Monitoring and visualization of nautical properties of inland waterways in Poland

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ABSTRACT

Monitoring of nautical properties of inland waterway covers recording, visualization and short-term prediction of their state. This paper describes the way of integration different data from many sources and simplified freshet wave propagation model on inland waterways in Poland. Computer programs developed for this task are shown as well.

Keywords : inland waterways in Poland, monitoring of nautical properties, visualization of nautical properties

INTRODUCTION

INOCOWATRANS project is dedicated to preparation of Polish inland water shipping system, as a part of international (Europe-Russia) transportation and tourism infrastructure. It contains 2 main parts. The first one is dedicated to inland fleet development, production and operation, the second one is dedicated to management of waterways infrastructure. For help in management of problems related to both of them a GIS database is developed. One of its task is delivery of current information about conditions of navigation on inland waterways in Poland, especially determined by waters state. Navigation targeted monitoring differs from usually performer one for environment or flooding protection. Basic difference covers range of water states. Low and high water caused by drought or flood exclude navigation, so only middle states are considered and existing models of flood and freshet wave are not applicable. Navigation requirements cover also short-term water state prediction for inland ships load management. This papers covers subjects as follows:

- data description
- inland navigation requirements
- water state prediction method.

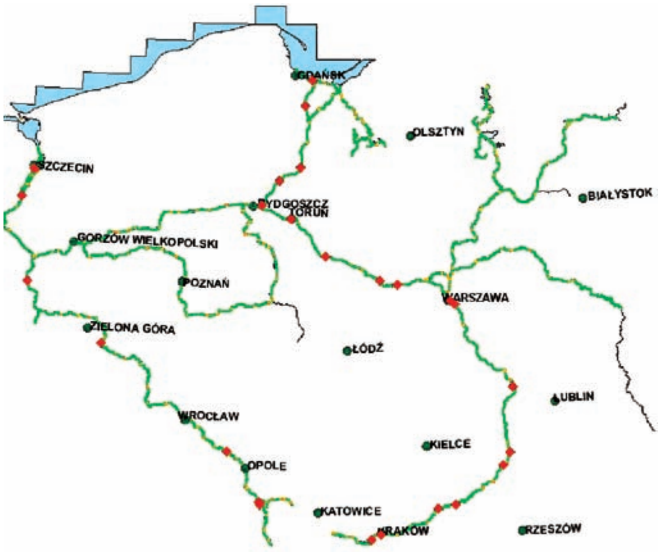
DATA

Hydrological monitoring for inland navigation requires integration and processing of data from different sources. They cover dynamically changing water state as well as relatively stable channel form (it is a simplifying assumption, channel changes are much slower than water state ones and their monitoring is a separate research problem which is not subject of this paper).

Waters state

Inland waters state in Poland is monitored by many institutions, but only Institute of Meteorology and Water Management (IMGW) provides permanent and free access to their current data, published daily in "Water State Bulletin" under Internet address: http://www.imgw.pl/wl/internet/zz/rzeki/biul_hyd_codz.html. Although set of water gauges is relatively small (only 51 gauges on Vistula River and 32 on Odra River), in connection with model of water state dynamics is good enough for navigation related tasks. Location of IMGW water gauges shows picture 1.

Picture 1. *Set of IMGW water gauges.*



Picture 2. *Set of IMGW water gauges on inland waterways.*

For data import from IMGW home page simple application is developed. It writes data to MS Access database file *wodowskaz.mdb* which is connected to GeoMedia workspace. The database contains data from lat 5 days. The application is developed with Visual Basic for Application embedded in all applications of MS Office package, including MS Access. It is executed from MS Access level but it is planned to be built as dll run from GeoMedia level.

Model of object „Wodowskaz" (water gauge) contains a set of attributes where the most important for data updating are:

- ✩ SWW – middle navigable water; the average gauge indication [cm]
- ✩ GLEB – depth; current gauge indication [cm]
- ✩ DSWW – difference between SWW and GLEB [cm]
- ✩ KM – kilometrage; location of gauge on the waterway length.

Two first attributes are used for DSWW computation for water gauges and DSWW with KM is used for linear interpolation of DSWW for waterways segments between gauges.

Bathymetry

Structure of data model for INCOWATRANS project takes into consideration many rules and guides set by formal requirements of Polish and European law regulations as well as structure of exiting data used in the project. The most important rules are:

- ❖ Each water-course is divided into segments with constant properties. Additional splitting points are necessary in node location even if the segment does not change its properties. In used database (Hydrologic Map of Poland - MPHP, scale 1:50 000) length of segments varies from 20 m to 30 km.
- ❖ Data gathered in INCOWATRANS project will be used for updating and correcting of existing source databases. For providing of easy back-integration our data with source bases we do not modify definitions of attributes of existing classes. For nautical tasks not covered by source bases we define new classes (or new attributes of existing classes if they do not accomplish law regulation, even if it makes data redundant).

The layer containing bathymetry data is titled "rzeki_o" and inherited from MPHP. It was primarily not designed for bathymetry description so we extended its definition by set of attributes:

- ✶ SWW – average navigable water. This attribute describes course of channel bottom. Currently we use highly incomplete data. Their acquisition is a separate research problem due to few reasons:
  - Coherent program of inland waterways bathymetry monitoring does not exist in Poland. Some measurements are preformed in chosen locations – mainly for flooding and natural environment protection targeted analysis.
  - Channels shape is dynamically changing. In extreme cases data should be updated even every week. Measurements mentioned above are performed occasionally and we can not trust them.
    Due to reasons mentioned above for software testing we have used data from inland sailing directions, which are not current. In many cases these data are estimated on the basis of formal minimal requirements for navigation. The true value of waterway depth and width is usually higher. Permanent monitoring and acquisition of bathymetry data (with usage of satellite picture for example) is a separate research problem and is not the subject of this paper.
- ✶ KM – kilometrage; location of segment midpoint on the waterway length. According to formal rules for waterways kilometrage starts at the beginning of the highest located segment and is counted downstream. For other rivers kilometrage starts at outlet and is counted upstream.
- ✶ DSWW – the current aberration form SWW [cm] computed as follows:
  - DSWW is determined for 2 closest water gauge (one upstream and one downstream).
  - Value of DSWW is linearly interpolated between water gauges.
  - Interpolated DSWW value for segment midpoint is set for the entire segment.

$$DSWWs = DWW2 - \{(DWW2 - DWW1) * \\ * (KM2 - KMs) / (KM2 - KM1)$$

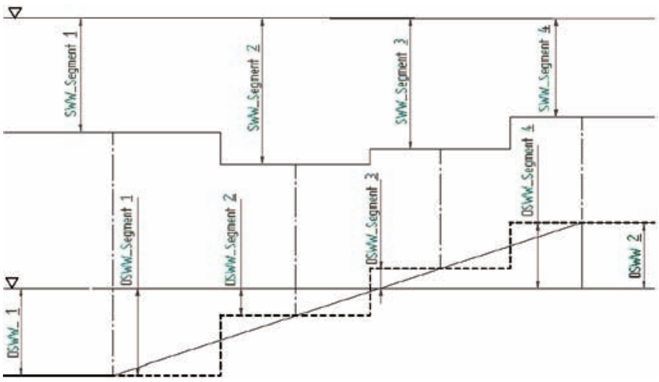
or

$$DSWWs = DWW1 + \{(DWW2 - DWW1) * \\ * (KMs - KM1) / (KM2 - KM1)\}$$

where:

DSWWs	– segment DSWW,
KMs	– kilometrage for segment midpoint,
DWW1; DWW2	– DSWW for 2 neighbor water gauges,
KM1; KM2	– kilometrage for 2 neighbor water gauges.

For segment laying out of range between first and last water gauge DSWW from the closest one is set.



Picture 3. *Graphical illustration for DSWWs computing algorithm.*

- ✶ GLEB current depth of segment [cm]; GLEB = SWW + + DSWW

NAVIGABILITY REQUIREMENTS

Requirements for navigation related water state analysis and visualization differ from the ones usually set by flooding or environment protection problems. The most significant differences are:

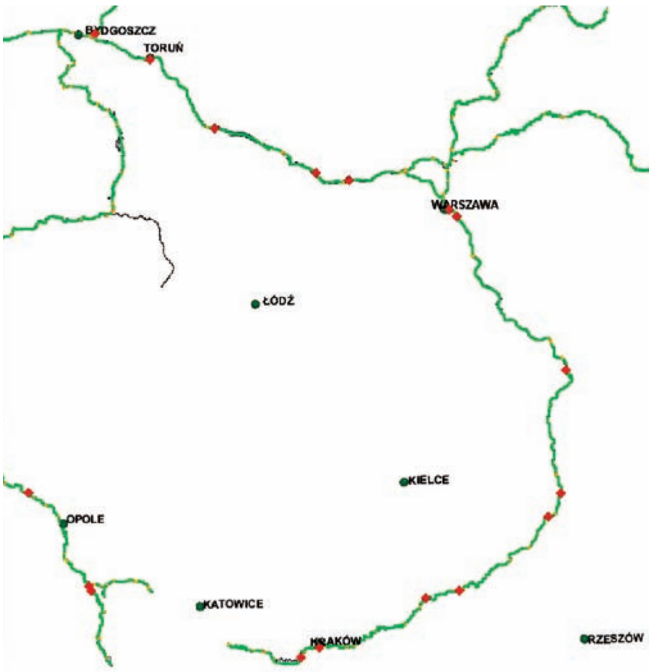
- ➢ Geographical range of analysis. The condition of waterway navigability is patency of its bottlenecks. So we are neither interested in general situation nor in the state of side streams, rather in parameters of the chosen segments.
- ➢ Very high and very low water states make waterway unnavigable so we are interested in middle states. The part

of navigability analysis is a short term prediction. Existing models of flood water propagation have limited applicability for middle states so we need new model of waters state changes propagation for middle and low states.

- The scope of analysis – we are not limited to waters state only but we have to take under consideration also:
  - Land neighborhood - navigability can be also limited through land objects. For example very important parameter is the height of bridges (pipes, cables) crossing over waterways, limiting the height of ship/cargo in conjunction with waters state.
  - Network analysis – it is also a part of transportation analysis. It can be a first stage for determining of waterways segment for next waters state analysis or in more complex case it can be an inner part of navigability analysis, driving to determining alternative trace in case of inpatent bottlenecks. Another example can be determining of mixed water/land trace with detours of bottlenecks.

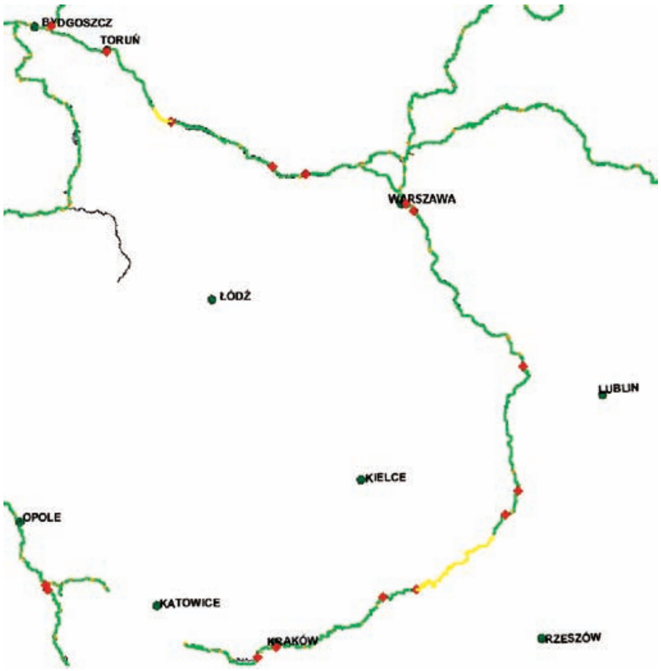
Realization of these requirements is usually possible through standard functionalities of GIS systems although few of them need extended functions available through own developed applications. In our case we have built few exemplary queries in GeoMedia 6 environment:

- Results of simple navigability analysis are shown at the pictures below. Analysis was performed for high and middle sector of Vistula River for ship with set draught (3 m) when water state changes from high (Picture 4) through middle (Picture 5) to low-middle (Picture 6). Green lines marks safely navigable segments (depth of segment > ship draught), yellow lines – navigation alert (depth is close to ship draught) and red ones – segments unnavigable (depth < draught).

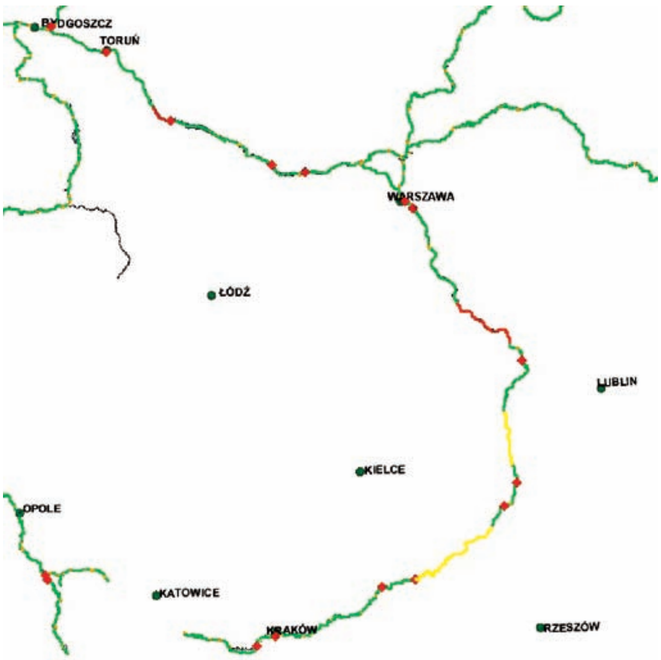


Picture 4. *Results of Vistula River navigability analysis based on current water state monitoring, for high state.*

- Network analysis – determining the shortest water way between 2 locations, without any additional conditions describing ship, cargo or waterways or their land neighborhood.



Picture 5. *Results of Vistula River navigability analysis based on current water state monitoring, for middle state.*

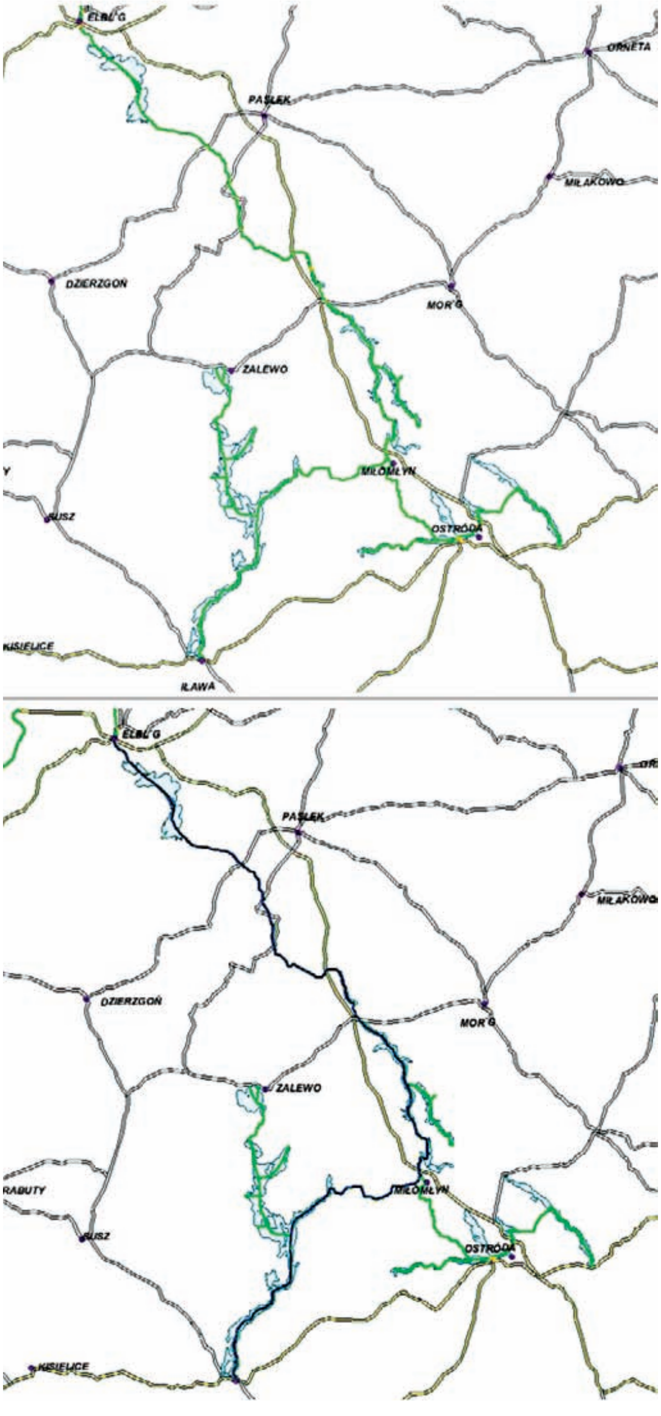


Picture 6. *Results of Vistula River navigability analysis based on current water state monitoring, for low-middle (c) state.*

- Finding existing bottlenecks on waterway. In the presented case red line shows unnavigable segments because of exceeded ship/cargo height. The reason of this limitation is height of few bridges crossing over the waterway. Developed algorithm classifies segment as unnavigable if it is crossed over by bridge segment (yellow short lines) with height over water less then ship/cargo height. The bridge height computation is based on current water state.

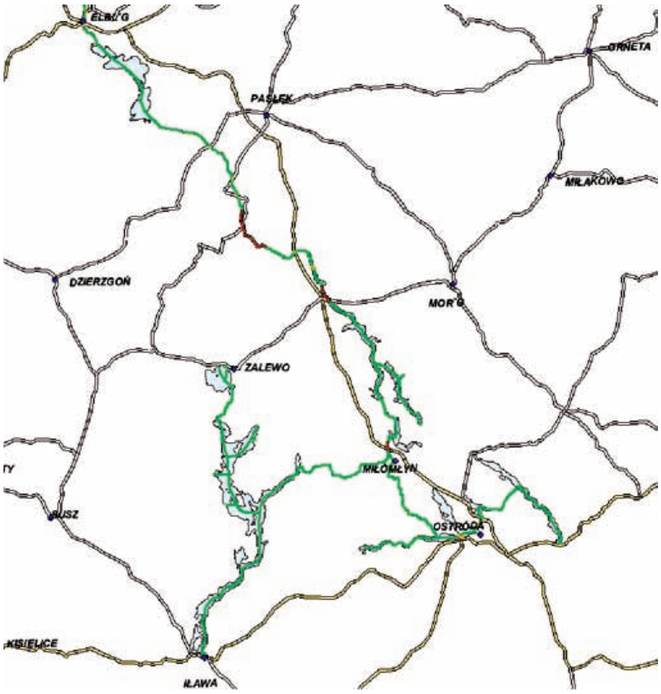
- More complex problem is determining alternative traces between 2 locations with respect to existing bottlenecks. Some additional conditions have been defined: due to reloading time and cost only one land detour is acceptable and waterway is preferred so we look for the shortest land detour. We have implemented 2 algorithms:

- finding of simple land detour of bottleneck – all segments between terminal bottlenecks are joined in single set (“congestion”), the first water/land junction before and after congestion is connected by the shortest land route. In this case algorithm has found alternative all-land way (Picture 9 – dashed blue line). The application skipped shorter route (through Dzierzgon and Susz) because of errors in land ways network connection in used database (the node near Paslek).

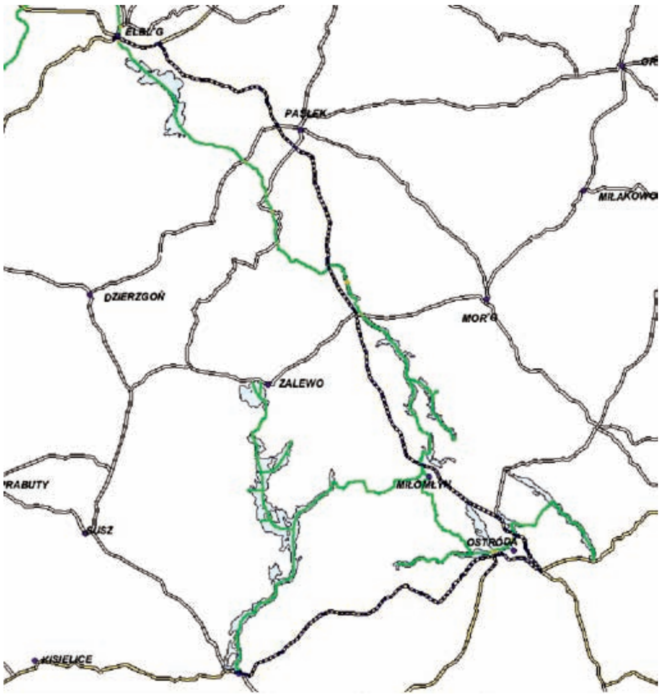


Picture 7. *Part of inland waterways in Poland (Elblag Chanel – green line) and the shortest waterway between Ilawa and Elblag (blue line).*

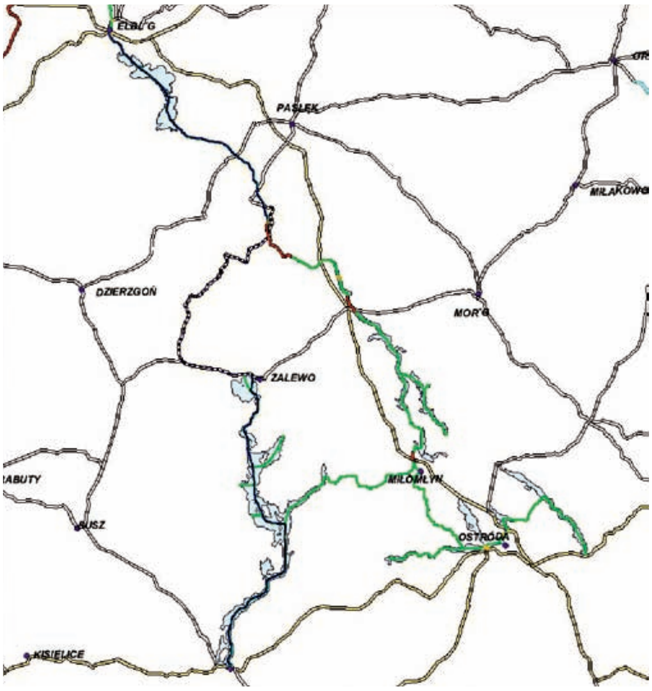
- Determining of alternative trace including alternative waterways segments. Algorithms determines many alternative waterways (if possible) up to the first unavigable bottleneck starting from both (start and end) locations. The second stage realizes looking for shortest land connection between free ends of determined alternative waterways. Determining of land ways does not take under consideration any vehicle/cargo dimension or weight limitations. Picture 10 shows result of such analysis. Blue solid line shows water part, dashed one – land part of the route between Ilawa and Elblag by-passing bottlenecks shown on the Picture 8. Application can give solutions inconsistent with good practice or even with common sense but we should remember that its target is control of algorithm formal correctness as well as connections between water and land ways networks.



Picture 8. *Appointing nonnavigational episodes (red line).*



Picture 9. *Alternative all-land way between Ilawa and Elblag.*



Picture 10. *Alternative mixed water-land connection between Iława and Elblag*

WATERS STATE PREDICTION

One of the important problems for inland navigation and transportation planning is a short time water state prediction. His task seems to be more and more important because of reputable lower and lower waters state during last 20 years. There are many models of flooding and freshet wave propagation but their high requirements on data quality cause that they seem to have limited application to low and middle state situation, which is the most important for navigation problems. Considering lack of high quality data on channels bathymetry using computationally expensive models does not make a sense. For this reason simplified model of waters state changes propagation is developed.

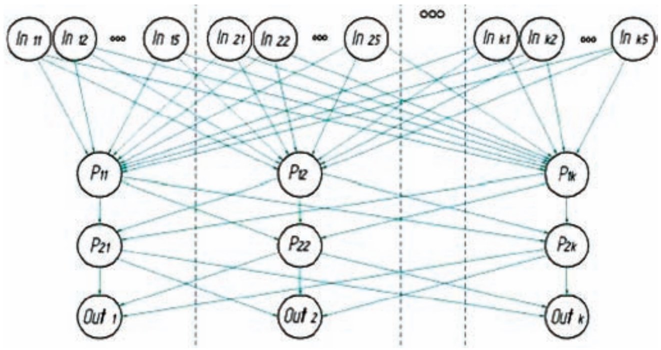
The main assumptions are:

- model should use only public accessible data
- it should be computationally inexpensive (in terms of time and resources).

The model was implemented as Neural Network developed in Matlab 6 with Neural Network Toolbox environment. The net was trained with data from published in Internet IMGW Daily Water State Bulletin for period: 01.04.2006 -01.06.2006. Testing data are from the same source and cover period 01.06.2006 – 30.06.2006. Data choice was caused by their accessibility (data gathered during project endurance were used).Two separate networks were developed, separately for Vistula (21 water gauges) and Odra (16 water gauges) rivers. Main assumptions for neural network are:

- training data are processed – we do not use water gauge indication (GLEB) but its aberration form average value (DSWW), so the model describes dynamics of waters state changes
- data covers all water gauges for main river of waterway (Vistula and Odra separately) without side streams
- only historical data from water gauges can be used (no precipitation directly considered). We have tested different range of historical data: from 2 to 10 days back, and no significant differences in results generated by nets trained on 5-10 days periods were observed. So our network is based on 5 days back data.

The network architecture: 4 layers perceptron net is used. Input layer (In) consists of cells in quantity of water gauges number multiplied by 5 (number of days back data were used), both intermediate (P1, P2) and output (Out) layers contain cell in quantity equal water gauges No (Picture 11). Input value in input cell with indexes (m, n) contains DSWW for m^{th} gauge n days back. Output cell with index m contains prediction of DSWW for m^{th} gauge for next day. Output data can be added at the beginning of input data and used for next prediction. Test shown usefulness of such procedure up to 3-days prediction.



Picture 11. *Neural Network for short term waters state prediction.*

CONCLUSIONS

Data describing current water state can be efficiently used in navigability analyses. Existing software allows for performing such analyses, but its reliability depends on existing data, which are highly incomplete. Developed model and application are ready for use, and next step should be dedicated to 2 problems:

- Data – coherent program of waterways bathymetry should be developed, including coordination of existing works realized for flooding and environment protection needs, as well as new project dedicated to navigation. Real time water gauges monitoring would be also useful. The separate problem is reliability of existing digital data (quality of used database, updating of existing data and inputting of new ones).
- Enabling of visualization data and analyses results in Internet. Currently works on publishing existing data through Intergraph Web Map are in the course. In future using Web-based Google Earth system for this task is considered as well.

LITERATURE

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