Hydrodynamic modelling in the Polish Zone of the Baltic Sea – an overview of Polish achievements*

OCEANOLOGIA, 45 (1), 2003.
pp. 107–120.

KEYWORDS
Modelling
Hydrodynamics
Baltic Sea

Ewa Jasińska[1]
Małgorzata Robakiewicz[1]
Antoni Staśkiewicz[2]

[1] Institute of Hydro-Engineering,
Polish Academy of Sciences,
Kościerska 7, PL–80–953 Gdańsk, Poland

[2] Maritime Institute in Gdańsk,
Długi Targ 41–42, PL–80–830 Gdańsk, Poland;
e-mail: marob@ibwpan.gda.pl

Manuscript received 17 December 2002, reviewed 6 February 2003, accepted 6 February 2003.

Abstract

This paper gives a general overview of Polish experience and achievements with regard to hydrodynamic modelling in the Polish zone of the Baltic Sea. The first work started already at the end of the sixties when the first 1D and 2D hydrodynamic models were set up. With the development of numerical methods and increasing computational power a number of 1D, 2D and 3D models were set up and tested. Global, regional and local models cover the most important water bodies, i.e. the Pomeranian Bay – Szczecin Lagoon and Gulf of Gdańsk – Vistula Lagoon systems.

1. Introduction

Compared to other parts of the Baltic Sea, the Polish coastline is rather regular. Here, two large rivers, the Vistula (Wisła) and the Odra (Oder), and a number of smaller ones enter the sea. Additionally, the Vistula

* This paper was presented at the ECSA Symposium 34 'Estuaries and other brackish areas – pollution barriers or sources to the sea?', Gdańsk–Sopot, 15–20 September 2002.

The complete text of the paper is available in PDF format at http://www.iopan.gda.pl/oceanologia/index.html

Lagoon (Zalew Wiślany) and the Szczecin Lagoon (Zalew Szczeciński), and the Pomeranian Bay and Gulf of Gdańsk complete the picture of the Polish coastal zone (Fig. 1).

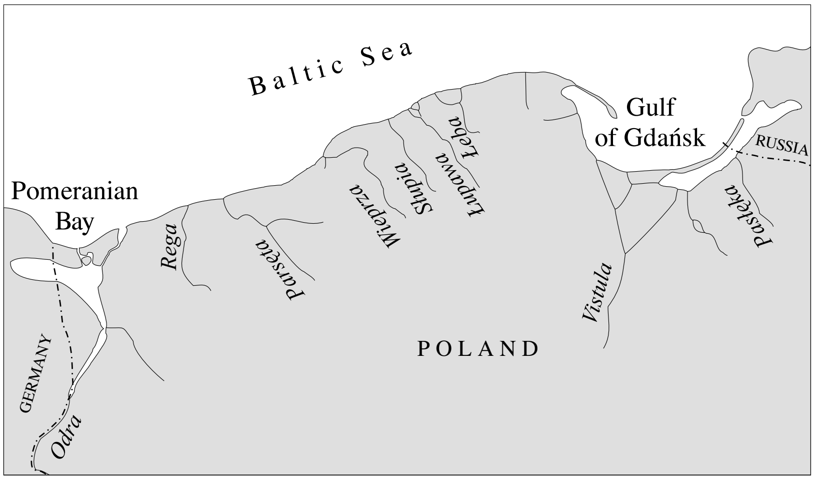

Fig. 1. Map of the Polish zone of the Baltic Sea

Most of these water bodies have been studied, some of them, e.g. the Szczecin Lagoon and the Gulf of Gdańsk, in detail from the standpoints of hydrodynamics, eutrophication, bacterial pollution, sediment pollution and oil pollution. Numerous *in situ* measurements have been carried out in the Polish coastal zone, and constitute the basis for the calibration and verification of numerical models. This paper concentrates on the hydrodynamic conditions, their modelling, and their relation to sediment transport and ecological modelling.

2. Modelling hydrodynamics

Modelling hydrodynamics has been a topic of interest within the Polish scientific community since the late 1960s, when the first 1D and 2D models were set up. Those models covered the entire Baltic Sea, its sub-basins and the outlets of rivers discharging directly into the sea. An overview of the hydrodynamic models and their applications for particular purposes will now be presented.

2.1. Hydrodynamics of the Baltic Sea

Modelling of the Baltic Sea began in the late sixties, when the first 2D depth-averaged models were set up by Laska (1966) and Kowalik (1969, 1970). Almost at the same time, Maliński (1972) developed a 1D model of the Baltic Sea. Mean climatic currents were investigated on the basis of steady-state baroclinic 3D models (Sarkisyan et al. 1975, Kowalik & Staśkiewicz 1976, Jankowski & Kowalik 1978, Staśkiewicz 1988). The modelling problems related to the Baltic Sea were discussed in detail in a number of works (e.g. Kowalik 1972, Kowalik & Taranowska 1974, Jankowski & Kowalik 1980, Jankowski 1985, 1988).

Recent Baltic Sea models have been based on the POM (Princeton Ocean Model). At present, applications prepared by Jankowski (e.g. 2002), Kowalewski (1997, 1998), Herman & Jankowski (2001) are being used for analysing the wind-induced variability of hydrological parameters (including upwelling) in the coastal zone of the southern Baltic. The POM application by Kowalewski (1998) is run regularly and some results are published on Gdańsk University's website.

2.1.1. Oil spill modelling and validation

Hydrodynamics is one of the major forcing phenomena with regard to oil spills at sea. To support the Polish Search and Rescue (SAR) Service, the Computer Aided Rescue and Oil Combating System (CAROCS) was developed at the Maritime Institute in Gdańsk (Gajewski 1997). It was additionally created to fulfil Recommendation 12/6 of the Helsinki Commission. It consists of the following parts:

- *Database* – contains information on: environmental parameters (including depth, water level, ice cover, wave height, direction and period, air and water temperature, current speed and direction, clouds, wind speed and direction, air pressure, humidity); physical and chemical parameters of dangerous substances transported on the Baltic Sea; rules governing combative measures, their potential effectiveness, organisation and communication; available technical measures and their location applicable for SAR actions and combating oil spills; historical oil spills;
- *Modules for forecasting* the drift of an object or an oil spill; the spread of pollution and the evolution of its physical and chemical parameters; wind waves;
- *Expert system* – controls the module responsible for possible technical solutions during SAR or combative actions;
- *Communication module*, called HIRNET (HIROMB Network), serves to: automatically transmit data via Internet, ISDN (Integrated Services Digital Network) and commutated lines; transmit data to/from files and databases; convert external data to the form used in CAROCS;

- *Mapping information server* used for data transmission via Internet and applying Arc View Internet Map Server to select the displayed quantities;
- *Client-applet WWW* enables remote running of the model using a WWW browser or running as an independent application.

To enable a drift prediction, forecast data for the next 48 hours for the hydrodynamic parameter model (HIROMB – High Resolution Model of the Baltic Sea with a resolution of 1 nautical mile run by the Swedish Meteorological and Hydrological Institute, Norrköping), wind waves (WAM4 – WAve Model version 4, 6 NM, MIG – Maritime Institute in Gdańsk), and meteorological parameters (UMPL – UK Unified Model Polish version, 9 NM, Warsaw University) are used in the system.

In 1996–99, CAROCS was validated continuously during the POLRODEX (Polish Rodamine Experiment) experiments in the Gulf of Gdańsk. In 1996 and 1997, a rhodamine solution was introduced into the surface waters in the vicinity of the Hel Peninsula (Gajewski & Gajewski 1997, Gajewski et al. 1999), while in 1998 and 1999 the vicinity of the oil terminal at Gdańsk – Port Północny (Gdańsk – Northern Port) was chosen as the most probable area of oil contamination. The calculations for the drift of the plume centre, based on forecasts from the HIROMB and UMPL models were in good agreement with the trajectories of the rhodamine plume centre recorded during the POLRODEX′97 experiment (Gajewski et al. 1999). In 1996, the agreement between experiment and numerical simulation was also good (Gajewski & Gajewski 1997) but not as good as in 1997, because the better weather forecast in 1997 resulted in a better hydrodynamic forecast.

The life-raft drift model verification showed a reduced search area as compared to the International Maritime Organisation's procedures; a very good result was achieved for the dummy-man drift forecast (Gajewski et al. 1999).

In 1998 and 1999, the results of simulations were not so successful, as the weather forecast turned out to be incorrect owing to rapid changes in wind direction. The results of the all these experiments show that CAROCS is a useful tool for the purposes of SAR actions and combating oil spills.

2.2. Hydrodynamics of the Lower Odra – Szczecin Lagoon – Pomeranian Bay

The Lower Odra – Szczecin Lagoon – Pomeranian Bay system is located in NW Poland near the border with Germany (Fig. 2). The modelling of this area is very often carried out in two sub-areas: 1 – the lowest part of the Odra; 2 – Szczecin Lagoon – Pomeranian Bay, where the Szczecin Lagoon acts as a buffer.

Fig. 2. Map of the river Odra – Szczecin Lagoon – Pomeranian Bay system

2.2.1. Modelling the Lower Odra

A modelling system for 2D free surface flows has been developed and applied to the Roztoka Odrzańska, part of the Odra estuary (Ewertowski 2000). This system describes hydrodynamic and transport processes by simulating flow and water level variations in response to forcing in the estuary (Ewertowski 1998). Hydrodynamics are the basis for simulations of transport processes of dissolved and suspended matter in this area. The depth-averaged advection-dispersion model has been implemented in the Roztoka Odrzańska to investigate the physical processes responsible for the distribution of pollutants in the aquatic environment. It is restricted to 1D and 2D systems, and assumes a uniform concentration in the vertical. The depth-averaged model of sediment transport has also been usefully applied to deposition and erosion studies in the same area. The model can be used for default or prescribed sediment characteristics.

This system of models is capable of simulating different hydrodynamic and pollution events, as demonstrated by experiments with dissolved oxygen and biological oxygen demand (Ewertowski 2000, Ewertowski & Dybkowska-Stefek 2001).

2.2.2. Szczecin Lagoon – Pomeranian Bay

The hydrodynamics of the Szczecin Lagoon are driven by wind action, water level differences between the Lagoon and the Pomeranian Bay, fresh water inflow from the Odra, and by salt water intrusions through the three straits (Dziwna, Świna, Piana (Peene)) connecting the Lagoon with the Pomeranian Bay. The Szczecin Lagoon is a shallow water body (average depth 3.7 m) traversed by a dredged shipping channel 250 m wide and 10 m deep from Świnoujście to the port of Szczecin (Fig. 2). This channel plays an important role in the water circulation in the system.

The Polish experience with modelling the hydrodynamics of this area dates back to the 1970s, when the first 1D model for the Świna strait was set up (Maliński 1970, 1971a, b, 1973). The eighties saw the first 2D model of the Szczecin Lagoon (Staśkiewicz 1984, 1990), though it was soon found that to represent the area's water circulation, a 3D model approach would be more suitable. In the next step, a 3D model was developed jointly by Institute of Hydro-Engeneering PAS (IBW PAN) and Hamburg University (Jasińska & Nöhren 1988, Jasińska 1991, 1993, Robakiewicz 1993).

In the late 90s another 3D model, ESTURO, was set up by IBW PAN using Delft 3D software (license – Delft Hydraulics 1999). To calibrate and verify it, *in situ* measurements carried out in 1985 and 1988 were applied (Jasińska & Robakiewicz 1999a). This model covers the final stretch of the Odra (starting at Police), the Szczecin Lagoon, the straits and the southern part of the Pomeranian Bay. The modelled area was discretised using a curvilinear orthogonal grid in the horizontal plane, and eight layers in the vertical using sigma coordinates. Comparison between measurements and model results showed that the water circulation and salt water intrusions in the Szczecin Lagoon and Świna Strait are reproduced with sufficient accuracy (Jasińska & Robakiewicz 1998). This model was applied in investigations preceding the modernisation of the Szczecin – Świnoujście deep-water channel, and its consequences for the stability of hydraulic engineering constructions, navigational safety, flood protection, and the environmental effects of possible stronger salt water intrusions (Jasińska & Robakiewicz 1999c). It was also used for the description of the water exchange in the Odra Estuary (Jasińska 2001).

2.3. Hydrodynamics of the Lower Vistula – Gulf of Gdańsk – Puck Bay – Vistula Lagoon

This system consists of the River Vistula, which discharges its waters into directly the Gulf, and the Vistula Lagoon, which has a narrow connection to the Gulf through the Baltiysk Strait (Fig. 3). In modelling hydrodynamics the Gulf of Gdańsk and the Vistula Lagoon are often regarded as two separate systems, each of which exchanges water with adjacent basins.

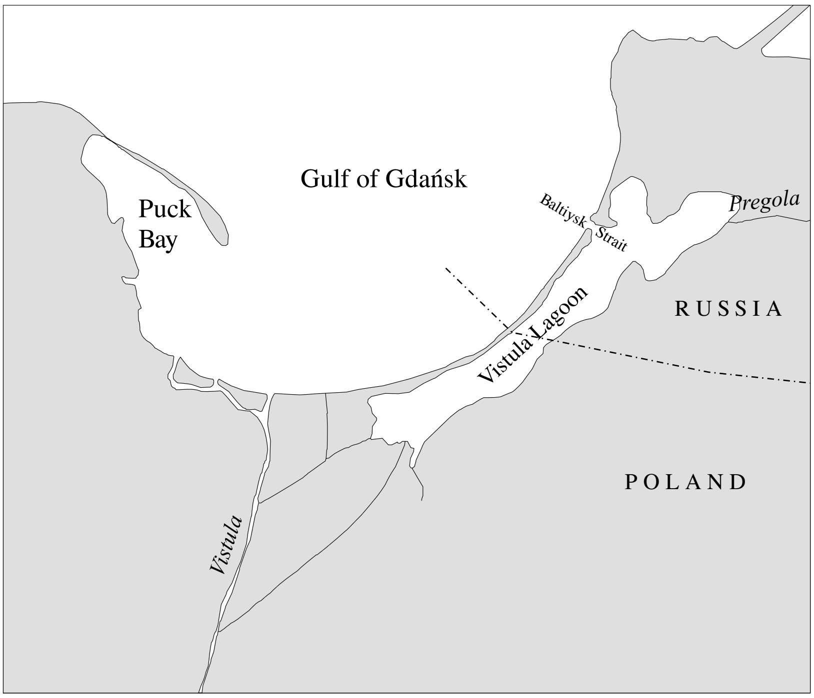

Fig. 3. Map of the river Vistula – Gulf of Gdańsk – Vistula Lagoon system

2.3.1. Gulf of Gdańsk

The hydrodynamics of the Gulf of Gdańsk is forced by wind conditions, river discharge, water exchange between the Gulf and the open sea, and water density stratification.

The first model of the Gulf of Gdańsk was set up as a 2D application (Kowalik & Wróblewski 1971) based on the Baltic Sea model (Kowalik 1969). In the next two decades a number of 2D depth-averaged models were developed (Jankowski 1983, 1984, 1985, Robakiewicz et al. 1992, Jankowski & Staśkiewicz 1994). In all cases the area was described by a regular grid, with the Vistula sketched in very roughly. Those models were generally used for steady-state water circulation calculations with the wind as the major forcing phenomenon. Staśkiewicz & Walczowski (1993) and Staśkiewicz (1993) investigated water levels and flows under real wind conditions in the western, shallow part of the Gulf of Gdańsk known as Puck Bay. The *in situ* measurements carried out in the Gulf of Gdańsk have demonstrated the existence of time- and space-variable phenomena (Robakiewicz & Jasińska 1998). Modelling this area using the 3D approach was started in the 90s (Robakiewicz & Karelse 1994). At present the Gulf of Gdańsk is modelled using a curvilinear orthogonal grid and Delft 3D software (e.g. Robakiewicz 1998), or a regular grid based on POM (e.g. Kowalewski 1998, Jankowski 2000) as part of the Baltic Sea model. In both cases discretisation in the sigma co-ordinates in the vertical was introduced.

Modelling of the Gulf of Gdańsk or its sub-areas (e.g. Puck Bay) has been used as a tool in a number of cases:

– to describe hydrodynamics as the driving force behind water quality changes, including bacterial pollution, (Van Gils et al. 1993, Graniczny et al. 1995, Staśkiewicz & Walczowski 1995, Semovsky et al. 1996, Jasińska & Bielecka-Kieloch 1997, Van der Vat & Robakiewicz 1997, Robakiewicz & Walkowiak 1998, Jasińska & Robakiewicz 1999b, Robakiewicz 2000);

– water treatment plant; changing the discharge point of treated waters into the sea; mixing conditions in such cases as: discharging effluent into the sea (Robakiewicz & Van der Vat 1994, Robakiewicz 1997b, 1998b);

– to assess the ecological consequences of uncontrolled leakage of aggressive substances into the environment, (Robakiewicz & Świeczkowski 1996);

– to describe water currents and temperatures in support of effective rescue efforts at sea (Robakiewicz 1997a).

2.3.2. Vistula Lagoon

Modelling the hydrodynamics of the Vistula Lagoon started in the 1980s, when the first 2D models where published (Catewicz & Jankowski 1983, Kołodko et al. 1983, Szymkiewicz 1986, 1992, Kapiński & Robakiewicz

1993, Staśkiewicz & Lewandowski 1994). All these models were used to represent water levels in this water body. With the use of the 2D model it was possible to represent water currents as depth-averaged values, but agreement with the available measurements was rather poor. The results of the 3D model set up by Kaźmierski (2001) using Delft 3D-flow software (Delft Hydraulics 1999) have supported *in situ* measurements showing a two-dimensional flow in the vertical.

The results from the 2D hydrodynamic model (Staśkiewicz & Lewandowski 1994) were used in a eutrophication model to estimate the seasonal changes in dissolved oxygen, inorganic and total nitrogen, inorganic and total phosphorus, chlorophyll a and Secchi disk depth (Kwiatkowski et al. 1997). Gajewski et al. (1995) analysed lithodynamic processes along the Vistula Spit (Mierzeja Wiślana).

2.4. Small Pomeranian rivers

Hydrodynamic models of the small Pomeranian rivers and their estuaries, e.g. the Rega, Łeba, Parsęta and Pasłęka, have been used in water quality investigations (Lewandowski 1993, 1995a, b, 1996). Information from *in situ* measurements was used in the verification of the models (e.g. Jasińska 1991, 1993).

3. Concluding remarks

This paper provides a brief overview of the experience and achievements in modelling the hydrodynamics in the Polish zone of the Baltic Sea. A number of applications of such modelling have been mentioned.

Hydrodynamic modelling has become an important tool in oceanographic investigations in the coastal zone and in the open sea. It can be used to study a wide range of phenomena related to hydrodynamics, such as water quality, heat and salt transport, and sediment processes. At present, most hydrotechnical projects are based not only on purely theoretical investigations and measurements but also on mathematical models, i.e. hydrodynamic models.

Calibration and validation procedures have been rather extensive in the case of 3D models based on POM and Delft 3D. As a consequence, the results from these models have already been applied to the reconstruction of historical events and in calculations of various scenarios. They also enable a representation of time-variable phenomena such as circulation patterns, distributions of water masses, water level, salinity and temperature fields. The same holds true for 2D models for estuaries and the small Pomeranian rivers, developed for practical purposes.

The CAROCS model is in operational use to support Polish SAR on a daily basis, while the Baltic Sea model based on POM is run regularly, and some results are published on the website of Gdańsk University.

Acknowledgements

The authors thank Dr Ryszard Ewertowski from the Szczecin Branch of the Maritime Institute in Gdańsk for his support in collecting publications with regard to Roztoka Odrzańska, and Dr Andrzej Lewandowski from Geomor, Gdańsk, for collecting publications on the small Pomeranian rivers.

References

Catewicz Z., Jankowski A., 1983, *H-N model of steady circulation in the Vistula Bay*, Stud. i Mater. Oceanol., 40, 229–239, (in Polish).

Delft Hydraulics, 1999, User Manual Delft 3D-Flow, Release 3.05.

Ewertowski R., 1998, *Unsteady flow in Odra River outlet generated during the passage of strong cyclones*, Adv. Hydro-Science, Proc. 3rd Int. Conf. Hydro-Science and -Engineering, Cottbus/Berlin 1998, K. P. Holz, W. Bechteler, S. S. Y. Wang & M. Kawahara (eds.), Univ. Mississippi, Oxford, 100 pp., (abstract), CDROM, ICHE'98, 24 pp.

Ewertowski R., 2000, *Evaluation of hydrodynamics and transport processes in Roztoka Part of the Odra Estuary*, Proc. 5th Int. Sci. Conf. Hydrodynamic and Ecological Aspects of Nutrient Forecasting for Odra and Ebro Estuaries, Mar. Res. Inst., Szczecin, 99–122.

Ewertowski R., Dybkowska-Stefek D., 2001, *Maritime Research Institute PIONEER final report (The MAST III Project within 4th EU Framework Program)*, Mar. Res. Inst., Szczecin, 21–27, 53–59, 73–94.

Gajewski J., 1997, *Conceptual design of Polish computer decision support system for aiding oil spill combating activities at sea*, Bull. Mar. Inst., Gdańsk, 24 (1), 69–73.

Gajewski L., Gajewski J., 1997, *Modelling of drift and spreading in view of rhodamine B tracing*, Bull. Mar. Inst., 24 (1), 59–67.

Gajewski J., Gajewski L., Jednorał T., Lewandowski A., 1995, *Lithodynamic maritime processes along the Vistula Spit*, Inż. Mor., 22 (6), 284–291, (in Polish).

Gajewski J., Gajewski L., Stachowiak A., 1999, *Verification of drift models of rhodamine spill, life-raft and dummy-man during experiment POLRODEX'97*, Bull. Mar. Inst., 26 (1), 87–96.

Graniczny M., Kowalski Z., Piątkowska A., Robakiewicz M., Zachowicz J., 1995, *Monitoring of the Gulf of Gdańsk by the teledetection method and modelling of hydrodynamics*, Prz. Geol., 43 (6), 465–472, (in Polish).

Herman A., Jankowski A., 2001, *Wind- and density-driven water circulation in the Southern Baltic Sea: a numerical analysis*, Task Quart., 5 (1), 29–58.

Jankowski A., 1983, *Steady wind-driven and river inflow circulations in the Gulf of Gdańsk*, Stud. i Mater. Oceanol., 40, 203–221, (in Polish).

Jankowski A., 1984, *Dynamics of the steady wind – driven circulation in the Gulf of Gdańsk (homogeneous basin)*, Stud. i Mater. Oceanol., 43, 5–79, (in Polish).

Jankowski A., 1985, *Water mass exchange between the Gulf of Gdańsk and Baltic Sea*, Oceanologia, 20, 5–15.

Jankowski A., 1988, *Mathematical modelling of water circulation in the Baltic Sea*, Ser. Pr. Habil. Inst. Oceanol. PAN, Ossolineum, Wrocław, 281 pp., (in Polish).

Jankowski A., 2000, *Wind-induced variability of hydrological parameters in the coastal zone of the southern Baltic Sea – numerical study*, Oceanol. Stud., 29 (3), 5–34.

Jankowski A., 2002, *Application of a σ-coordinate baroclinic model to the Baltic Sea*, Oceanologia, 44 (1), 59–90.

Jankowski A., Kowalik Z., 1978, *Wind-driven circulation in the Baltic Sea (homogeneous basin)*, Oceanologia, 9, 247–258.

Jankowski A., Kowalik Z., 1980, *Diagnostic model of wind- and density-driven currents the Baltic Sea*, Oceanol. Acta, 3 (3), 301–308.

Jankowski A., Staśkiewicz A., 1994, *Hydrology – Currents*, pp. 85–92, [in:] *The Baltic Sea atlas*, A. Majewski & Z. Lauer, Inst. Meteor. i Gosp. Wod., Warszawa, 214 pp., (in Polish).

Jasińska E., 1991, *Dynamics of saline waters in estuaries of Polish rivers*, IBW PAN, Gdańsk, 206 pp., (in Polish).

Jasińska E., 1993, *Motion of Salt Water and Associated Fronts in Tideless Estuaries*, ESTUARIES, J. Estuar. Res. Federat., 16 (1), 53–67.

Jasińska E., 2001, *Influence of morphology changes on flow and water exchange in the Odra estuary*, Arch. Hydro-Eng. Environ. Mech., 48 (3), 33–57.

Jasińska E., Bielecka-Kieloch M., 1997, *Modelling of spreading of pollutants in the coastal zone*, Proc. Conf. Modelling Ecosystems of the Gulf of Gdańsk, Univ. Gd., Gdynia, 183–192, (in Polish).

Jasińska E., Nöhren I., 1988, *Adaptation and Verification of Highresolving Three-dimensional Baroclinic Numerical Model of the Odra Estuary*, Proc. Franzius Inst., Hannover, 17 pp.

Jasińska E., Robakiewicz W., 1998, *Detailed recommendations for final design of the hydrotechnical structures on the waterway Świnoujście – Szczecin. Part I*, IBW PAN, Gdańsk, 77 pp., (in Polish).

Jasińska E., Robakiewicz W., 1999a, *Three dimensional numerical model of the Odra estuary ESTURO*, Proc. Problems of Environmental Engineering in the Odra River Mouth, Szczecin, 141–153.

Jasińska E., Robakiewicz W., 1999b, *Hydrodynamics of the Puck Bay – measurements and modelling*, Arch. Hydro-Eng. Environ. Mech., 46 (1–4), 73–90.

Jasińska E., Robakiewicz W., 1999c, *Mathematical model ESTURO for estimation of proposed measures in reconstruction of Świna strait*, Inż. Mor. i Geotech., 20 (5), 216–226, (in Polish).

Kapiński J., Robakiewicz W., 1993, *Mathematical model of hydrodynamic conditions in the Vistula Lagoon – two dimensional version*, IBW PAN, Gdańsk, 27 pp., (in Polish).

Kaźmierski J., 2001, *Hydrodynamic properties and modelling of near-shore stratified water reservoirs influenced by natural and anthropogenic factors*, KBN project report, IBW PAN, Gdańsk, 22 pp., (in Polish).

Kołodko J., Jackowski B., Wojtowicz E., 1983, *The effect partitioning the Vistula Lagoon during the creation of storm surges based on kinematic model*, IBW PAN, Gdańsk, 42 pp., (in Polish).

Kowalewski M., 1997, *A three-dimensional hydrodynamic model of the Gulf of Gdańsk*, Oceanol. Stud., 26 (4), 77–98.

Kowalewski M., 1998, *Coastal upwellings in stratified shallow sea based on Baltic Sea as an example*, Ph. D. thesis, Uniw. Gd., Gdynia, 83 pp., (in Polish).

Kowalik Z., 1969, *Wind-driven circulation in the shallow sea with application to the Baltic Sea*, Acta Geophys. Pol., 17 (1), 13–38.

Kowalik Z., 1970, *Wind-driven circulation in a shallow sea with application to the Baltic Sea. Part II*, Prz. Geofiz., 23 (2), 145–162, (in Polish).

Kowalik Z., 1972, *Wind-driven circulation in a shallow stratified sea*, Dt. Hydrogr. Z., 25 (6), 265–278.

Kowalik Z., Staśkiewicz A., 1976, *Diagnostic model of the circulation in the Baltic Sea*, Dt. Hydrogr. Z., 29 (6), 239–250.

Kowalik Z., Taranowska S., 1974, *Density-driven currents in the Baltic Sea*, Oceanologia, 3, 5–31.

Kowalik Z., Wróblewski A., 1971, *Wind-driven circulation in the Bay of Gdańsk*, Acta Geophys. Pol., 19 (2), 111–125, (in Polish).

Kwiatkowski J., Rasmussen E. K., Ezhova E., Chubarenko B., 1997, *The eutrophication model of the Vistula Lagoon*, Oceanol. Stud., 26 (1), 5–33.

Laska M., 1966, *The prediction problem of storm surges in the South Baltic Sea based on numerical model results*, Arch. Hydrotech., 13 (2), 335–366, (in Polish).

Lewandowski A. (ed.), 1993, *Rega river restoration project – impact study*, DHI –Hørsholm, Geomor–Sopot, 130 pp.

Lewandowski A. (ed.), 1995a, *Łeba basin restoration project*, SWECO–Stockholm, DHI–Hørsholm, Geomor–Sopot, 166 pp.

Lewandowski A. (ed.), 1995b, *Pilot prognostic model for water quality of the Pasłęka river and its estuary*, Geomor–Sopot, 102 pp., (in Polish).

Lewandowski A. (ed.), 1996, *Operational model for water quality of the Parsęta river catchment area and its estuary*, Geomor–Sopot, 120 pp., (in Polish).

Maliński J., 1970, *Model of a steady water flow through a shallow sea strait*, PIHM, 100, 95–103, (in Polish).

Maliński J., 1971a, *Theoretical calculations of flow in Świna strait using numerical method. Part I – steady state conditions*, IBW PAN, Gdańsk, 55 pp., (in Polish).

Maliński J., 1971b, *Theoretical calculations of flow in Świna strait using numerical method. Part II – unsteady conditions*, IBW PAN, Gdańsk, 11 pp., (in Polish).

Maliński J., 1972, *Numerical experiments on one-dimensional model of the Baltic Sea*, PIHM, 105, 41–59, (in Polish).

Maliński J., 1973, *Hydrodynamic model for a shallow branched sea strait. Part I – theoretical basis*, Arch. Hydrotech., 20 (2), 171–202, (in Polish).

Robakiewicz M., 1998a, *Modelling hydrodynamic conditions in the South Baltic Sea – TRISULA applications*, Hydroinformatics ′98, Balkema, 1447–1454.

Robakiewicz M., 1998b, *Environmental Impact Assessment for the underwater outlet from the WWTP Gdańsk Wschód to the Gulf of Gdańsk. Description of hydrodynamic conditions for two periods of in situ measurements. Part 5*, Rep. IBW PAN, Gdańsk, 106 pp., (in Polish).

Robakiewicz M., 2000, *Representation of hydrodynamic conditions in the Gulf of Gdańsk in the year 1994*, IBW PAN, Gdańsk, 16 pp., (in Polish).

Robakiewicz M., Jasińska E., 1998, *Hydrodynamics of the Vistula Estuary: measurements and modelling*, Oceanol. Stud., 27 (3), 83–93.

Robakiewicz M., Karelse M., 1994, *Hydrodynamics of Gdańsk Bay by 3D model*, Proc. 19th Conf. Baltic Oceanogr., Sopot, 487–496.

Robakiewicz M., Świeczkowski S., 1996, *Analysis of the movement of oil substances in the south Baltic Sea*, Inż. Mor. i Geotech., 17 (2), 163–166, (in Polish).

Robakiewicz M., Van der Vat M. P., 1994, *Impact of upgrading Gdynia sewage system on Puck Bay water quality*, Delft Hydraulics–IBW PAN, Delft–Gdańsk, 16 pp.

Robakiewicz M., Walkowiak A., 1998, *Spreading of Vistula waters in Gdańsk Bay during the passage of a flood wave (19–21.07.1997)*, Inż. Mor. i Geotech., 19 (2), 77–79, (in Polish).

Robakiewicz W. (ed.), 1993, *Hydrodynamic conditions of Szczecin Lagoon and straits connecting with the Bay of Pomerania*, IBW PAN, Gdańsk, 287 pp., (in Polish).

Robakiewicz W., (1997a), *Application of hydrodynamic model of Gdańsk Bay in search of people from helicopter 'Anakonda'*, Rep. IBW PAN, Gdańsk, 25 pp., (in Polish).

Robakiewicz W., 1997b, *Definition of location and characteristics of the outlet from the WWTP Gdynia – Dębogórze, Part III*, Rep. IBW PAN, 28 pp., (in Polish).

Robakiewicz W., Robakiewicz M., Kapiński J., 1992, *Representation of water currents in the Gulf of Gdańsk by numerical model*, Rep. IBW PAN, Gdańsk, 27 pp., (in Polish).

Sarkisyan A. S., Staśkiewicz A., Kowalik Z., 1975, *Diagnostic calculations of summer circulation in the Baltic Sea*, Okeanologiya, 15 (6), 1002–1009, (in Russian).

Semovsky S. V., Woźniak B., Hapter R., Staśkiewicz A., 1996, *Gulf of Gdańsk spring bloom physical, bio-optical and biological modelling and contact data assimilation*, J. Mar. Sys., 7, 145–159.

Staśkiewicz A., 1984, *H-N model of Szczecin Lagoon system*, Conf. Proc. Problems of Hydrotechnics in Odra River Mouth, Szczecin, 203–213, (in Polish).

Staśkiewicz A., 1988, *Mean climatic water circulation in the Baltic Sea calculated for different seasons*, Proc. 16th Conf. Baltic Oceanogr., Vol. 2, Kiel, 962–978.

Staśkiewicz A., 1990, *Mathematical model of the Odra estuary and its verification by measurements*, [in:] *Results of measurement campaign in the Odra estuary 'Zalew Szczeciński '83'*, W. Robakiewicz (ed.), IBW PAN, 155–186, (in Polish).

Staśkiewicz A., 1993, *Preparation and implementation of the warning forecast system in case of storm surges from both sides of Hel Peninsula in different meteorological situations. Final report of the project: Chosen problems of ecological development of Hel Peninsula*, Inst. Mor., Gdańsk, 104 pp., (in Polish).

Staśkiewicz A., Lewandowski A., 1994, *Application of multifunctional mathematical model MIKE-21 for simulations of hydrodynamic and ecological processes in the Vistula Lagoon*, Inż. Mor. i Geotech., 15 (4), 163–167, (in Polish).

Staśkiewicz A., Walczowski W., 1993, *Investigations of water circulation in Puck Bay using a numerical model. Final report of the project: Chosen problems of ecological development of Hel Peninsula*, Inst. Mor., Gdańsk, 138 pp., (in Polish).

Staśkiewicz A., Walczowski W., 1995, *Gulf of Gdańsk currents as an indicator of pollution transport*, [in:] *The Gulf of Gdańsk – environmental state in 1992*, L. Kruk-Dowgiałło & P. Ciszewski (eds.), Inst. Ochr. Środ., Warszawa, 13–25, (in Polish).

Szymkiewicz R., 1986, *Dynamics of coastal basins, influenced by the open sea*, Zesz. Nauk. Politech. Gd., Gdańsk, 97 pp., (in Polish).

Szymkiewicz R. (ed.), 1992, *Hydrodynamics of the Vistula Lagoon*, Wyd. Politech. Warsz., Warszawa, 101 pp., (in Polish).

Van der Vat M. P., Robakiewicz M., 1997, *The effect of pollutants from the Vistula river on the water quality of the Bay of Gdańsk*, Int. River Water Qual., G. A. Best, T. Bogacka & E. Niemirycz (eds.), E&FN Spon, London, 81–88.

Van Gils J., Robakiewicz W., Robakiewicz M., Bielecka-Kieloch M., Postma L., 1993, *A water quality model to support management for the Bay of Gdańsk*, Proc. Conf. Water Pollution II, Modelling, Measurements and Prediction, Milan (Italy), 191–198.