic overhauls, lasting 25 years, has led to devastation of bodies of longitudinal protecting groynes and almost complete destruction of most transverse repelling spurs, from which only small fragments remained. The buildings are not capable of stabilizing the main-stream position and improving navigation conditions, sometimes in reverse – their rests located in the main-stream constitute a serious hazard to shipping (Fig.1). Changes of the main stream-way position happen after every larger freshet as well as ice run-off.



Fig. 1. Remainder of regulation infrastructure in the main stream-way of the Vistula (Wisła) .

In the existing river-bed several characteristic situations can be distinguished :

1) The river-bed is divided by high islands into several side arms of similar widths

In the period of occurrence of mean and high water flow rates one of the arms is dominating. It leads not only a substantial part of water flow but also prevailing amount of traction. At water states lower than mean energy of water is too small and the traction in the dominating arm rapidly drops and complex macro-folds appear to be obstacles for flowing water. The water flow then passes into one of the side arms often developed by means of a system of wing dams or transverse repelling spurs. Such situation exists e.g. in the region of Czerwińsk and Raków. Fast destruction of these buildings may then occur and on the bed sudden upheavals and deep scours may alternately appear, especially close to remainders of foundations of such buildings. Scours due to such obstacles can be compared with those created below bridge pier protections.

The remaining arms contain many chaotically spread sand outwashes of various heights. A part of them, protruding water-level, remains motionless, and other ones still but slowly change their planar location and affect local slopes of water-level.

2) Between the islands there is a wide arm which maintains its dominating role in water flowing and rubble traction at water-level states below the mean

Then in the central part of the river-bed systematic accumulation of tracted rubble starts to occur, gradually covering larger and larger part of the width of the bed's cross-section and shifting the flowing water together with a part of the rubble material towards the banks. Along with water-level sloping larger and larger areas of low sandy islands emerge and narrow and deep beds similar to "chutes" appear close to the banks. In some cases water inflow to a "chute" occurs laterally to the bank (Fig.2).



Fig. 2. Lateral transition of the stream-way towards the river bank .

They appear near one or both banks, depending on local morphological conditions.

After passing-by the emerged sandy outwash the "chutes" gradually become wider and shallower and the stream-way comes back to the central zone of the river-bed. In such places no such sudden changes of the stream-way direction as those before the obstacle, are observed.

3) The river-bed without high islands

In the river-bed many macro-folds left by high waters and transformed during water-level sloping, occur. Two situations

can happen : the first when the central zone of the river-bed becomes shallow and the “chutes” at the banks appear, and the other when – in reverse – the zones near the banks become shallow and the deeper portions appear in the central zone of the river-bed. The bed’s morphology is generally similar to that in the situation with the dominating arm, described in 2).



Fig. 3. The edge of the macro-fold along the firm river-bed section of the Vistula (Wisła).

Compensated water-level slopes of the Vistula vary insignificantly and amount to : from Warsaw down to the inlet of the Narew (551th km) – about 0.23 ‰, and further – about 0.19 ‰.

Geomorphology of the Bug valley is associated with the Middle-Poland glaciation and its further stages. In consequence, in the region of Mielnik and Niemirów, in the zone of uplifted chains of end moraines, appeared a fissure in which the huge bed-deposited layers of cobbles and boulders constitute the erosion boundary for subterranean river. The moraine cobble roof found also in other places, deposited just under the alluvial formations, constitutes the absolute boundary for subterranean erosion. In many places the alluvial formations were washed out and the moraine cobbles can be there found uncovered in the form of stone reefs and boulders. In the work [Report 2005] the following places of the kind are specified : 43rd km ÷ 45.5th km, Brańszczyk, Nakiel, Kamieńczyk, 67th km ÷ 68th km, 103rd km, 107th km, 110th km, 133rd km, 135th km ÷ 136th km, 145th km, 151st km, and 195th km.

Evolution of many sections of the Bug valley led to creation of the elements constraining the course of the river-bed and limiting free changes of its developing. These are the sections of the so called ripe constrained river (not winding its way despite many bends and curves). An example of such form is the fragment of the valley between Drohiczyń and Nur and that in the vicinity of Wólka Nadburzańska (surroundings of Siemiatycze) where the outcroppings of almost non-washable ground, i.e. moraine cobbles and rocky morass ore, appear a constraining factor. Another factor constraining development of the Bug river-bed are the sand dunes commonly found along the whole length of the middle and lower section of the river’s valley.

Over its prevailing length the Bug shows the features of winding river. A degree of development of course of a river, including its particular bends, is conditioned by geological structure of its bed and geomorphology of the valley. From its winding character erosion of its banks result in many places. The erosion process lasts the whole year and specially intensifies in the time of spring water run-off. In such case position of the waterway may change each year as ice jamming often happen during ice drifting. The clogged water finds its outlet in

the side arm making it deeper. This way a section of relatively deep river-bed of a limited width, is formed. Water-level slopes along the considered section of the Bug change insignificantly and range from 0.21 ‰ to 0.25 ‰. Only the initial section of the Bug, about 50 km long, from the side of the State border, has much smaller slope amounting to 0.15 ‰. The next so small water-level slope appears only at the inlet to Zegrze Reservoir.

The Bug is generally non-regulated. Only its sections from 9th km to 18th km and from 25th km to 35th km have been fully regulated. The regulating infrastructure along other fragments of the river-bed is aimed at stabilizing the banks near bridges, or fulfils the role of local bank protection, especially against intensive side erosion. However most of the buildings is devastated to a large extent.

NAVIGATION CONDITIONS

In the decree of the Council of Ministers, dated 07.05.2002, the Vistula along the considered section has been classified to Class Ib, and the Bug – to Class Ia.

Dimensions of the waterway of Class Ib should be equal at least to :

- ◆ 20 m – width measured at the bottom of fully loaded floating object
- ◆ 1.6 m – transit water depth
- ◆ 200 m – radius of waterway bend axis.

The maximum main dimensions of floating objects amount to :

- ◆ length – 41 m
- ◆ breadth – 4.7 m
- ◆ draught – 1.4 m.

The data for the Vistula between Warszawa and Toruń, published in the 1950s [Tablice 1958] showed the transit water depths of 90 cm at the mean – low state lasting – together with the higher states - for about 80% of the navigation period, and of 110 cm at the mean state lasting – together with the higher states – for about 50 % of that period.

The data published in 1968 [Studia i materiały RNET 1968] showed the transit water depth of 1.0 m at the mean – low state for the Vistula between Warszawa and Toruń. In its stream-way appeared shoals of almost steady location, which required to be dredged. Between Czerwińsk (578th km) and Płock (631st km) nine shoals including the two decreasing water depth to 75 cm, were then found.

The partial regulating works carried out beneath the Narew outlet in the places difficult for navigation, made it possible to reach the water depth of 1 m at the mean-low state.

Bathometric measurements performed in 2004 revealed only three places of the water depth of 40 cm, a dozen or so meters long. Sections of 55 cm water depth were often found, their length did not however exceed 100 m. The shoal patches constituted fragments of the macro-folds on the surface of which intensive folding movement of traction material occurred despite a low water state. Surface of such bed is mild hence not leading to any failure to ship hull or its propelling devices. However it may be impossible for a ship of 1.4 m draught to pass over such long shoal patch, without any appropriate water depth margin at the yearly mean water state.

In Rakowo (596th km) the main river-bed in the period of low water states is not navigable. In 2005 in the period of water depths lower by about 15 – 20 cm than that yearly mean the smallest depth amounted to 45 cm. To sail this section over is

possible only through the right-hand arm of the river, crossing over the damaged wing dams. The increased velocity of water in that river arm is an additional difficulty for navigation. The measured surface velocity amounted to over 1 m/s. The so distinct worsening of navigation conditions as compared with the state from before a few dozen of years, results from a large degree of devastation of regulation infrastructure. Along the considered section of the Vistula no problems resulting from the magnitude of bend radius and waterway width can be expected.

In the present state of the Vistula river-bed it is hard to determine a radius of the waterway.

From approximate estimations it can be assumed not smaller than 500 m.

Żerań Canal which connects the Vistula with Zegrze Reservoir, is 17.3 km long. Its depth amounts to 3.0 m at the normal backwater level in Zegrze Reservoir. Usual variations of water-level in the reservoir are equal to 0.5 m, its depth then drops to 2.5 m. The Canal is 25 m wide at the bottom. From the side of the Vistula it is closed by a sluice of the dimensions : 85 m length of the lock, 12 m serviceable width, and 3.0 m water depth at the upper threshold. The depth at the lower threshold of the sluice depends on water state in the Vistula [Materiały 2001].

Minimum dimensions of the waterway of the Class Ia to which the Bug belongs, were determined as follows :

- its width measured at the bottom of fully loaded floating object – 15 m;
- its transit water depth – 1.2 m;
- bend axis radius of waterway– 100 m.

The maximum main dimensions of floating objects amount to :

- length – 24 m
- breadth – 3.5 m
- draught – 1.0 m.

The data published in the 1950s [Tablice 1958] and in 1968 [Studia i materiały RNET 1968] showed the transit water depths in the range from 0.8 m to 1.0 m at the yearly mean water state. The measurements performed in 2005 at the water level state higher by about 40 cm than the yearly mean, showed, after correction, the decrease of the transit water depth to 0.5m – 0.6 m. Results of the investigations performed ten days later at the water states higher by only about 15 cm than the yearly mean, confirmed the above presented results. The most difficult place for sailing is the section of the river-bed in the vicinity of Granne (144th km ÷ 145th km) in the place of the change (break) of the overall longitudinal rate of descent of the river on the outcropping of the almost non-washable grounds, located there.

The equalizing process of the river-bed during water state dropping, probably would improve water depth conditions, however a decrease of transit depth is obvious.

An important limitation for navigation on the Bug are curvature radiuses of the waterway. Taking into account the river bank curvatures one can expect the smallest radiuses to have about 100 m. On the bends of large curvatures the waterway width can be decreased – due to flow concentration – even to 15 ÷ 20 m (Fig.4). And, relatively favourable navigation conditions are observed along eroded banks. The stream –way is shifted towards the concave bank and only fallen-down trees can constitute an obstacle. In many cases the minimum width of the Bug waterway and its minimum radius can amount to a somewhat smaller values that those required by the rules.

Floating objects should then reduce its speed.



Fig. 4. A typical course of the Bug river- bed .

A decisive limitation of navigation on the Bug waterway is its transit depth which – even at the yearly mean flow rate – is smaller than that required by the rules for Class Ia. Because of many stony reefs, traffic of ships at the minimum water depth margins under the bottom equal to 20 cm, can be very dangerous.

Though in the information materials [Informator 1961] the highest navigable water-level is given higher than the warning state, these authors have assumed that navigation will be continued only at the water-level contained within the river banks. Number of islands located in the main river-bed both of the Vistula and the Bug makes navigation at the higher water states more hazardous (Fig.5).



Fig. 5. Mark signing the cape of the island on the Bug waterway .

SUMMARY AND CONCLUSIONS

- After over 50- year break in using the river-beds for shipping purposes, both the Vistula (Wisła) and the Bug lost their former, not very high values of waterway parameters as a result of devastation of their then regulation infrastructure, and uncontrolled processes of river-bed forming
- Many deposits of stones in the form of natural reefs on the beds of both the rivers and damaged regulation buildings constitute a significant obstacle and hazard to navigation
- A more detail marking of both the Vistula and the Bug waterways is necessary in the case of intensive – or at least regular – ship traffic on the considered waterways.

BIBLIOGRAPHY

1. *Report on the realization of the successive stage of INCOWATRANS project* (in Polish). Institute of Environment Engineering Systems, Warsaw University of Technology. Warsaw, 2006
2. *Report on the realization of the successive stage of INCOWATRANS project* (in Polish). Institute of Environment Engineering Systems, Warsaw University of Technology. Warsaw, 2005
3. *Information materials of Regional Water Management Board in Warsaw* (in Polish), Warsaw 2001
4. IMGW : *Characteristic water-level states* (in Polish). Warsaw, 1997
5. Falkowski Z.: *Engineering and geological problems of anthropo-genetic transformations of geological environment* (in Polish). Proceedings of the Conference on Engineering and geological problems of human environment. Faculty of Geology, Warsaw University. Warsaw, 1989
6. *Monograph of the river. The VISTULA* (Collective work in Polish). Transport and Communication Publishing House. Warsaw, 1982
7. *Geological and touring guide. Down the Vistula* (Collective work in Polish) Geological Publishing House. Warsaw, 1967
8. CBS I PBW ? *Hydroprojekt : Protection against flooding of the Vistula Valley along the section from Warsaw to the backwater end of Włocławek Reservoir* (in Polish). Warsaw, 1982
9. RNET ? *studies and materials: Problems of activation of water transport and passenger shipping in the Warsaw Province* (in Polish). Warsaw, 1968
10. *Guidebook of navigable inland waterways* (in Polish). Transport and Communication Publishing House. Warsaw, 1961
11. *Engineering tables, 5th vol., Hydro-engineering* (in Polish). State Scientific Publishing House. Poznań, 1958

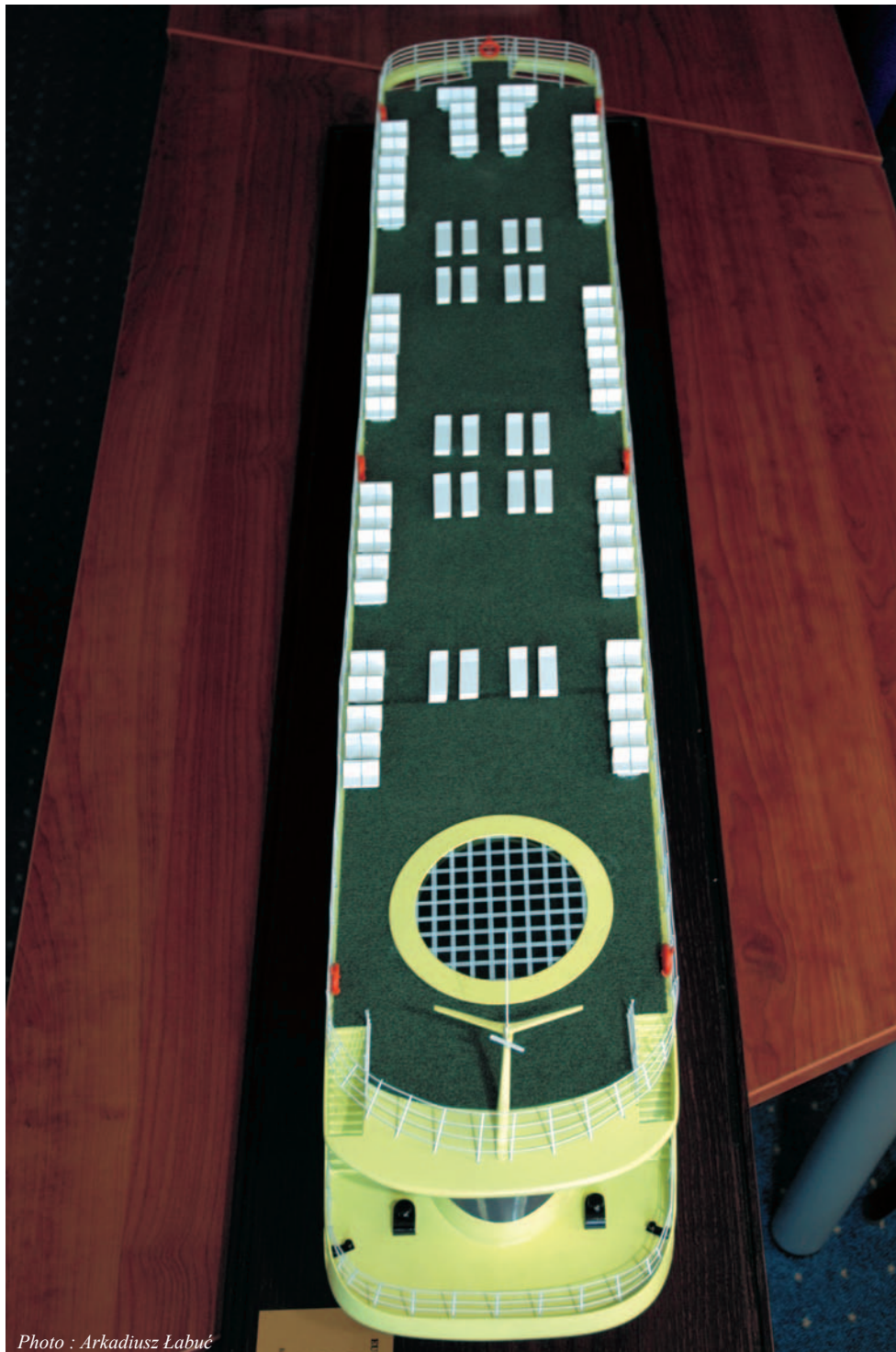


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