ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1217183

THE INFLUENCE OF REGULAR RIVER NAVIGATION IN SPECIAL PROTECTION AREAS OF NATURA 2000 NETWORK

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Abstract

The development of inland shipping with respect to the EC guidelines should support sustainable transport system and its evolution to less energy consuming ecological and safer forms. The waterborne inland transport in Poland has the biggest reserves and its development is best placed in the frames of EU sustainable development policy. The technical state of the national waterborne inland transport in Poland is poor. This is the result of many years negligence in its modernization. Most of inland vessels in Poland were built before 1970 and their parameters do not comply with the present requirements for the power-propulsion systems effectiveness and influence on environment. The implementation of ecological solutions in river vessels design makes possible the passenger and goods transport services expanding to the waterways inaccessible for traditional transport means like Special Protection Areas of Natura 2000 network. The new designs of innovative river vessels should allow for the reduction of environment disturbances and can have a positive impact on the environment. The paper presents the main problems related to the revitalising the river transport in Poland, the potential negative influence of inland waterways on habitats and species under special EU protection, the influence of the regular navigation on the river environment and innovative solutions in waterborne inland transport.

Keywords: *waterborne inland transport, environmental protection*

1. Introduction

Transport Development Strategy until 2020, with the prospect of 2030, adopted by the Council of Ministers on 22 January 2013, included two stages of Polish inland waterways modernization. The 2020 stage included preparation and implementation of the multiannual program of restoration of operating parameters of inland waterways [9]:

– development of the lower Vistula River, urgent due to the safety of the Wloclawek barrage,
– continuation of the multiannual program for the restoration of the operating parameters on inland waterways serving transport functions,
– adaptation of inland waterway connection Odra River – Vistula River – Vistula Lagoon (E-70) to the Class II navigability requirements.

Recently the four priorities were formulated by Polish Government included in the Assumptions for the plans of inland waterways development in Poland in the years 2016-2020 with the 2030 perspective [15]:

– development and implementation of E-30 waterway into the international waterways network,
– improvement of navigational conditions on Vistula river,
– preparation for the modernisation of E-40 and E-70, implementation of RIS, development of national partnership, national and international collaboration.

Natura 2000 special environment protection areas are placed along 13 most important rivers of European lowland covering their significant percentage (Tab. 1).

The classification of an area as a part of Natura 2000 network means that the new projects within this area have to be in line with the guidelines on the implementation of birds and habitats directives in estuaries and coastal zones [13]. The environment impact assessment should be included in planning documentation of all new projects related to transport and water management and should take account of the following conditions included in Article 34 of the Act of Environment Protection:

- the action is of a master public interest,
- there is a lack of alternative solutions,
- a compensation has been provided.

Tab. 1. Natura 2000 areas placed along 13 most important rivers of European lowland with the percentage of their parts belonging to Natura 2000 network (on the basis of the total river length measured from the source of the river including not navigable parts [13]

River	No. of Natura 2000 areas	Total area of Natura 2000 [km^2]	Total length [km]	Length of areas within Natura 2000 network [km]	Length of areas within Natura 2000 network as a percent of total length [%]
Danube	230	5033.99	2770.38	1234.08	44.55
Elbe	174	1708.89	1087.29	681.07	62.64
Ems	33	361.72	345.06	213.30	61.52
Men	100	202.04	473.15	65.70	13.89
Meuse	83	704.31	731.18	192.62	26.34
Moselle	37	230.38	429.08	54.97	12.81
Odra	71	1627.69	823.75	605.13	73.46
Rhine	199	1423.09	1159.96	448.62	38.68
Rhone	52	591.89	910.62	233.40	25.63
Scheldt	17	150.31	268.05	57.24	21.35
Seine	31	490.89	673.65	121.03	17.97
Vistula	53	990.10	895.68	276.41	30.86
Weser	66	351.19	444.09	98.59	21.75

Lower Vistula is an example of the inland waterway included in the Natura 2000 network of an untapped transport potential. According to the resolution on the adoption of the Assumptions for the plans of inland waterways development in Poland in the years 2016-2020 with the 2030 perspective [15] Vistula River in part Warsaw-Gdansk will become the international waterway until 2030. After first stage of the modernisation, the prognosis for the transport of goods is on the level of 7.8-12 million tons/year [11]. The fast growth of the handling capacity of the container terminals in Port of Gdansk and Port of Gdynia can speed up this process. This will be followed by the necessity for development of a new fleet of innovative ecological river vessels and barges. The innovative shipbuilding technologies for waterborne inland transport and coastal shipping as an example dedicated for Lower Vistula are planned to be realized within a horizontal project of Pomorskie Smart Specialisation Strategy [14].

2. Environmental impact of inland shipping

There are three international waterways in Poland (Fig. 1):

- E30 is linking the Baltic Sea with Danube in Bratislava, including Odra River from Swinoujscie to the border with Czech Republic,
- E40 is linking the Baltic Sea in Gdansk with Dnieper in Chernobyl region and further via Kiev and Kherson with the Black Sea, including in Poland Vistula River from Gdansk to Warsaw, Narew River and Bug River to Brest,
- E70 is linking the Netherlands with Russia and Lithuania, including in Poland Odra River from the estuary of Odra-Havel canal to the estuary of Warta River in Kostrzyn, waterway Vistula – Odra to Bydgoszcz, Lower Vistula to Gdansk and Szkarpawa River via Vistula Lagoon to Konigsberg in Russia.

Fig. 1. International waterways in Poland [1]

The share of inland shipping in the total transport work of goods in 2010 was only 0.3%. The navigational conditions in E70 i E40 waterways are not sufficient for regular shipping.

Vistula River due to the fragmented facilities has the best operational parameters in the canalized upper part from Przemsza mouth to Przewoz barrage, in the lower part from Plock to Wloclawek barrage and from Tczew to the Gulf of Gdansk [13].

The ecological costs of inland shipping are incurred in development phase of streamlining the river and futher in the fase of operation. The costs are related to the environmental effects on the water, soil, air or direct effects on nature and human being [1, 3]. These additional costs are usually not included in economic analyses, because of difficulties in their estimation.

2.1. The potential negative influence of inland waterways on habitats and species under special EU protection

The main problems, which should be considered in the analyses of individual projects on waterways management, are the technical river training and ships traffic. The technical river training consisted in cutting off meanders and straightening river channel can result in flow acceleration, changes of the natural riverbed equilibrium, riverbed and bank erosion. The increased ships movement can be the reason of hydrodynamic alterations and temporal or constant turbidity increase, sediments resuspension and toxic engine emissions. Ship generated waves and drawdown, return currents and currents induced by propeller jets can be the reason of riverbed and bank erosion, uprooting plants, disturbing the benthic fauna and flora and spawning area for fish. The acceleration of morphologic process can influence lowering the water quality and makes more difficult water treatment to a desired drinking quality. Therefore, the maintenance and development of inland waterways has to combine both the navigational and ecological demands [12].

2.2. Influence of the regular navigation on the river environment

The main factors determining the interference of river navigation with nature, dependent on the vessel design and operational characteristics are as follows:

– ship hull characteristics – ship main particulars and hull form,
– ship propulsion characteristics – type and powering, propeller jets characteristics,

– ship velocity relative to water velocity and water depth to ship draft ratio, river profile – depth Froude number.

Depending on the river profile, the water flows generated by a ship have different transport patterns. Water depth is the main factor determining the critical speed in the areas unrestricted in horizontal plane. The depth Froude number determines whether a ship navigates in shallow, transitional or deep water, affecting the amplitude and period of the generated waves, drawdown and ship squat. The influence of ship movement on the riverbed scouring may be neglected at water depth to draft ratios above 2. The limiting values of scouring velocities in dependence of bed material are from 0.1 m/s for fine sand to 4 m/s for boulders (0.7 m grain size). The critical speed 4 m/s corresponds to 1.7 m water depth and about 2.2 m/s (8 km/h) achievable under critical ship speed. The over bed velocities can reach 160-180% of ship speed equal to 2.44 m/s to 4 m/s, exceeding the scouring limits [7]. In practice, the limiting ship speeds in shallow waterways are determined by ship squat and ship resistance to motion ratios.

Much greater influence on the waterway has propeller jet streams and ship-generated waves. The deteriorating effect of propeller jets is bigger under higher propeller loads during ship manoeuvring. The prediction and modelling of the real scour should be based on the period during which a specific section of the bed is affected by jets and specific ship characteristics.

Ship waves generate increased shear stress acting on the riverbed and banks. The amplitude of the waves depends mainly on the vessel velocity. The small fast recreational crafts produce higher waves with shorter wave periods than the slow large ships and barges. The drawdown can produce a hydraulic impact endangering the slope stability of the bank and can lead to induced flows in side channels and backwaters [3]. The generated waves can break upon the bank when the wave trough is following the drawdown exceeding the still water level prior to ship passage.

Several approaches were proposed to determine shear stress on the riverbed based on the observed wave systems and drawdown parameters. The empirical formulae developed on the basis of observations in particular examined areas cannot be used in all cases. Formula (1) recommended by PIANC [9] was developed in 1969 for the confined channels is based on vessel velocity and blockage factor A_c/A_m. In the modified formula (2) the additional parameter – the ship length was used. Similar formula (3) modified for the Upper Mississippi River conditions, presented in [8], was developed on the basis of the multi-variate regression analysis.

$$H_{\max} = 0.3806 \frac{v^2}{g} \left[1 - \left(1 - \left(4.2 + \frac{A_c}{A_m} \right)^{-0.5} \right) \left(1 - \frac{A_m}{A_c} \right)^2 \right], \tag{1}$$

$$H_{\max} = 0.0412 \frac{v^2}{g} \left(\frac{T}{L} \right)^{0.5} \left(1 - \frac{A_m}{A_c} \right)^{-2.5}, \tag{2}$$

$$H_{\max} = 0.1324 \frac{v^2}{g} \left(\frac{T}{L} \right)^{0.26} \left(1 - \frac{A_m}{A_c} \right)^{-3}, \tag{3}$$

where:

$H_{\max}$ – wave height [m],
v – vessel velocity [m/s],
g – gravitational acceleration [m/s^2],
A_c – cross-sectional area of the channel [m^2],
$A_m = BT$ – submerged cross-sectional area of the vessel [m^2], B – beam [m], T – draft [m].

Kriebel and Seelig [6] derived a general formula to determine $H_{\max}$ (4) using a dimensionless hull form coefficient β (5) and modified Froude number F_m (6) dependent on ship length, length Froude number and ship draft to water depth ratio.

$$H_{\max} = 0.102 \cdot v^2 \beta (F_m - 0.1)^2 \left(\frac{y}{L} \right)^{-0.3}, \tag{4}$$

where:
β – dimensionless coefficient dependent on ship entrance length L_e [m], defined as the distance between the ship bow and point of maximum hull width,

$$\beta = 1 + 8 \cdot \tanh^3 \left[0.45 \left(\frac{L}{L_e} - 2 \right) \right], \tag{5}$$

$$F_m = F_n \exp\left(\alpha \cdot \frac{T}{h} \right), \quad 0.1 \le F_m \le 0.5, \tag{6}$$

where:
F_n – length based Froude number,
α – dimensionless hull shape coefficient based on ship block coefficient,

$$\alpha = 2.5(1 - c_B), \tag{7}$$

where:
c_B – ship block coefficient.

The field investigations on Göta River in Sweden allowed for the formulation of equation (8). The equation was developed on the basis of 13 passages of ships traveling in the upstream direction. The coefficients of correlation and determination were 0.84 and 0.70 respectively [2].

$$H_{\max} = 0.051 \cdot v^2 \left(0.09893 - 08796 \frac{Q}{v\,L\,B} - 03968 \frac{h}{T} + 1.246 F_n \right), \tag{8}$$

where:
Q – river flow rate [m^3/s].

3. Introduction of innovative solutions in waterborne inland transport

3.1. Policy for the introduction of innovative solutions in waterborne inland transport

The SWOT analysis for transport in Poland presented in [9] allows recognising the strengths and weaknesses faced with respect to the inland waterborne transport infrastructure:

The main strengths are as follows:
- the resource and potential of existed network of ports and transport nodes is relatively big,
- the layout of the system of inland waterways creates favourable conditions for development of waterborne transport.

The main weakness is the limited use of inland waterborne transport because of insufficient river training and adapting waterways to navigation. The directions of innovative technological development and interventions are included in Article 7.3 of the guidelines related to Trans-European Transport Network (TEN-T) [8]:
- striving to create favourable conditions for the transfer of shipping from roads to rail, especially on the distances over 300 km,
- promotion of the ecological means of transport powered by the alternative clean energy sources, resulting with the reduction of air pollution,
- introduction of a new generation of inland vessels, including the energy efficient inland containerships with the low carbon dioxide footprint.

Promoting the energy efficiency includes development of intermodal transport of goods and energy-efficient means of transport, and decrease of the dependence on fuels based on nonrenewable energy sources. Article 8 of the Trans-European Transport Network (TEN-T) guidelines recommends that the evaluation the environment impact of the project should be based on appropriate ratings related to the Birds and Habitats Directives [13].

3.2. Environment friendly design of waterborne inland transport means

The innovative solutions of transport means for Polish waterways are closely related to the ecological conditioning including the influence on the induced dynamic flows – return currents, drawdown, waves, wake wash and propulsion initiated water jets of high velocity [4].

The new concept of INBAT (Odra) push train developed within the frames of a collaborative research project INBAT (Innovative Barge Trains for Effective Transport on Shallow Waters) leaded by Wroclaw University of Technology [1] included pusher boat and barge adapted for operation in shallow inland waterways with variable navigational conditions of Odra and Elba rivers. The concept of pusher boat included triple screw propulsion, which enables the push train operation in the ranges 0.6 m to 1.2 m draft. The computer program for the optimisation of operational parameters of propulsion system, detailed analysis of the influence of push train movement on the waterway and numerical method for prediction of propulsion prognosis have been developed. The main particulars of the proposed universal barge are presented in Tab. 2.

Tab. 2. Main particulars of the proposed universal barge INBAT (Odra)

Parameter	Value
Length L [m]	48.75
Breadth B [m]	9
Draft T [m]	1.7
Height H [m]	2.2

The capacity of the barge is 21 TEU in 1 layer, the minimum permissible draft is 0.6 m however the operation of the push train can be profitable at drafts greater than $T = 0.8$ m.

The studies on the minimised resistance and influence on the waterway, included drawdown, return current forming, design and optimisation of a bow shape of the inland cargo vessel using CFD methods and towing tank tests [1]. The use of vessels with a slender bow, long entrance length is recommended to reduce ship generated waves height [4].

The research problems selected in the area of waterborne inland transport in the Lower Vistula region are mainly related to the difficulties in transport of outsize goods and export of containers via A1 motorway and railway from Port of Gdansk (6000 containers per day). The expertise carried out within European project INVAPO confirmed the possibilities of waterborne transport of containers on the route Gdansk-Tczew-Solec Kujawski [1, 3]. The transport of containers on barges in 3 layers independent on their mass is possible *n* relation Gdansk – Tczew, transport of two container layers is possible in relation to Solec Kujawski, transport of three layers is dependent on the mass of containers and high navigational water [1, 3]. The parameters of the presently operated barges originally designed for Odra Waterway are not adapted to the navigational conditions of the Lower Vistula waterway mainly due to the small beam.

Transport of containers in the Gulf of Gdansk, mainly the export of the empty containers from DCT (Deepwater Container Terminal) to the depot in Gdynia can solve the bottleneck problems in ports. It is related now to the development of a new generation of coastal barges and appropriate classification rules.

An example of a design for the minimised environment impact is a concept of the small waterplane area twin hull coastal vessel, developed at Gdynia Maritime University, presented in Fig. 2, which can be implemented to reduce side erosion by ship-generated waves.

An innovative method to reduce the hull resistance, not used so far for the river vessels, is the implementation of Air Lubrication System, which produces air bubbles on the surface of ship bottom. The air bubble distribution across the hull surface can reduce the frictional resistance, significant savings of fuel and up to 10-15% reduction of CO_2 emissions.

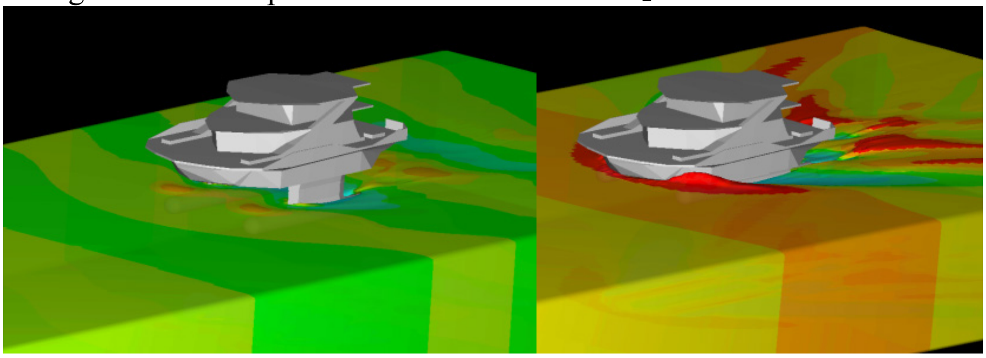

Fig. 2. Concept of the small waterplane area twin hull coastal vessel, developed at Gdynia Maritime University

The small propeller induced currents, not close to the riverbed as in case of screw propeller is produced by wheel drive and ball drive systems [4].

4. Conclusion

All the factors influencing environment impact of waterways in special protection areas should be considered using systemic approach [4] including the natural river processes, which can increase or decrease the influence of ship traffic. The natural rubble transportation in rivers can cause more significant changes than the ship motion. A very important issue is now the untapped transport potential of Lower Vistula. Much better exploitation of the navigational conditions of river parts placed in Natura 2000 network can be obtained by the introduction of a new generation of river vessels, barges, push trains, traffic management systems and automatic vessel operation improving energy efficiency [4]. The regular movement of the innovative river vessels can decrease the amount of required maintenance works, especially dredging and winter ice breaking necessary for flood protection.

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