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Development and Standardization of Hydraulic Bases of Flood Protection in the South of Poland

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Abstract

Discussion on the development of open channel hydraulics application methodology for the development of flood protection system is the subject of the paper. The requirements of systems recently developed in this area are focused on increasing the accuracy of flood hazard analysis to improve the efficiency of means reducing of this hazard. Consequently, this requires detailed analyses on a small spatial scale where output data quality is the basic problem. The experiences of past and recent floods in our country place these problems in one of the first places in the category of developing tools for the needs of water management.

1. Introduction

The need for flood protection in the catchments areas of the upper Vistula and Oder basins is still great. Its magnitude is increased by the increasingly intense problem of flash floods in urban and industrial areas, affecting towns throughout the country.

After the 1997 flood, the need for flood hazard abatement has not been fully and responsibly identified. This, among others things, resulted in that neither flood mitigation strategy being implemented nor consistent plans of flood effects reduction being developed. The process of planning and implementing protection activities is continuous. Typically, however, it concerns individual projects or local (gmina) protection plans. Modernizing and extension of levees financed from European means (e.g., EBI funds) is an exception here. The uniform methodological requirements in this field are still lacking. This results e.g. in that the adjacent modernized sections of levees differ considerably in their design crest elevations at the end cross-sections, at the contact of these sections, and, most frequently, also in technology of modernization and repair works or construction of a new structure.

The importance of the problem is confirmed be the effects of the 2001 flood in the upper Vistula basin. E.g., the flood losses in the Małopolskie Voivodship were approximately the same as in 1997. The following questions still remain open:

a) modernization and safe extension of the existing transport infrastructure within the flood inundation zone,
b) rational substantiation of constructing flood protection technical means, including specification of priorities,
c) efficiency assessment and substantiation of development of technical and semi-technical means in extending storage capacity of catchments and urban areas,
d) changes in developing riparian areas exposed to the flood hazard,
e) identification and reduction of other flood hazards produced by intense flood flow in mountainous and piedmont areas.

A considerable part of problems listed above require using open channel hydraulics methodology in the planning and design part. Usually, the hydraulic methodology is strictly connected with the runoff hydrology and called hydraulic-hydrological methodology.

Selected problems of hydraulic foundation in flood protection are the subject of the paper presented. The author's selection was based on her own experiences in flood protection practice in the basins of the upper Vistula and upper and middle Oder rivers, verified by experiences of other countries in their long process of the complex development of flood protection. The selection was dictated by the requirements forced by the need for standardization of open channel hydraulics in the process of development and implementation of a flood protection system in our country.

2. Open Channel Hydraulics in the Flood Protection System

In Fig. 1, the three columns contain successively: flood protection activity groups, basic tools, and flood protection means. Direct hydraulic bases of flood protection are included in the B.5 package. However, in their modern meaning, they are also related to the spatial interpretation of flood hazard effects and, in GIS, are also connected with

- Digital Terrain Model (DTM),
- surface development of land hazarded by flood (thematic layers of DTM map),
- spatial interpolation of hydrological information on the depth and temporal distribution of flood runoff.

A. Flood protection activity groups	
A.1	Direct protection of the health, and life of people and animals, property and economy
A.2	Restraining infrastructure development on flood prone areas
A.3	Activities delaying and decreasing flood runoff on catchment scale

B. Basic tools for flood protection	
B.1	Maps of flood hazard zones (including riverbed capacity estimation)
B.2	Assessment of flood vulnerability in flood hazard zones
B.3	Assessment of flood risk in flood hazard zones
B.4	Reliable system of collecting, processing and transmitting information on flood hazard
B.5	Methodological and strucural tools supporting: ❑ implementation of tools B.1 – B.4 ❑ planning and performing tasks specified in C.1 – C.5

C. Flood protection means	
C.1	Legal establishing of limits for land use on flood prone areas
C.2	Technical means of direct, active and passive, flood protection
C.3	Technical, semi-technical and non-technical means delaying and decreasing flood runoff on catchcment scale
C.4	Flood management system maintained in full efficiency and co-ordinated at the national, regional and local scales (prediction, warnings, reaction, reduction of flood effects)
C.5	Flood education system

Fig. 1. Schematic of flood protection activity groups, basic tools, and flood protection means

The B.5 package should include first of all:

(1) climatic and hydrological flood scenarios (with their spatial structure) based on historical data, and potential scenarios based on flood statistics,
(2) hydrological models of catchment runoff (on assumed level of information detailed availability in the spatial form) with an adequate data basis,
(3) hydraulic models of flood wave propagation in the system of riverbeds (taking into account hydrotechnical and engineering infrastructure in the flow zone) with an adequate data basis,
(4) additional hydraulic packages for determining the parameters of breakdown water outflow (e.g., resulting from a levee breakdown), design of flow-through and storage polders (e.g. feasibility study of local retention for planning purposes under operational conditions) with access to the relevant data basis
(5) system of GIS tools with an adequate data basis for implementing packages B.1, B.2 and B.3, supporting performance of tasks in packages C.2 and C.3,
(6) flood management system at regional and local levels, co-ordinated on a countrywide scale, and also to services having an adequate flood information system at their disposal,
(7) operational activities on local and regional scales,
(8) local technical means used in the operational system to abate flood effects.

The place of open channel hydraulics in flood protection is precisely defined in this task specification and hierarchy. However, as in other countries, the need for standardization of hydraulic bases should be adjusted to the rules and temporal development of the flood protection system as this development is determined by the level of "flood culture", i.e., the society level of familiarity with floods.

This level determines, in turn, recognition of society's needs for flood protection, and, backing up these available, those which are expected and justified socially and economically, as well as by the available knowledge and technology. This is a consistent process resulting from the fact that the flood is a social problem.

In the flood protection development process, three paradigms were distinguished by Western countries (Smith and Ward 1998):

I. Engineering paradigm, based on technical means of flood protection and as old as our civilization. In past times, in planning technical activities, hydraulic bases constituted ca. 80%. Up to the present, the term "hydraulic construction" has been used in French nomenclature. Present times have verified this rule. Beside hydraulic bases connected with hydrological ones (ca. 20%), their proper place have been found by: social aspects, economic bases, natural aspects, environmental bases, ... (ca. 80%);

II. Conservative paradigm, where, beside technical means in modern meaning, the means included in packages C.3, C.4 and C.5, also in C.1 (see Fig. 1) are implemented in full or a specified range;

III. Developmental paradigm, initiated in the 70's of the last century, is specified by the sustainable development principle which imposes corresponding requirements on flood protection:

- both in selection and proportion of protection means (see Fig. 1)
- and in relation to the process of construction of the target responsible flood management system being a part of integrated catchment planning.

The rules of attaining sustainable development based on the integrated catchment planning are presented in Fig. 2.

The phases of flood protection development, listed above, influence directly and indirectly the development and application of open channel hydraulics for the needs of flood protection activities.

It should be stressed that the development of hydraulic methodology takes place in this field mainly through applications. They dictate the needs for seeking new solutions and are a natural area verifying the obtained results. Also, the applications determine tasks and needs for data base extension, including data base identifying of hydraulic parameters. Such a data basis, based on surface and airborne measurements, stabilized and archived at a uniform reference level, becomes an important tool in the development of hydraulic methodology. On the other hand, it dictates and makes possible elaboration of standard methodical solutions for specified needs.

Standardization of methodology is one of the basic conditions of the proper development of flood protection. On the one hand, the standard guarantees an

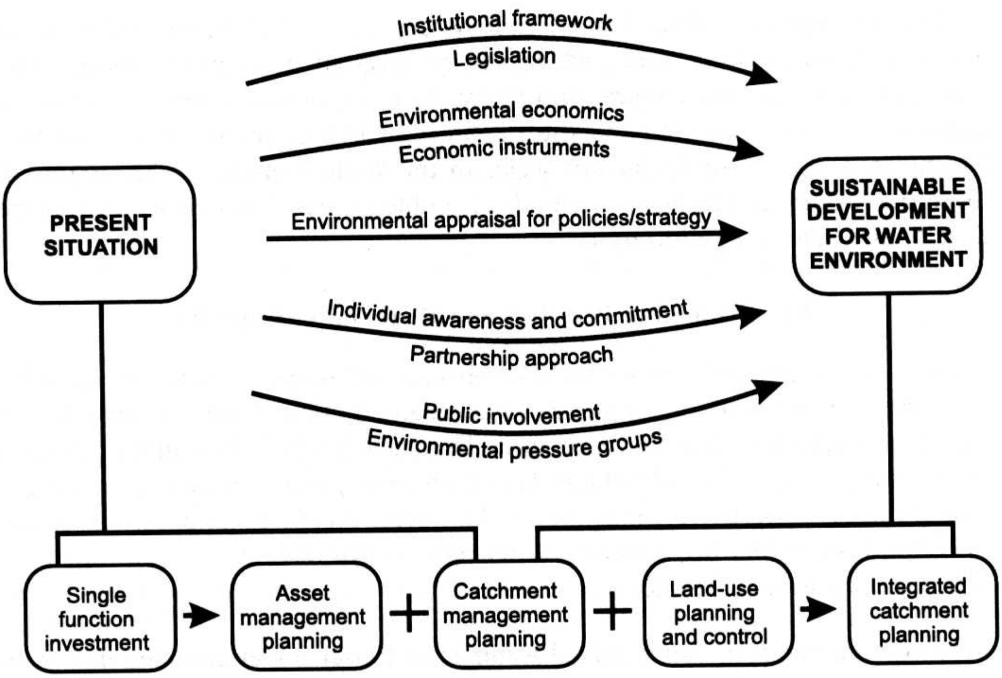

Fig. 2. Pathways to sustainable development based on integrated catchment planning
Source: After Gardiner (1994)

adequately high methodological level, on the other, it permits comparability of optional flood protection solutions and also standardization of certain technological solutions in realising flood protection tasks.

Below are presented problems where open channel hydraulics play an important role while its methods require development and standardization under the conditions existing in our country.

3. Selected Problems of Open Channel Hydraulics in Flood Protection Planning

Attention was paid to two problems in which hydraulic methods are the basis for assessing the effect of flood hazard and its mitigation. In southern Poland, these belong to the most important problems, as their correct solution influences the correct assessment of the flood hazard level and, consequently, flood losses. Based on this, decisions are made on the level of expenses incurred on flood reducing investments. These embrace the following problems:

- Determination of flood hazard zones based on the estimates of riverbed and river valley capacity.
- Flood reduction planning and flood protection operational activities based on the development of flood scenarios using hydrodynamic models.

The development of flood protection systems in the Vistula and Oder upper basins is based on these tools, which will be adapted more in the future. The tools belong to the hydrological and hydraulic tools and class are based on the hydraulic methodology with the use of direct hydrological information or that interpolated at river or catchment scale. In the context of the problems raised, those open channel hydraulics methodical problems are discussed which require development and standardization.

3.1. Estimating Riverbed and River Valley Capacity

The solution to this problem seems to be obvious and simple. It concerns applying one-dimensional equations of steady or unsteady motion along the river length taking into account streambed structure. This includes both hydraulic structures (weirs, jumps, levees, lateral polders, lateral channels) and engineering infrastructure (bridges, culverts, retaining walls). However, recent experiences, after the 1997 flood, show that this problem is still open in our country.
The solutions needed should:

(a) correctly map the longitudinal water level layout under complex flow conditions,
(b) be comparable for the reaches of various rivers, i.e., their application supports decision-making – based on the same criteria.

The most serious and urgent problem to be solved is that of the capacity estimation of river reaches in the vicinity of bridges. It concerns cities and, generally, the urban areas along small and large rivers. It is sufficient to say that in the 1997 period, about 400 bridges on the upper Vistula river area alone were damaged or destroyed. This resulted from the insufficient through-flow capacity of these structures and their incorrect construction. The latter case concerns the bridges on mountainous areas where the pillars have been situated in river current up to the present. The bridges with a too small through-flow capacity, the majority in southern Poland, cause significant overdamming of water, resulting in additional flood hazards. Two bridges on the Nysa Kłodzka river can serve as examples: in 1997 they caused overdamming significantly exceeding 2 m and were one of the causes of flooding of the central parts of the town. Correct mapping of the river water level layout is the basis for correct determination of flood hazard zones in urban areas, in natural and embanked streambeds (Nachlik et al. 2000).

In Poland, the hydraulics of flow in areas influenced by bridges and culverts have no stringent recommendations concerning methods of determining the longitudinal river water level layout. Various relevant methods are adopted In the world, although preferences are stated under specified flow conditions. In general, the following are applied (Hoggan 1989):

- Steady or unsteady flow model based on the Bernoulli or the St. Venant equations. Application requires the fulfilling of adequate criteria in the description of riverbed and river valley geometry;
- The above solution in the bridge area is completed with a detailed description of flow conditions in the bridge influence zone, with the application of
  a) energy equation in all cases, i.e., low and high water related to the bottom of the structure,
  b) momentum equation related to low water, depending on the hydraulic regime,
  c) combined pressure and weir flow equations for high water cases,
  d) Rehbock or Yarnell empirical formulas, or other formulas on mechanical energy losses.

Application in a given case of one of the above listed solutions, requires detailed determination of flow condition and measuring verification. This data has not been available so far. Uncritical use of one of the solutions or even a simpler one, based solely on the simplified formula on the value of water overdamming before the bridge, may result in erroneous outcomes. To illustrate the problem, in Tables 1 and 2 the results of calculations of flood elevation in the area of the bridges on the Nysa Kłodzka and Vistula rivers using energy equations (EE) and combined pressure and weir flow equations (P/W) are presented. As can be seen, the differences are significant and without control measurement it is impossible to decide which formula is suitable for a particular river.

Table 1. The bridge in the Sportowa Street run in Kłodzko on the Nysa Kłodzka river

Km of river	**Floodwater overdamming [m]**			
	For $Q_{10\%}$		**For $Q_{1\%}$**	
	Acc. to EE	**Acc. to P/W**	**Acc. to EE**	**Acc. to P/W**
130.956	0.00	0.00	0.00	0.00
130.775	0.01	0.00	0.04	0.01
130.593	0.02	0.00	0.12	0.02
130.412	0.14	−0.03	0.30	0.08
130.231	0.26	−0.14	0.53	0.21
130.050	1.00	0.30	1.00	0.62
129.872	1.69	0.94	1.36	0.96
129.695	2.17	1.41	1.47	1.06
129.517	2.54	1.76	1.52	1.10
129.340	2.80	2.02	1.55	1.13

Table 2. Bridges in Kraków on the Vistula river; high flow $Q_{0.1\%}$

Name of bridge	Km of river	Elevation of bottom of structure	Elevation of water level upstream from the bridge	
			Acc. to EE [m]	Acc. to P/W [m]
Dębnicki	76.390	205.17	207.69	208.10
Grunwaldzki	77.220	205.99	207.22	207.42
Piłsudskiego	78.310	206.20	206.68	206.83
Powstańców Śl.	79.000	205.24	206.16	206.39
Kolejowy II	79.210	202.41	205.48	206.33
Kolejowy I	80.130	207.08	204.55	—

3.2. Flood Building Scenarios using Hydrodynamic Models

Flood scenarios for rivers are based on the courses of historical floods, potential floods, and the basis of high flows with specified exceedance probability. First of all, the problem is connected with the mapping of lateral inflow between the water gauge cross-sections usually located at considerable distances. In southern Poland, the cachtment area (ungauged) inbetween them increases significantly. It is therefore impossible to apply simple solutions to build the flood scenarios under discussion. The methodology of flood protection building should be developed, taking into account:

a) lack of relevant historical measurement data,
b) measuring errors of the present network.

A solution to the problem will be found before long. A new measuring system is now under construction with a full control system based on current flood development modelling, which will enable elimination of the gross errors in runoff estimates. However, the effects of this modernisation will only be noticeable after a few years. Now we have to use historical data. Development of studies on the application of hydrodynamic models is necessary for correct interpolation of hydrological information along a river length in order to enable historical data to be used for building flood scenarios during the erection of successive stages of the flood protection system.

To illustrate this complex problem, an analysis of historical floods on the Raba river reach, the right-hand Carpathian tributary of the Vistula river, has been given here. A river reach from between the Dobczyce and Proszówki water gauges was taken into consideration. To illustrate the problem of balancing inflow and outflow, data from before the Dobczyce reservoir was built was used. In Table 3, basic catchment characteristics and the half-year balance of flows are presented.

Table 3. The Raba inflow and outflow balance in the half-year flood period

Water gauge cross-section / inflow	Catchment area [km^2	inflow/outflow volume [million m^3]		
		1972	1983	1984
Dobczyce water gauge (Raba)	768	1.643	4.450	2.451
Stradomka tributary	362	0.738	0.736	0.968
Stradomka-Proszówki reach sub-catchment	340	0.920	−1.688	−0.534
Proszówki water gauge (Raba)	1470	3.301	3.498	2.885

As can be seen, the inflow and outflow balance represented by the sub-catchment is seriously disturbed in years 1983 and 1984. The value of outflow from this catchment should be 20–30% of the outflow at the Proszówki cross-section. All qualitative analyses of flood development are based on historical data, probable high flows and complementary empirical or calculation formulae. The last to be connected with empirical ones are used in calculating flood flow transformation for estimation of lateral inflow from the sub-catchment. Three approaches or their combinations are used:

- the function of lateral flow in time is proportional to the inflow hydrograph (in our case: at the Dobczyce cross-section – ver. 1);
- the function of lateral flow in time is proportional to the outflow hydrograph (in our case: at the Proszówki cross-section – ver. 2);
- the function of lateral flow in time is proportional to the hydrograph of inflow concentrated on the investigated reach (in our case: to the tributary of the Stradomka river – ver. 3).

What such a simulation on the Raba river looks like is illustrated in Figs. 3 and 4, where the outflow hydrographs at the Proszówki cross-section for the 1972 and 1984 floods, measured and simulated according to the above versions, are presented. It can be clearly seen that the 1984 historical data is disturbed, which is confirmed by the inflow and outflow balance presented in Table 3.

The problem is serious, requires rapid development and standardization of application methods based on hydraulic and hydrological analyses. Only then can the methodology of correct elaboration of flood scenarios in supporting the responsible flood protection development be worked out step by step.

4. Summary and Conclusions

The author has planned by to initiate discussion and activities in the area of the problems presented. They are an exemplary illustration of the problem encompassing a wider range of needs. They also include the problem of floodwater retention on the catchment scale (surface retention, reservoir and local) and urban

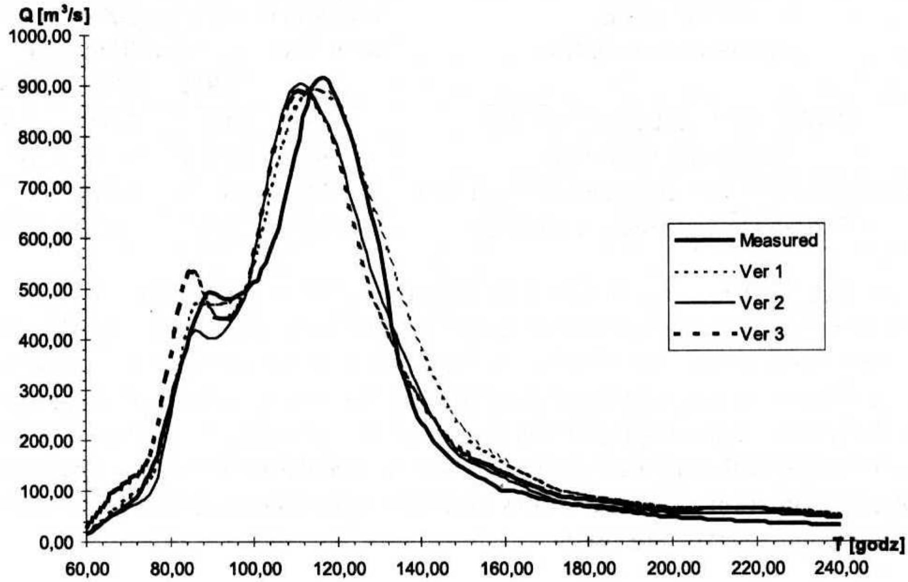

Fig. 3. Measured and simulated outflow hydrographs at the Proszówki cross-section (1972)

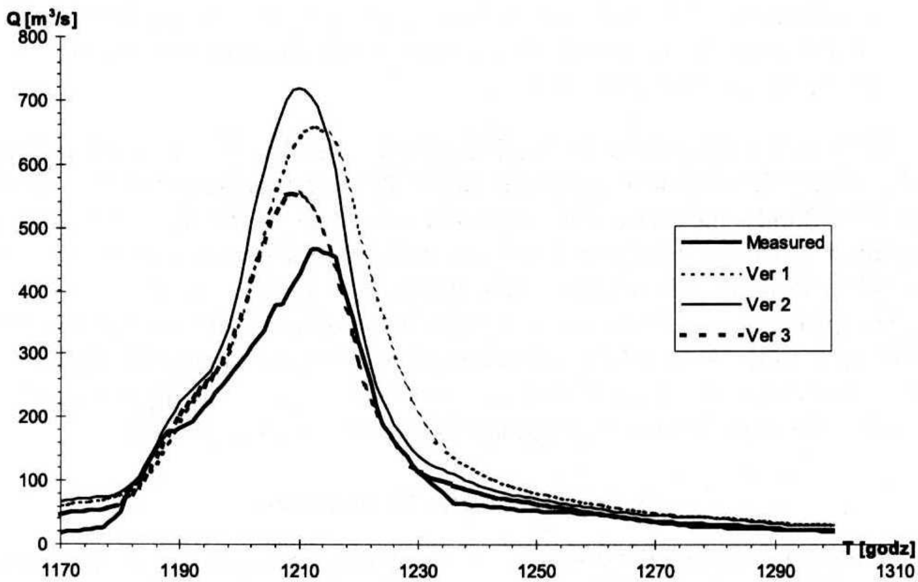

Fig. 4. Measured and simulated outflow hydrographs at the Proszówki cross-section (1983)

areas. In the latter case, the problem is urgent as flash floods, generated by violent and short rainfalls, are becoming increasingly intense. The frequency of such events's increasing and covers increasing number of agglomerations.

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