Governments and communities around the world are increasingly adopting risk-based approaches to the planning, design and operation of systems to reduce flood damage. This approach underpinned the EU Directive (2007/60/EC) on the assessment and management of flood risk. Increasing practical experience of flood risk analysis is revealing the severe uncertainties associated with management decisions. Decisions that may have appeared sound when based on best estimates can be called into question when uncertainty is taken into account. The risk from floods is defined as the multiple of the probability of flooding and the estimated costs of flood damage. Both factors require an uncertainty analysis. Floods on the River Odra in 1997 and on the River Vistula in 2001 and 2010 serve as examples of the limitations of a purely deterministic, defensive approach to flow modelling. The immense flood in 1997 triggered a number of central government flood protection initiatives that included inter alia the modernisation of the monitoring system (Systems of Monitoring and Country Protection; in Polish: Systemy Monitoringu i Ochrony Kraju, Lindel et al. 1997; Mierkiewicz et al. 1999; Kadłubowski 2005). This system automatically transfers measurements to the operational systems responsible for flood forecasting and protection. Flood forecasts prepared by national operational systems in the Vistula basin are based on HBV rainfall-run-off models and flow routing hydrodynamic models (Lindel et al. 1997; Kadłubowski et al. 2011). However, flood incidents in the River Vistula in Spring 2010 revealed shortcomings in the national system of flood forecasting and protection. The development of fully realistic probabilistic flood forecasting models has not yet been attempted and has been a severe drawback to management decisions and infrastructure planning. Nor has there been any attempt so far to develop probabilistic online flood forecasting systems for both long-term planning and short-term emergency warning.

The research project “Stochastic flood forecasting system (The River Vistula reach from Zawichost to Warsaw)” carried out by order of the National Science Centre (contract No. 2011/01/B/ST10/06866) in the Institute of Geophysics, Warsaw, is an example of the work on flood forecasting problems that takes into account stochastic aspects of risk assessment. This book gives a summary of the project’s achievements.

The novelty of the approach consists in the integration of a number of different hydrological modelling tools, including distributed, lumped parameter, deterministic
and stochastic models that can be run separately or in parallel. The system has a modular structure, including models describing rainfall-run-off and snow-melt processes for tributary catchments and the transformation of a flood wave within the reach.

This is the first study to integrate different aspects of flow forecasting at different temporal and spatial scales. These include catchment scale rainfall-run-off modelling and flow routing processes. Catchment geography and land cover changes during the last 25 years are described by Gutry-Korycka et al. (2015; this book). Long-term changes of the river flow regime are analysed using mathematical modelling based on 50 years of daily flow and water-level records (Karamuz et al. 2015; this book). On the other hand, detailed flow and bed topography measurements performed locally at one of the gauging stations provide information on the short-term flow variability (Bialik et al. 2015; this book). Flood frequency analysis (FFA) plays an important part in flood risk assessment. However, that approach requires the assumption of a stationarity of the flow regime. Bogdanowicz et al. (2015; this book) apply a first-order Markov model to describe flood-poor and flood-rich period lengths in a Warsaw maximum flow series in order to assess the changes in flow regime. The rainfall-run-off models described by Osuch (2015a; this book) consist of the conceptual HBV models developed for the catchments located in the study area. The sensitivity and uncertainty analyses of model parameters and their predictions provide information on the dominant processes that control rainfall-run-off in the basin.

A step-by-step procedure for the distributed modelling of river flow by contrasting two commonly used modelling tools, MIKE 11 and HEC-RAS, is presented by Kochanek et al. (2015; this book). This chapter is aimed at the end-user to facilitate the application of the scenario analysis research by water management bodies (e.g. the Warsaw Water Management Board). There is a clear priority of automated calibration over the hand-tuning of model parameters, as exemplified by the MIKE11 (automatically calibrated) and HEC-RAS (hand-tuned) modelling results. The sensitivity and uncertainty analyses of the MIKE11 model predictions are presented by Osuch (2015b; this book). Three methods of sensitivity analysis are compared, namely Morris, Sobol and a correlation-based approach allowing for the choice of an appropriate model calibration strategy. The results indicate that an appropriate strategy should not consist of a series of model optimisations for independent sub-reaches but should rather be integrated over all reaches and simultaneously take into account the model fit at each controlled cross section. The 1-D modelling of the river flow presented so far is extended to a 2-D model by Magnuszewski (2015; this book), by the application of a two-dimensional hydrodynamic model CCHE2D to model flow in the contemporary River Vistula channel in Warsaw. The application of the 2-D hydrodynamic model for different scenarios of floodplain maintenance has helped to predict flood conveyance in highly urbanised and vulnerable areas of Warsaw.

In the next part of the study, lumped parameter models were applied to describe flow routing in the studied river reach. A semi-distributed stochastic flood forecasting system for the middle River Vistula is presented by Romanowicz and Osuch (2015a; this book). Due to the stochastic nature of the methods applied, the confidence limits of the predictions are also estimated in a straightforward way. The ability to tackle the nonlinearity of flood wave transformation by means of the Hammerstein–Wiener modelling approach is assessed. Due to the lack of the historical series of short-time
period observations necessary to obtain short-term online flow forecasts, a stochastic transfer function-based emulator is introduced by Romanowicz and Osuch (2015b; this book). Application of a distributed flow routing model makes it possible to interpolate forecasts both in time and in space. The application of the ECMWF ensemble forecasts to prolong the forecast lead time for the Biała Tarnowska catchment, southern Poland, is presented by Kiczko et al. (2015; this book). This study presents the first application in Poland of online assimilation of ECMWF forecasts. Medium-range probabilistic weather forecasts (ECMWF) and online observations of temperature, precipitation and water levels are used to prolong the forecast lead time.

The interests of end-users are discussed by Rucinska (2015; this book) in an analysis of the social aspects of flood risk assessment. Potential end-users will benefit from a description of the social vulnerability to natural hazards in the study area.

In summary, the book covers a broad range of problems related to stochastic flow forecasting. The fourth and first chapters describe the spatial and temporal variability of flow regimes, flood frequency analysis under non-stationary conditions and river morphology based on analytical studies and measurements. These are followed by physically based modelling, including rainfall-flow and flow routing models. Particular attention is paid to the uncertainty aspects of flood predictions. The semi-distributed approach, following the idea of the data-based modelling, is presented in the next three chapters, which also provide a bridge between distributed and lumped flow routing models in the form of emulators. The ensemble forecasts presented in the last section of that group illustrate an ability to extend the flood forecast lead beyond the flood wave travel times. The social aspects arising in flood risk assessment are discussed in the final chapter.

This book aims to stimulate similar approaches in Poland and elsewhere. An important aim is to raise awareness of the need for a critical, rigorous stochastic approach to flood forecasting. It also provides the tools to decision-makers (Warsaw Regional Water Board) in the form of an integrated system for scenario analysis. Our main objective has been to raise interest and to motivate further research in this difficult area.

Acknowledgments

The authors would like to thank Ray Macdonald and Anna Dziembowska for their help in editing this book. Finally, we would like to thank all reviewers for their constructive and critical reviews which helped to improve the quality of the papers. This work was partly supported by the project “Stochastic flood forecasting system (The River Vistula reach from Zawichost to Warsaw)” carried by the Institute of Geophysics, Polish Academy of Sciences on the order of the National Science Centre (contract No. 2011/01/B/ST10/06866).

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Stochastic Flood Forecasting System
The Middle River Vistula Case Study
Romanowicz, R.; Osuch, M. (Eds.)
2015, XVI, 198 p. 88 illus., 79 illus. in color., Hardcover
ISBN: 978-3-319-18853-9