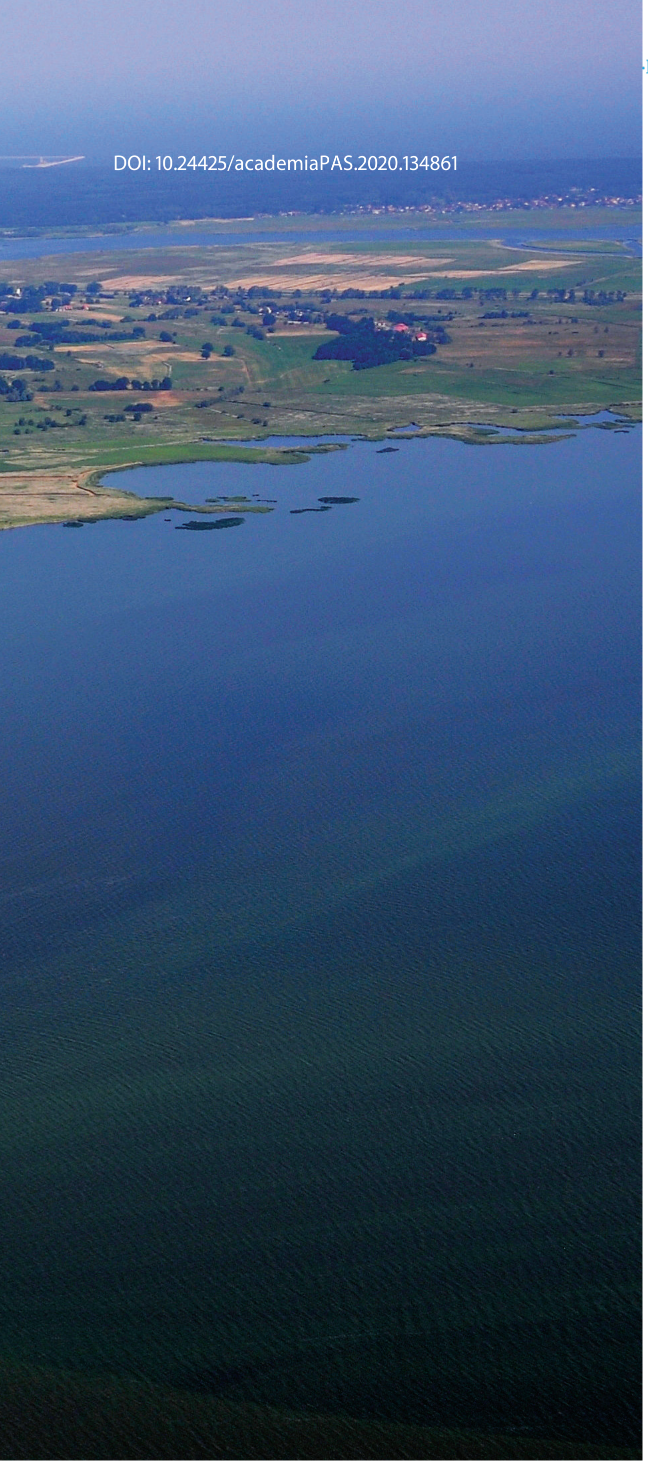
Fairway Gate 1 where the Świna River enters the Szczecin Lagoon. Aerial photograph after completion of the construction process

In Support of Hydroengineering

The successful design and implementation of hydroengineering projects crucially rests upon three collaborative pillars of research: field observations, physical models, and mathematical models.

DOI: 10.24425/academiaPAS.2020.134861



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Hydraulic structures are built for the purposes of water management and water resource development, so as to help use water more efficiently. Such structures interfere with the water environment in a controlled way, and they can usefully be classified into inland vs marine structures. As our ecological awareness and our understanding of natural processes grow, we can better plan such structures drawing on the existing knowledge and using state-of-the-art research methods. All investment projects and modernization works need to be preceded by detailed analyses of the present and projected changes in the environment based on the following three pillars: field investigations, physical hydraulic models, and mathematical modelling.

Field investigations

All aspects of any hydroengineering project should be firmly grounded in sound knowledge of the environment, as well as forecasts concerning changes that are likely to occur where the project is to be developed. First and foremost, the hydrometeorological conditions, the dynamics of water movement and sediment transport as well as the condition of the ecosystem need to be carefully determined. Forecast climate changes that could have a significant impact on the hydrological and meteorological conditions should also be factored into the planning process, e.g. the risk of extreme phenomena such as droughts and floods or increased frequency and intensity of storms. This is because it is the observed and forecasted extreme phenomena that determine the technical parameters of a given hydraulic structure, as is directly reflected in the extent of environmental interference deemed necessary. Knowledge of a given ecosystem where the planned project is to be developed is no less important: environmental valuation helps informed decisions to be made about where a project should be situated while minimizing the risk of negative consequences of such technological interference.

Hydraulic research using physical models

This particular pillar of knowledge is instrumental in finding optimum technological solutions for hydroengineering projects. Worldwide, such research has a long-established tradition going back to the nineteenth century (Germany, United Kingdom, USA). In Poland, it started in the wake of World War II, when the Gdańsk University of Technology, a successor of the Danzig Technische Hochschule, began studies on hydraulic models in the early post-war years. A new hydraulic laboratory was set up in 1953 at the Institute of Hydro-Engineering of the Polish Academy of Sciences in Gdańsk, on the premises of the Gdańsk University of Technology. In 1970, the Institute opened a large, open-space hydraulic laboratory in Gdańsk-Oliwa, which was fitted out primarily in order to investigate large-scale marine structures associated with the construction of the Northern Port. Until 2000, the laboratory conducted research on many marine projects (e.g. ports in

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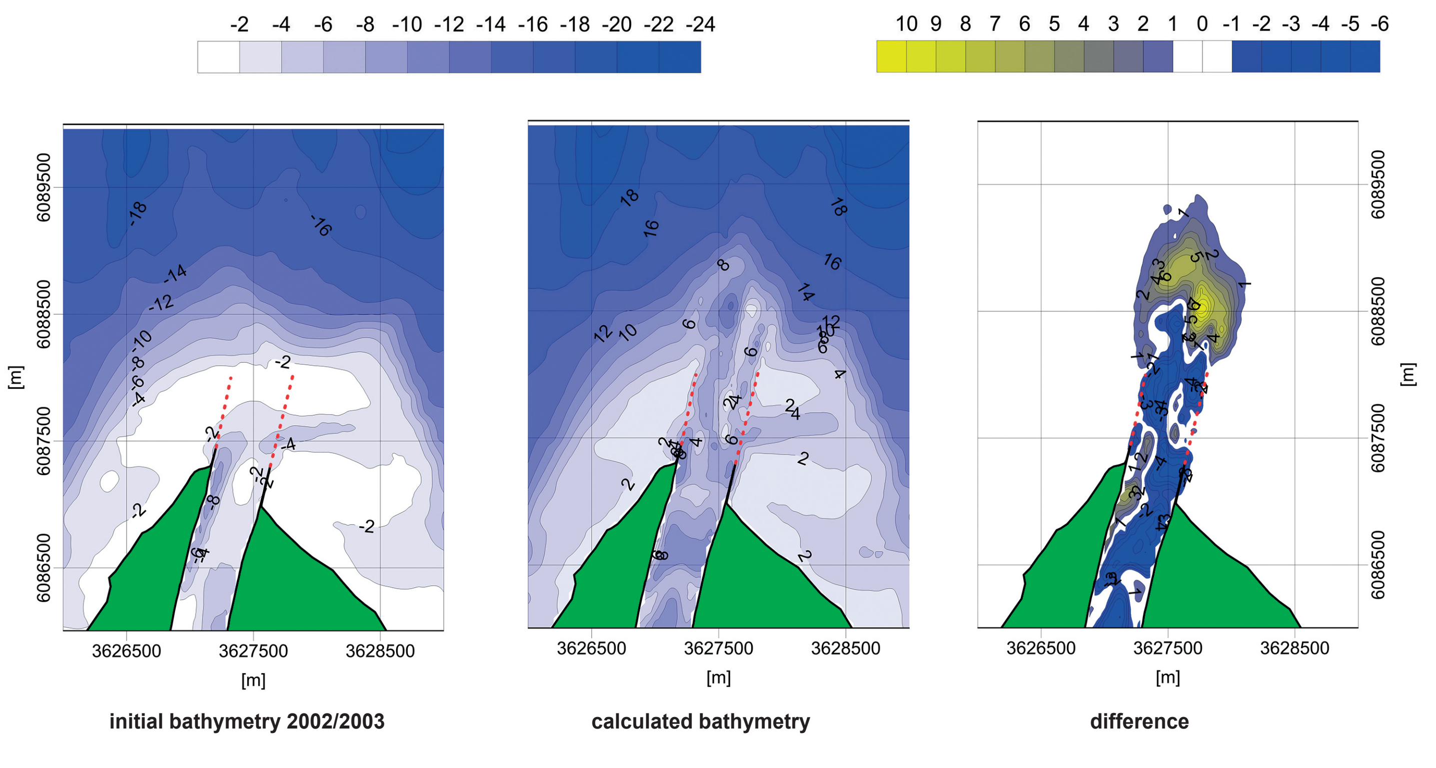
Darłowo, Kołobrzeg, Ustka, Łeba) and inland projects (e.g. dams in Włocławek and Wyszogród, the Świna Strait, the weir in Chahala, Iraq), as well as projects concerning areas where the land meets the sea (e.g. estuary of the Vistula into the Bay of Gdańsk). Currently, the laboratory is in the process of modernization, with investigations using physical models slated to be reinstated in 2021.

Hydraulic models facilitate observation and analysis of the natural phenomena occurring in the vicinity of a given structure (such as dams or ports) or its selected elements (such as weirs, locks, port basins, river training structures) and, as such, help optimize the contemplated solution. Such research uses actual scaled-down physical models of the planned structure to represent the flow of water and sediment transport close to a given structure. Models may be undistorted (i.e. with all the geometrical dimensions similarly reduced) or distorted (i.e. where the vertical dimension is scaled down less than the horizontal one). The actual manner of model scaling depends on the technical capability of a given laboratory, mostly on the space available for its construction, the amount of available water that can be fed into the model, and the particular issue under investigation. As a general rule, a physical model should emulate as closely as possible the movements occurring in real-life conditions. In all situations where sediment transport plays a significant role, models with bed scouring are built; in all other cases fixed-bed models are prepared.

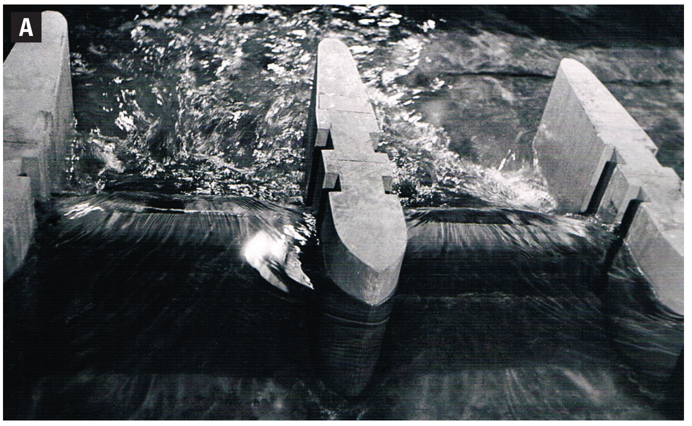
Since physical models require adequate laboratory conditions and qualified research personnel, such investigations are costly. For this reason, interest has shifted over the last two or three decades to work based on mathematical models. Nevertheless, physical models still have no equal in all situations where we cannot analytically describe the phenomena at hand.

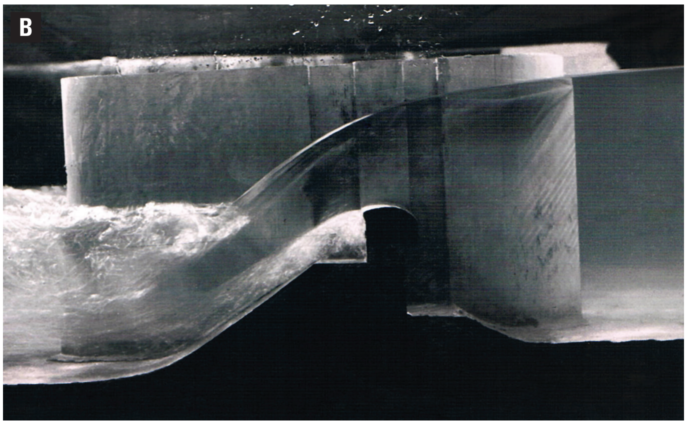
Mathematical modelling

Mathematical modelling of natural phenomena enables comparisons to be drawn between the current condition of the environment and the changes that are likely to occur once the planned project is completed, depending on the particular solutions adopted. Mathematical models emulate specific phenomena and allow projections to be made at varying levels of detail. One-dimensional (1D) models, i.e. models where the flow conditions are averaged for depth and river cross-section, are commonly employed to assess changes in the water level caused by the construction of hydraulic structures. Two-dimensional (2D) models, currently the most popular ones, represent the flow conditions and sediment transport averaged for depth, while three-dimensional (3D) models can be used to emulate complex phenomena such as two-directional water flow, i.e. backwater, a phenomenon that periodically occurs in river estuaries. Mathematical modelling is also a tool that can be used to augment



Forecast changes in the bathymetry of the Vistula estuary following the extension of the western breakwater by 560 m and eastern breakwater by 760 m, after one year of operation, average waterflow





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Water flow through the weir with fully opened gates: A – lateral cross-section view, B – view of two spans from above

the information collected during field measurements and allows changes in hydrodynamic conditions arising from climate change to be forecast.

Hydrodynamic mathematical models are increasingly being combined with ecological models. It should be borne in mind, however, that emulating real and forecast phenomena using mathematical modelling has certain limitations due to insufficient knowledge about the interactions between the natural factors present in these phenomena. In order to assess the reliability of the developed models they are calibrated and verified, i.e. assessed for consistency between the obtained modelling results and the observations in nature, using no fewer than two datasets from different periods. If the results of the model's computations are not validated by field measurements, they should be considered a source of information of a limited value. It should be noted that the results of field measurements, especially those made in extreme conditions, may also be fraught with error, arising for instance from technical difficulties during the measurement exercise.

Several instances of projects whose execution was preceded by wide-ranging research are provided below.

The construction of the Włocławek Dam completed in 1962–1970 was preceded by field measurements and hydraulic modelling investigations carried out in 1957–1966. The scope of the studies employing physical models was very wide and comprised a spatial model of the dam with a fixed and scouring bed, a sectional model of the weir, models of the lock, cofferdam and partition of the open section of the river channel. All the research was done at the PAS Institute of Hydro-Engineering lab at the Gdańsk University of Technology.

The Northern Port in Gdańsk was built in 1970–1975, and its construction was preceded by research in 1968–1973, which included an analysis of the wave and current conditions and sediment transport at the site as well as physical modelling of the breakwater system in the Northern Port, performed at the PAS Institute of Hydro-Engineering lab in Gdańsk-Oliwa.

To prepare a modernization plan for the Świnoujście-Szczecin fairway (1998–2000), a dozen variants of deepening and hydroengineering development of the fairway running from Szczecin to the outlet to the Pomeranian Bay were analyzed. To that end, 3D mathematical models of the Szczecin Lagoon and the Pomeranian Bay and of the Szczecin Lagoon and the Świna Strait were prepared and then verified using the data from the field measurements made in the previous years. Special emphasis was placed on the area of Fairway Gate 1, where the Świna River enters the Szczecin Lagoon. Two models, physical and mathematical, were prepared for this section of the waterway in order to optimize its shape; the research results were reflected in the draft of the project and later in its execution.

An analysis of the possibilities to improve navigability in the Vistula estuary by extending the breakwaters, conducted with the use of mathematical modelling in 2002/2003 and 2009, allowed for the first stage of works, i.e. extension of the eastern breakwater by 200 meters, to be completed in 2015.

The several examples cited above outline the variety of research types which have effectively supported the construction or modernization of hydraulic structures in Poland.

Following Poland's signature of the Agreement on Main Inland Waterways of International Importance (the AGN Convention), many investment projects in the field of water management are planned in the coming years. We should take advantage of all available research opportunities to ensure that new hydraulic structures are designed and executed in accordance with best engineering practices and with respect for the environment.

Further reading:

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