Adv. Geosci., 11, 1–6, 2007
www.adv-geosci.net/11/1/2007/

Advances in Geosciences

Preface

Large-scale hydrological modelling and the Water Framework Directive and Floods Directive of the European Union – 10th Workshop on Large-Scale Hydrological Modelling

K.-E. Lindenschmidt[1], F. Hattermann[2], V. Mohaupt[3], B. Merz[1], Z. W. Kundzewicz[2,4], and A. Bronstert[5]

[1]GeoForschungsZentrum Potsdam, Telegrafenberg, 14473 Potsdam, Germany
[2]Potsdam Institut für Klimafolgenforschung, Telegrafenberg, 14473 Potsdam, Germany
[3]Federal Environment Agency, Postfach 1406, 06813 Dessau, Germany
[4]Res. Centre for Agricultural and Forest Environment, Polish Academy of Sciences, Bukowska 19, 60-809 Poznan, Poland
[5]University of Potsdam, Karl-Liebknecht-Straße 24-25, 14476 Golm, Germany

1 Introduction

In December 2000, the Water Framework Directive (WFD) of the European Union (EU) was enforced (EC, 2000) to provide a new legislative basis for water management in Europe. The main goal of the WFD is the implementation of river basin water management plans in which comprehensive studies of the current status of the surface and ground water bodies must be reported and management programs must be enforced with cost-effective measures with which a good ecological condition of the water bodies can be attained and sustained.

For many EU country members, the WFD poses a difficult challenge because the directive requires an integrated management involving all stakeholders influencing the water resources at the river basin scale, including large basins. Here, computer modelling systems can make an important contribution to management integration and decision support, in particular for establishing action plans to implement the management measures, to optimise the monitoring and sampling programs of the water bodies and to accompany the implementation and evaluation of the measures and their impacts.

The Floods Directive (FD), proposed by the EU (Commission of the European Communities, 2006) but not yet in force, will play a comparable role to the WFD as a policy tool. Just as the WFD provides the political basis for water resource management in Europe, so too will the FD provide the legislative foundation for flood protection and mitigation in Europe. Since most large river basins in Europe extend over several countries, the directive will help to orient and broaden flood management efforts beyond the municipal and state authorities to the national and international levels and establish an improved and more cost-effective flood protection scheme. Here too, models and modelling systems are likely to prove to be indispensable in aiding the process of implementing flood risk assessment and management plans.

The focus of the 10th Workshop on Large-Scale Hydrological Modelling, held in Potsdam on 9–10 November 2006, was placed on how large-scale hydrological and water-quality modelling can help in fulfilling the requirements of these two EU water policy directives. Four themes provided the framework for the oral sessions and poster presentations:

1. *Precipitation-runoff modelling* which included case studies on hydrological modelling, on large (including global) scale. These aspects are imperative in providing the hydrological database required for decision making for both the WFD and FD.

2. *Water-quality modelling* which included the transport and transformation processes of nitrogen and phosphorus-based nutrients on land surfaces and in river waters of large river basins. These presentations were geared towards attaining the targets of good water quality set by the WFD.

3. *Flood and flood risk modelling* which provided a plenum for presenting new approaches in modelling and forecasting floods and introduced methodologies for assessing and mapping flood damages and risk. These

Correspondence to: K.-E. Lindenschmidt
(kel@gfz-potsdam.de)

offered insight on particular concerns and challenges posed by the demands of the FD.

4. *Uncertainty analysis and model coupling* where methods and case studies for calibration, sensitivity analyses and quantification of uncertainty in models and modelling systems were presented. The session showed that uncertainty is an important aspect for interpreting results and further research in this field is necessary in order to address gaps in understanding.

Included in the workshop program were four key-note lectures by:

1. Axel Bronstert from the Institute for Geoecology at the University of Potsdam: *10 years of large-scale modelling: synopsis and outlook.*

2. Volker Mohaupt from the Federal Environmental Agency in Dessau, Germany: *Water Framework Directive demands on large-scale river basin management tools*.

3. Zbigniew W. Kundzewicz from the Research Centre for Agricultural and Forest Environment at the Polish Academy of Sciences in Poznan, Poland and the Potsdam Institute for Climate Impact Research in Potsdam, Germany: *Climate change and the new European Union Floods Directive: challenges for large-scale hydrological modelling*.

4. Bruno Merz from the Engineering Hydrology Section at GeoForschungsZentrum in Potsdam, Germany: *Analysis and assessment of flood risk: requirements of the European Union Floods Directive*.

2 Hydrological modelling – synopsis and outlook

Axel Bronstert gave a synopsis of large-scale hydrological modelling in the past 10 years and an outlook for future directives. Table 1 gives a summary of the annual workshops on large-scale hydrological modelling held in the past ten years. He was invited to open the workshop with his lecture to honour his initiation of the first workshop in November 1997 and to commend his continued involvement and input in the subsequent workshops.

Some of the main achievements in hydrological modelling have been the advances in middle- and large-scale modelling of the water regime. This has been attributed to the differentiation of the simulated discharge in fast, intermediate, and slow runoff components. Progress has also been made in characterising hydrological response to altered climatic conditions, which has been made possible due to improvements in model-coupling technologies. Advances in model coupling have also aided research into regional integrated modelling across different media (e.g. meteorology – hydrology – groundwater). Considerable developments have also been attained in multi-scale flood modelling.

In some areas, such as representation of process variability in large-scale models, achievements have not been satisfactory and additional research effort is required. Global water-budget modelling and generally, two-way coupling between the atmosphere and land surfaces at large scales still require much work for their advancement. These modelling systems call for additional research impetus in uncertainty analysis of cross-media parameter combinations and the integration of remote-sensing data in the modelling process.

Deadlocks have been identified, referring to the subjects of equifinality, model structure uncertainty, developing generic decision support systems, making integrated modelling systems less case- or data-specific, and establishing arbitrary scenarios which these modelling systems can simulate.

Urgent research questions that should be tackled are attaining better representations of the runoff processes and mass fluxes on large (including global) scale. This requires, in particular, using improved input data of precipitation which better capture process variability in space and time. On the medium scale, determination of flow and immission pathways of water-quality constituents, such as phosphorus, need to be improved. Still in their infancy (but urgently required) are generic modelling tools to aid in testing scenarios to fulfil the requirements of the EU WFD. In light of the proposed FD, probability-based global and regional climate-change scenarios should be established that are applicable for hydrological impact assessment.

3 Modelling and the EU Water Framework Directive

Volker Mohaupt gave his key-note lecture on the demands on management and modelling tools to fulfil the requirements of the EU WFD. The main demands include:

1. representing quality elements of good ecological status of the water bodies in the models,

2. quantifying how pressures on the aquatic systems impact the ecological status, and

3. selecting cost-effective measures to attain and sustain a good ecological status.

The WFD stated several new concepts, such as “ecological status”, “water body type related assessment”, “river basin management”, “public participation” or “economic feasibility of objectives”, and changed water management as a whole. A large number of issues of the directive were further described in guidance documents of the “Common Implementation Strategy of the EU” (CIS) on the WFD. The river basin characterisation with the analyses of pressures and impacts, including risk assessment, was the first practical step in the implementation of the WFD. The results for ten

Table 1. Summary of the large-scale modelling workshops in the past 10 years.

No.	Workshop title	Focus	Sponsoring Institutes	Location	Date	Proceedings
1	Modelling water and substance transport in large river basins	modelling runoff generation at large and global scales; climate change; interactions between land surfaces and atmosphere	Potsdam Institute for Climate Impact Research (PIK) and Institute for Geoecology, U. Potsdam	Potsdam	15–16 Nov 1997	Bronstert et al. (1998)
2	Modelling water and substance transport in large river basins	Integrated modelling at large and global scales; uncertainty; floods; groundwater	U. Gießen and U. Kassel	Rauischholzhausen bei Gießen	19–20 Nov 1998	Fohrer and Döll (1999)
3	Effects of landscape heterogeneity on water and substance transformations in river basins	Integrated modelling; influence of spatial variability; regionalisation and scale transferability	Institute for Geography, Landscape Ecology, U. Göttingen	Göttingen	18–19 Nov 1999	Gerold (2000)
4	Modelling middle and large scale river basins	Coupling hydrological and atmospheric processes; integrated water management; remote sensing	Institute for Physics of the Atmosphere, GKSS Research Centre, Geesthacht	Lauenburg	16–17 Nov 2000	Sutmöller and Raschke (2001)
5	Modelling water and substance transport – opportunities and limits of model implementation in politics, economics and climate impact research	Changing boundary conditions; decision support systems; scale-dependent validation	Institute for Geography, Hydrology, U. Bonn	Bonn-Röttgen	1–2 Nov 2001	Stephan, Bormann and Diekkrüger (2002)
6	Large-scale modelling in hydrology – river basin management	Uncertainty; groundwater; water quality; integrated water management	Centre for Environmental Research (UFZ) and Institute for Geoecology, U. Potsdam	Magdeburg	28–29 Nov 2002	Hennrich, Rode and Bronstert (2003)
7	New methodological approaches to model the water and substance transport in large river basins	Water quality and substance transport; different methods for runoff modelling at the global scale; uncertainty	Department of Geo- and Environmental Sciences, Geography and Remote Sensing, U. Munich	Munich	27–28 Nov 2003	Ludwig, Reichert and Mauser (2004)
8	Large scale hydrological modelling	Uncertainty; Groundwater; water quality; calibration methodologies; remote sensing	Geoinformatics, Hydrology and Modelling, U. Jena	Oppurg	11–12 Nov 2004	Krause, Bongartz and Flügel (2005)
9	Large scale hydrological modelling	Model coupling; regionalisation and scale transferability; objective calibration methodologies	Institute for Water Engineering, Hydrology and Geohydrology, U. Stuttgart	Lauterbad bei Freudenstadt	10–11 Nov 2005	Barthel et al. (2006)
10	Large-scale hydrological modelling and the European Union water policies - water framework directive and floods directive	Precipitation – runoff modelling; water quality; modelling floods and risk assessment; model identification and uncertainty; model coupling	GeoForschungsZentrum Potsdam (GFZ), Potsdam Institute for Climate Impact Research (PIK) and Institute for Geoecology, U. Potsdam	Potsdam	9–10 Nov 2006	Lindenschmidt, Hattermann and Bronstert (this volume)

river basins in Germany show improvements in water quality but many measures are necessary to fulfil the WFD's requirements for a good ecological status (BMU, 2005). Most (62%) of all river water bodies are assessed as being at high risk of failing to attain a good ecological status if additional measures are not realised. For 26% of the rivers, the risk is unclear. The main reasons for not attaining a good status are due to the modifications in river morphology, presence

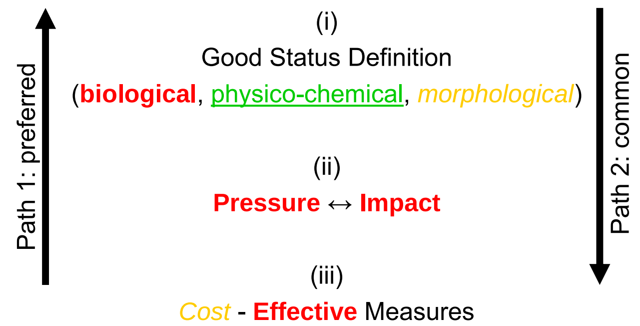

Fig. 1. Do models help in fulfilling the requirements of the EU Water Framework Directive? Font style and colour pertain to model capabilities and process knowledge: bold & red – scientific basis is in its infancy and much research and development is necessary; italic & yellow – scientific basis exists but further development is required; underlined & green - well established scientific and modelling basis. Path 1 indicates the preferred model development with possible measures already in mind during the design of the modelling system. Path 2 is the most common route taken where model structure is given priority which restricts the modelling system's utility in developing and evaluating measures.

of migration barriers for fish and smaller aquatic organisms, emission of nutrients from non-point sources and to a lesser extent, point loadings of specific pollutants. The assessment for the ecological status of lakes is more positive; 38% are at risk and for 24% the risk is unclear. For transitional and coastal waters, the assessment is very negative; 91% are at risk and for 2% the risk is unclear. For the latter, nutrient loading is the most dominant pressure causing eutrophication in these stagnant waters. Problems pertaining to the chemical status of rivers oriented on compliance with European-wide objectives for priority substances are of minor importance. In this case, 9% of the water bodies were assessed at being at risk of not attaining good ecological status; for 28% the risk is unclear. For most (53%) of groundwater bodies, achieving the good-status criterion is problematic, mostly due to the high nitrate pollution and the presence of pesticides. The pressures and impacts analysis was made without having fully developed assessment systems for ecological status. Hence, commonly used factors were used (e.g. physico-chemical parameters and threshold values) which have been established by experts and water managers.

Insightful was the illustration of applicability of models (Fig. 1) in providing results for certain aspects of the WFD demands. Physico-chemical conditions of waters are reflected generally quite well with today's models, while formation of morphological conditions and in particular its influences on aquatic ecology are not. There is still a deficit in process knowledge and model capabilities in capturing the influences on biological components, which are the decisive parameters of ecological status. A large gap also exists in the ability of models to relate pressures on the aquatic system to their impacts on the ecological condition of the water bodies. An urgent need is evident in equipping models with decision-support capabilities for the selection of the most cost-effective measures that can lead to achieving and maintaining a good ecological status. A plea was also made to begin model development with consideration of the possible measures at hand and move from there towards investigating the pressures/impacts and then to the description of the ecosystems' status (Path 1 in Fig. 1), instead of the reverse order as in most modelling studies to date (Path 2 in Fig. 1). This would increase the chance of models playing a more significant role in helping to fulfil the requirements of the WFD.

4 Modelling and the proposed EU Floods Directive

Both Zbigniew W. Kundzewicz and Bruno Merz focused their lectures on modelling requirements imposed by the proposed FD. Flood risk assessments and mapping of river basins, river sub-basins and coastal zones will become mandatory for the EU Member States under the new directive. The preliminary flood risk assessment shall include at least the following:

1. a map of the river basin district including the borders of the river basins, subbasins and where appropriate associated coastal zones, showing topography and land use;
2. a description of the floods which have occurred in the past;
3. a description of flooding processes and their sensitivity to change, including the role of floodplain areas as a natural retention/buffer of floods and flood conveyance routes now or in the future.

The flood risk maps should display the potential damage associated with three scenarios of floods:

1. floods with a high probability (likely return period, once every 10 years);
2. floods with a medium probability (likely return period, once every 100 years);
3. floods with a low probability (extreme events)

and be expressed in terms of the number of inhabitants potentially affected, the potential economic damage in the area and the potential damage to the environment. These will then form the basis for flood risk management plans, as specified below:

1. Member States shall prepare and implement flood risk management plans at the level of the river basin district for the river basins, subbasins and stretches of coastline.

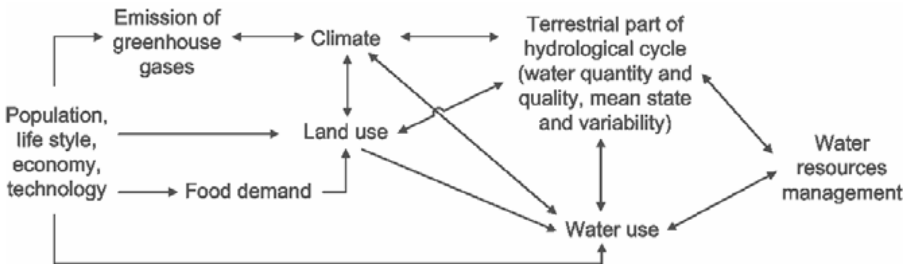

Fig. 2. Conceptual example of an integrated modelling system to help fulfil the requirements of the European Union Floods Directive. Climate and land-use change, river flow, flood risk and economic and social impacts are intimately connected and have to be jointly taken into consideration. Source: concept of Taikan Oki, cf. Kundzewicz and Mata (2007).

2. Member States shall establish appropriate levels of protection, specific to each river basin, subbasin or stretch of coastline, focusing on the reduction of the probability of flooding and of potential consequences of flooding to human health, the environment and economic activity, and taking into account relevant aspects of water management, soil management, spatial planning, land use and nature conservation.

3. Flood risk management plans shall include measures that aim at achieving the required levels of protection and address all phases of the flood risk management cycle. Here the focus is placed on prevention, protection and preparedness taking into account the characteristics of the particular river basin or subbasin.

4. Flood risk management measures taken in one Member State must not increase flood risks in neighbouring countries.

The Floods directive will impose new challenges for the modelling community. A flood risk assessment must include the likelihood of future floods based on hydrological data, types of floods and the projected impact of climate change and land-use trends. Climate change must also be taken into account when forecasting estimated consequences of future floods to human health, the environment and economic activity. Water managers in some European countries, including the UK, Germany, and the Netherlands, have begun to consider the implications of climate change explicitly in flood management. In the UK, for example, design flood magnitudes are proposed to increase by 20% (rate based on earlier impact assessments) to reflect the possible effects of climate change, while in the German State of Bavaria, the design values are increased by 15%. Measures to cope with the increase of the design discharge for the Rhine in the Netherlands from 15 000 to 16 000 m^3/s must be implemented by 2015 and it is planned to increase the design discharge further to 18 000 m^3/s in the long term due to climate change (cf. Kundzewicz and Mata, 2007).

Except where land-use change occurs, it has conventionally been assumed that the natural resource base is constant.

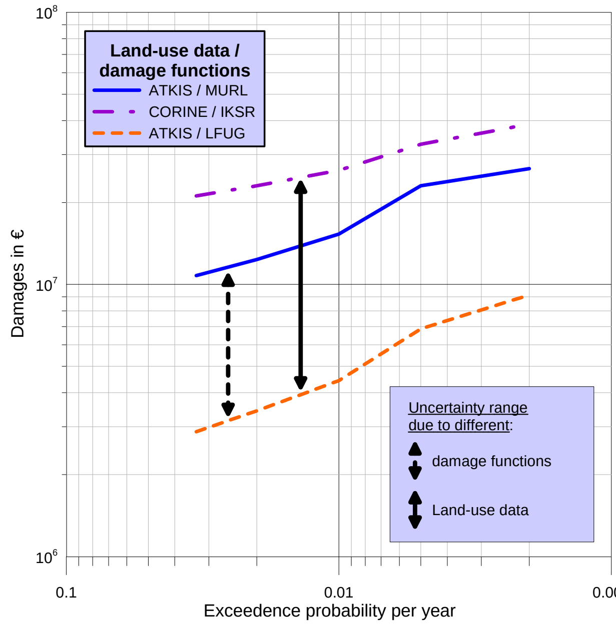

Fig. 3. Total flood damages for return periods up to 500 years for the community of Meissen on the Elbe River in Germany. Calculations are based on different damage functions and land-use data. (source: Herrmann et al., 2007[1]).

[1] Herrmann, U., Thieken, A. H., Suhr, U., and Lindenschmidt, K.-E.: Hochwasserrisikoanalysen an der Elbe – Methodenvergleich und Datenauflösung, Österreichische Wasser- und Abfallwirtschaft, submitted, 2007.

Traditionally, hydrological design rules have been based on the assumption of stationary hydrology, tantamount to the principle that the past is the key to the future, and this is no longer valid under the ongoing global change. The current procedures for designing water-related infrastructures therefore have to be revised. Otherwise, systems would be over- or under-designed resulting in either poor performance or excessive costs. These will pose challenges in the areas of precipitation-runoff modelling, flood routing, spatial flood risk assessment tools (e.g. delineation of flooded areas and flood damage potential, modelling climate and land-use change, downscaling and disaggregation of climate model results, simulation of what-if analysis and modelling coastal flooding).

To meet the demands of the new directive, integrated modelling will be imperative. A conceptual example of such a modelling configuration is given in Fig. 2. These modelling systems require a means of transferring the effects of climate and land-use change to river flow, which further influences flood risk and its impact on economic and social systems.

Both lectures also pointed out specific problems of flood frequency analyses, even if the stationarity assumption is justified. Flood frequency is generally analysed using time series of annual maximum river discharges. Since most discharge data cover only short durations (e.g. 50 years), there is a large uncertainty in characterising rare extreme events with return periods of 100 years or more. In addition, these flood frequency analyses do not incorporate the probabilistic nature of failure of protection measures such as dikes. Hence, additional methods need to be developed to reduce the uncertainty in the flood frequency analysis and provide more accurate estimates of the discharge design specifications. Complimentary methods that may be used to reduce the uncertainty in estimating flood frequencies include incorporation of historical data, inclusion of the probability of dike breaches and calculation of a probable worst flood. Such methods are currently being investigated by the Helmholtz junior research group "Flood" at GeoForschungsZentrum Potsdam (Lindenschmidt et al., 2005, 2006a).

Bruno Merz also stressed the importance of continued research into developing more accurate damage functions. There is still much uncertainty in these functions and the data used to associate the damage in its spatial dimensions, in particular the type and resolution of land-use data (Lindenschmidt et al., 2006b). As an example, Fig. 3 shows the variation in total damages calculated for flood return periods of up to 500 years for the community of Meissen. There is a large variation in the results depending on the damage functions and the land-use data used for the analysis.

References

Barthel, R., Götzinger, J., Hartmann, G., Jagelke, J., Rojanschi, V., and Wolf, J.: Integration of hydrological models on different spatial and temporal scales, Adv. Geosci., 9 (complete volume), http://www.adv-geosci.net/9/, 2006.

BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2005): Water Framework Directive – Summary of River Basin District Analysis 2004 in Germany, 2005.

Bronstert, A., Krysanova, V., Schröder, A., Becker, A., and Bork, H.-R.: Modellierung des Wasser- und Stofftransportes in großen Einzugsgebieten, PIK-Report, No. 43, 216 pp., 1998.

Commission of the European Communities: Directive of the European Parliament and of the Council on the assessment and management of floods (Proposal), {SEC(2006) 66} COM(2006) 15 final 2006/0005(COD), http://ec.europa.eu/environment/water/flood_risk/, 2006.

EC: Establishing a framework for community action in the field of water policy. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000, Official Journal of the European Communities, Brussels, http://ec.europa.eu/environment/water/water-framework/index_en.html, 2000.

Fohrer, N. and Döll, P.: Modellierung des Wasser- und Stofftransportes in großen Einzugsgebieten, Kassel University Press, 229 pp., 1999.

Hennrich, K., Rode, M., and Bronstert, A.: Großskalige Modellierung in der Hydrologie: Flußeinzugsgebietsmanagement, Kassel University Press, 224 pp., 2003.

Gerold, G.: Heterogenität landschaftshaushaltlicher Wasser- und Stoffumsätze in Einzugsgebieten, EcoRegio, 8, 221 pp., 2000.

Krause, P., Bongartz, K., and Flügel, W.-A.: Proceedings of the 8th Workshop for Large Scale Hydrological Modelling – Oppurg 2004, Adv. Geosci., 5 (complete volume), http://www.adv-geosci.net/5/, 2005.

Kundzewicz, Z. W. and Mata, L. J. (coordinating lead authors): Freshwater Resources and their Management, Chapter 3 in: Climate Change 2007. Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, in press, 2007.

Lindenschmidt, K.-E., Fleischbein, K., Petrow, T., Vorogushyn, S., Theobald, S., and Merz, B.: Model system and scenario development for the provisionary management of extreme floods in large river basins, Adv. Geosci., 5, 99–104, 2005, http://www.adv-geosci.net/5/99/2005/.

Lindenschmidt, K.-E., Fleischbein, K., Petrow, Th., Vorogushyn, S., and Merz, B.: Concept for provision management of extreme floods in large river basins using a computer modelling system, Forum für Hydrologie und Wasserbewirtschaftung, 15.06, Proceedings from "Tag der Hydrologie: Risk management of extreme hydrological events" in München, 22/23 March 2006 (Volume 3), ISBN-10: 3-939057-31-2, pp. 205–208, 2006a.

Lindenschmidt, K.-E., Herrmann, U., Pech, I. Suhr, U., Apel, H., and Thieken, A. H.: Risk assessment and mapping of extreme floods in non-dyked communities along the rivers Elbe and Mulde, Adv. Geosci., 9, 1–9, 2006b.

Ludwig, R., Reichert, D., and Mauser, W.: Neue methodische Ansätze zur Modellierung der Wasser- und Stoffumsätze in großen Einzugsgebieten, Kassel University Press, 209 pp., 2004.

Stephan, K., Bormann, H., and Diekkrüger, B.: Möglichkeiten und Grenzen für den Einsatz hydrologischer Modelle in Politik, Wirtschaft und Klimafolgeforschung, Kassel University Press, 162 pp., 2002.

Sutmöller, J. and Raschke, E.: Modellierung in meso- bis makroskaligen Flußeinzugsgebieten, Berichte der GKSS, 15, 171 pp., 2001.