WATER MANAGEMENT OF A THERMAL POWER PLANT – A SITE SPECIFIC APPROACH CONCERNING CLIMATE CHANGE

STEFANIE GREIS, JEANNETTE SCHULZ[*]
AND ULRIKE MÜLLER
European Institute for Energy Research, Germany

Abstract. In this paper a site-specific approach is presented that aims at the analysis of climate change impacts on the water management of a thermal power plant in order to evaluate and identify possible adaptation measures. On the one hand, a model-based quantification of the impacts of changing air and water temperatures on a cooling system is described. On the other hand, a GIS-based risk management is created on the basis of changing flood water levels.

Keywords: Climate change; electricity production; power plant; water management

1. Introduction

The electricity sector is affected by several meteorological and hydrological parameters, e.g. air and water temperatures, humidity and water levels. Most meteorological and hydrological parameters show significant changes in their recent development (positive as well as negative trends depending on the parameter and season). Due to climate change, these variations are expected to increase in mean or extremes respectively (IPCC, 2007; Jacob et al., 2008). In order to identify suitable adaptation measures, a site-specific approach is chosen that provides detailed information on the impact of changing meteorological and hydrological parameters (air and water temperature, floods) of a specific thermal power plant site in Germany (conventional steam/gas power plants). The impacts are quantified and analysed, so that as a next step, effective adaptation measures can be identified

---

[*] To whom correspondence should be addressed: Ms J. Schulz, European Institute for Energy Research EIFER, Emmy-Noether-Str. 11, D - 76131 Karlsruhe, Germany. E-mail: schulz@eifer.uka.de

A. Troccoli (ed.), *Management of Weather and Climate Risk in the Energy Industry*,

and implemented, e.g. an adjusted flood risk management. In the following, the impacts of climate change on power plant cooling systems as well as on flood risks are identified (Chapter 2). Subsequently, the methods and first results of the current study are presented in Chapters 3 and 4.

2. Identification of Climate Change Impacts on Thermal Power Plants

In this section, the impacts of climate change on the water management of thermal power plants are presented. On the one hand, the cooling systems of most power plants are affected, since these are influenced by air and water temperatures. On the other hand, flood risks might increase, which affect the power plant sites along rivers.

2.1. IMPACT OF CLIMATE CHANGE ON THE COOLING SYSTEM OF A THERMAL POWER PLANT

Ambient air and water temperatures influence the electricity production of thermal power plants in different ways: Firstly, the power plant efficiency decreases with high air and water temperatures. The efficiency of a thermal power plant depends on the temperature interval of the steam/gas upstream and downstream the turbine. Since the temperature upstream turbine is limited by material conditions, the steam/gas after the turbine needs to be cooled down as far as possible, if it is not extracted as local or district heat. Due to its high thermal absorption capacity, water is the most effective cooling medium (Kalide, 2005). In water-cooled thermal power plants the steam/gas downstream turbine is conveyed through a condenser where the remaining heat energy is dissipated to a second water cycle. The heated cooling water is either directly discharged into the receiving water (e.g. river) by means of a so-called once-through cooling system or a cooling tower is interposed (mixed-cycle or closed-cycle cooling system) (Kalide, 2005). In comparison to the once-through cooling, the operation of a cooling tower on the one hand decreases power efficiency up to 2–3% due to e.g. increased energy consumption by water pumps or ventilators. On the other hand, the heat discharge into the receiving water is significantly reduced while up to 5% of the cooling water volume is lost through evaporation (Kobus and Bürkle, 1996; Maniak, 2005).

Secondly, the withdrawal of surface water for means of cooling and its discharge back into the receiving water is regulated by threshold values. These are assigned site-specifically by German authorities and regulate e.g. the cooling water temperature, the mixed water temperature after heat discharge or the maximum evaporation loss (Maniak, 2005). The thresholds could be reached more frequently in future, as water and air temperatures significantly correlate and both air temperatures (heat periods respectively) and summer droughts increase due to climate change (IPCC, 2007; Jacob et al., 2008). To prevent the exceedance of the described thresholds, thermal power plants have to reduce the heat discharge into the receiving water by, in the first place, changing the cooling system operation mode from once-through cooling to mixed-cycle or closed-cycle cooling (if technically available). As a last resort, the electricity production has to be decreased or even shut down (Rothstein et al., 2008; Müller et al., 2007). Concerning the studied power plant site, the cooling system operation mode can be switched from once-through to mixed-cycle or closed-cycle cooling. The complex interactions between meteorological and hydrological parameters and the cooling system operation are represented with a dynamic model, which is discussed in Section 3.1. Additionally to the impacts on the cooling system of a power plant, the site itself might be affected as flood risks could increase along rivers. The latter is shown in the following section.

2.2. FLOODS AND THERMAL POWER PLANTS

Most thermal power plants are built along rivers due to their need of high amounts of water for cooling purposes. This can turn into a disadvantage in case of high water levels or floods. Power plants are critical infrastructures since lots of industries, infrastructures and telecommunication depend on electricity. The floods along the River Elbe in the year 2002 and 2006, along the River Oder in 1997 and along the River Rhine in 1993, 1995 and 1999 showed the need for power plants to adapt to flood situations in general.

Power plants in Germany are subject to two different regulations concerning flood protection. The Association of German Engineers (VDI) states a protection level of a 100-year flood for thermal power plants, while the Nuclear Safety Standards Commission (KTA) states a protection level of a 10,000-year flood especially for nuclear power plants (VDI, 2006; KTA, 2004).

Due to climate change, air temperatures and precipitation are expected to increase in Germany, the latter especially in winter (UBA, 2007). Due to the direct influence of increasing precipitation on the river runoff, higher and more frequent floods are expected (Moser, 2006). The German research group KLIWA (climate change and consequences for water management) initiated a research project on 158 gauging stations in Bavaria and Baden-Wuerttemberg. There was no change observed regarding the average runoff, whereas more frequent floods occurred during the winter season in the last decades. An explanation could be a seasonal shift in heavy precipitation from the summer to the winter months (AK KLIWA, 2002). Based on climate projections and the resulting change in runoff, the co-operation project "climate change and consequences for water management" (AK KLIWA) decided to put on a climate change factor which describes a climate-induced extra amount for planning tasks. In order to plan flood protection measures, a so-called design water level or design flood is calculated. It is the highest water level to be expected for certain regions and a certain return period. The design water level at the River Rhine for a 100-year flood needs to be multiplied by 1.15, this means that the new design water level would be e.g. 4.6 m instead of 4 m. The climate change factor is specific to different regions in Southern Germany (AK KLIWA, 2006). The rating of existing as well as the planning of new power plants needs to take into account the climate change factor in order to adapt to future floods. That means the design specifications for the protection against floods need to be revised. Since precipitation will increase in winter, the hazard of flood situations will increase on average as well. When applying the climate change factor to design floods, the amounts of runoff associated with certain return periods rises (AK KLIWA, 2006; Table 1).

TABLE 1. Overview of the climate change factor in Baden-Wuerttemberg, the most relevant return periods for the water management of HQ_2 and HQ_{100} are coloured light grey (LFU, 2005).

T [years]	Climate change factors $f_{T,K}$				
	1	2	3	4	5
2	1.25	1.50	1.75	1.50	1.75
5	1.24	1.45	1.65	1.45	1.67
10	1.23	1.40	1.55	1.43	1.60
20	1.21	1.33	1.42	1.40	1.50
50	1.18	1.23	1.25	1.31	1.35
100	1.15	1.15	1.15	1.25	1.25
200	1.12	1.08	1.07	1.18	1.15
500	1.06	1.03	1.00	1.08	1.05
1,000	1.00	1.00	1.00	1.00	1.00

For the return periods >1,000 years the factor equals 1; $f_{T,K}$ = factor for a certain return period T in a certain climate K

Since thermal power plants are built on different terrain levels, a protection against flooding can never be standardised. Therefore, all flood protection measures are calculated taking into account the return period for floods at a specific site. For example, the height of a dike is calculated using the design flood and the so-called freeboard, the vertical difference between design flood level and dike top (DIN 19712, 1997). The application of this method to site-specific risk management is described in the following Section (Section 3.2.).

3. Methods

Two different approaches are chosen in this study to evaluate possible future effects on water management: on the one hand, a model-based quantification of climate change impacts on a cooling system is chosen. On the other hand, a GIS-based flood risk management is created for a specific power plant site.

3.1. MODELLING CLIMATE CHANGE IMPACTS ON COOLING SYSTEM OPERATION

To quantify the impacts of climate change on the operation of the cooling system of a thermal power plant a model of a cooling system is created using the System Dynamics approach (Software VENSIM®). This approach assumes that dynamical systems, which are characterised by feedbacks and temporal delays, should be analysed by means of dynamical models in order to fully understand the behaviour of the system (Sterman, 2000). The created System Dynamics model allows scenario calculations that show the impact of changing meteorological and hydrological parameters on each part of the cooling system. Hence, e.g. the site-specific probability of reduced electricity production due to the exceedance of statutory thresholds or the possible future changes in gross electrical output can be evaluated.

The database consists of hourly measured data for air and water temperature, humidity, water level, power load, operation mode and cooling water temperature (before and after the cooling tower). Time series with length of approximately 15 years (1993–2008) were provided by the power plant considered in this study. Firstly, missing data and outliers were assessed for each time series. Secondly, the quality of the air and water temperature series was tested with the Standard Normal Homogeneity test by Alexandersson and Moberg (1997). As reference series, measurements of the German Weather Service (DWD) and the State Office for Environment of Baden-Wuerttemberg (LUBW) were utilised (DWD, 2007; LUBW, 2007).

The model relies on the assumptions that the applicable water related thresholds and the future power load remain constant. In order to identify the direct effects of changing air and water temperatures on cooling system operation, another central assumption is a constant electricity price (spot market).

The main input parameter into the model is the air temperature at the power plant site. To simulate the operation of the cooling system until the year 2050, projected air temperatures of the regional climate model REMO (by the Max Planck-Institute of Meteorology, MPI-MET) are used. These are employed as average of nine grid boxes for all of the scenarios calculated by REMO: A1B, A2 and B1 (Jacob et al., 2008; IPCC, 2007; Jacob, 2005). Before simulating cooling system operation under climate change, the results of the REMO control run are compared with the measured data at the site.

Water temperatures are projected using a regression model with daily air temperatures as explanatory variable. To find the best fitting regression function, firstly, a cross-correlation analysis with air and water temperatures is calculated (Schönwiese, 2006). It shows the maximum correlation coefficient at an offset of 3 days. To take this offset into account, a time lag of 3 days is integrated in the model to improve projection quality (Erickson and Stefan, 2000). The daily changes in water temperature are subsequently calculated with a fifth-order polynomial regression. To assess the quality of the water temperature regression model, the correlation between lagged air and water temperature is calculated. The additional input parameters reference water level and relative humidity are estimated with a seasonal cycle, which is created by averaging the available data sets.

A major output variable is the gross electrical output. It is calculated according to the design specifications of the power plant considered here combining them with the parameters cooling water temperature upstream of the condenser and operated load. Furthermore, several parameters specific for the cooling system, like e.g. cooling water temperature at discharge, are computed. Their calculation is based on the design specifications as well. The model parameters are compared with the applicable, site-specific threshold values. If they are exceeded, the cooling system operation is altered. The generalised model structure can be seen in Figure 1.

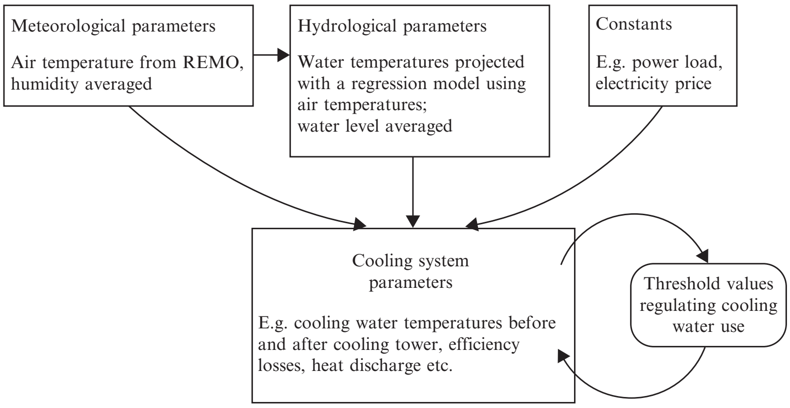

Figure 1. Design of the model for the quantification of the impacts of changing meteorological and hydrological parameter on cooling system use.

3.2. CREATION OF A GIS-BASED FLOOD RISK MANAGEMENT

So far, there is no general concept in Germany for a Geographical Information System (GIS)-based approach of mapping and managing flood risk at a thermal power plant. The advantage of a GIS-based approach is the storage, manipulation and visualisation of all available data of the specific power plant site as well as the legislation and regulations.

According to a scheme by Schmidt-Thomé (Greiving and Fleischhauer, 2006), the four phases of risk management planning are adjusted for the use in a GIS. The four relevant aspects of the scheme of damage assessment are as follow (Büchele et al., 2006):

- Problem analysis: power plant sites are supposed to be protected against flooding. Therefore, all relevant data is collected and integrated into a GIS. This implies the selection of the investigation area as well as the identification and cataloguing of each building in the study area. Furthermore, the design water levels need to be combined with the terrain levels, which can be extracted from a Digital Elevation Model (DEM).
- Assessment of alternatives: different design water levels are illustrated for the different sites. Afterwards a comparison is made.
- Decision-making: based on the illustrated water levels, an individual emergency plan is established and tested. A first assessment of damage according to the degree of utilisation can be provided.
- Implementation: the emergency plan gets implemented at the sites. In this phase, missing protection measures, storage places for mobile protection measures and access routes can be identified within the GIS.

According to this scheme, a standardised GIS-based flood risk management for power plants needs to combine those aspects in order to provide significant background information as well as a practical approach for all types of thermal power plants. The Federal Ministry of the Interior describes risk management as a circle of plan, do, check and act (BMI, 2008). This means that after the preparation of a site-specific plan, implementation is intended. After the occurrence of a flood, the plan needs to be checked whether it worked properly and again, action is needed to improve the plan.

4. First Results

In this section, first results of the site-specific approaches described above are presented. This section is again divided in two parts, i.e. the model-based cooling system analysis and the GIS-based flood risk mapping.

4.1. MODELLING CLIMATE CHANGE IMPACTS ON A COOLING SYSTEM

The available time series contain few missing data or outliers and the tested series are homogenous at the significance level of 95%. Therefore, the quality of the data was deemed satisfactory.

An essential factor for changes in cooling system operation is the evolution of the temperatures in the receiving water. The water temperature regression model (see Section 3.1.) has a good projection quality: the Spearman's correlation coefficient is 0.96 and the coefficient of determination r^2 is 0.92. The result is significant at the level of 99%. The quality of the air/water temperature projection turns out to be acceptable in comparison to other studies, which calculate weekly or monthly water temperatures from air temperatures with coefficients of determination between 0.9 and 0.99 (Pedersen and Sand-Jensen, 2007; Mohensi et al., 1998; Mackey and Berrie, 1991).

The differences between the REMO control run and the available measured data is plotted for monthly mean air temperature over the reference time period 1993–2000 (Figure 2). It becomes apparent that the variations are more distinct in the winter months than during the summer with the exception of the month June.

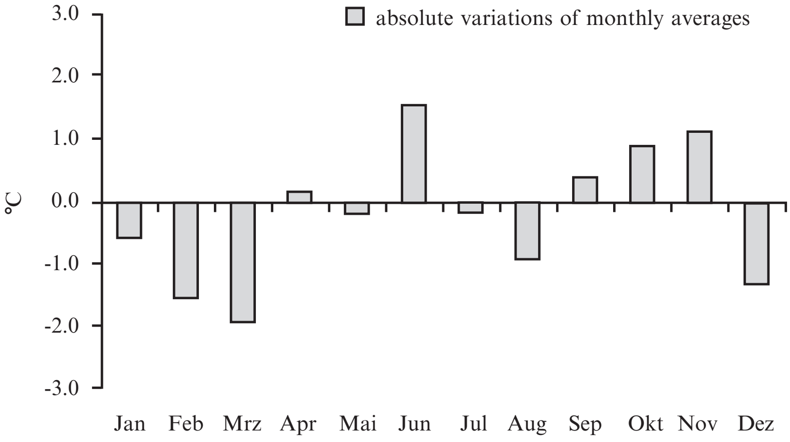

Figure 2. Absolute differences of monthly means of air temperature between the REMO control run and the measured time series for the years 1993–2000.

The results of the water temperature projection until 2050 show an average increase. The change in water temperature in the time span 2021–2050 in comparison to 1961–1990 is 0.8 K for scenario A1B, 0.7 K for scenario A2 and 0.5 K for B1. The average course of the year shows an indentation for the month March and April (Figure 3). This is in accordance with the evolution of the air temperatures for the regarded grid boxes. The standard deviation in the time series increases slightly with 0.2 for scenarios A1B and A2. The exceeding probabilities for high water temperatures change accordingly: The probability for a daily mean water temperature above 22°C increases by 100% for A1B, 76.5% for A2 and 30.2% for B1.

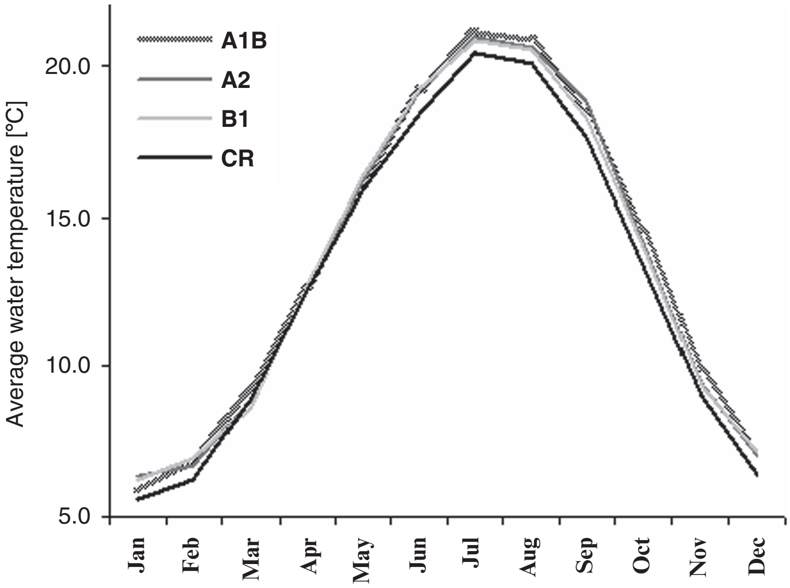

Figure 3. Monthly averages for water temperatures projected from REMO air temperatures for the scenarios A1B, A2 and B1 (2001–2050) and the control run (1961–2000).

The model simulation shows an average decrease in gross electrical output of the power plant considered in this study. The relative decrease comparing the time span 2021–2050 to the control run simulation 1961–1990 is 0.19% for A1B, 0.16% for A2 and 0.09% for B1. The reduction of average gross output is more apparent in summer (0.36% for A1B, 0.18% for B1) than in winter or spring (0.05% for A1B, 0.01% for B1), but still very small (Table 2). The reason for the marginal changes might be the possibility to switch the cooling system operation mode according to the meteorological and hydrological situation (see Section 2.1).

TABLE 2. Relative change in percent of gross electrical output for the scenarios A1B, A2 and B1 for 2021–2050 compared to the control run simulation for 1961–1990.

	Change in A1B in %	**Change in A2** in %	**Change in B1** in %
Spring (Mar, Apr, May)	0.05	0.05	0.00
Summer (June, July, Aug)	0.36	0.28	0.18
Autumn (Sept, Oct, Nov)	0.25	0.23	0.13
Winter (Dec, Jan, Feb)	0.08	0.07	0.06
Year	**0.19**	**0.16**	**0.09**

4.2. MAPPING FLOOD RISK AT AN EXEMPLARY POWER PLANT SITE

In Figure 4 the available data of a DEM, the site and the design water level, which were implemented in a GIS, are displayed. The design water level is calculated to have an overview section through the terrain level, but no real simulation was calculated due to the lack of data. This first visualisation can be used as an overview on the situation at a site and can be easily read even by non-experts.

For responsible persons it is possible to identify dry and flooded areas simply by shades of grey (Figure 4). Darker areas are flooded, which means, that for example a cooling tower might be flooded already whereas the power plant unit is still not flooded and therefore not at risk. Beyond this, a lot of areas are neither flooded nor covered with buildings, so those areas might be possible storage places for mobile protection measures or shelters. Lighter areas that surround the flooded ones are dikes or higher terrain levels. In this case, no modification of the dike is needed since there is no overtopping of the dike to be expected. In case of an overtopping, the GIS could show the areas at risk and therefore the areas that need a modification, for example the heightening of a dike.

As seen in Figure 4, this exemplary power plant does not have to adapt to the current flood level situation. A flood protection was created before the power plant was built. Further calculations might show an increase in the design water level. For this, further maps need to be created in order to assess the water levels site-specifically.

In addition to the maps, a manual for map-making and interpretation as well as a standardised procedure for decision-making in case of an emergency (high water levels) will be established. The responsible persons at the power plant site get the possibility to react to changes in the operating procedure. Power plant sites are obliged to be independent in their planning, so a person in-situ needs the knowledge and the ability to create different maps on his own, especially in case of flooding where the information flow from outside the power plant might be disturbed.

In comparison to an analogue map, mapping within the GIS is fast and includes a high resolution DEM instead of contour lines. An intersection of water levels and the DEM is more accurate. Moreover, background information, e.g. worth of buildings and height of entrances, can be stored and retrieved by selecting them directly. Furthermore, a comparison of terrain and water level reveals the depth of the flooding, so that an analysis, e.g. whether the street is still accessible, can be calculated.

Figure 4. Exemplary map for a thermal power plant. (1) The cooling tower is in a flooded area, the cooling tower pond is already flooded to avoid its floating. (2) The production unit is in a non-flooded area as well as (3) the offices and shops, no damages are expected.

5. Conclusion

The presented site-specific approach, which is used to identify and analyse the impacts of climate change on the water management of a thermal power plant, provides a basis for decision-making concerning relevant adaptation measures. The power plant operators gain insight into the site-specific changes affecting on the one hand cooling system operation and on the other hand their flood risk management.

Regarding the modelling of the climate change impacts on cooling system operation, it can be concluded that the System Dynamics approach is a flexible and powerful tool to analyse the impacts of climate change. The simulation shows that increasing average air and water temperatures result in only very small changes in gross electrical output until 2050. Those changes might become more distinct with intensified global warming until 2100. In the long-term, the scenario calculations provide a basis for site-specific adaptation measures, e.g. future investment decisions for the cooling system can be reviewed taking climate change into account and design specifications can be altered with respect to changing air or water temperatures.

The GIS-based flood risk mapping offers detailed maps to identify dry and flooded areas. These can be used, e.g. to convey the necessary actions in the case of flooding. The combination of maps, which illustrate the emergency, and handbooks or regulations, which describe the procedure in an emergency, is much more comprehensible than the plain description in handbooks/regulations.

References

Alexandersson, H., and Moberg, A., 1997, Homogenization of Swedish temperature data. Part I: Homogeneity test for linear trends, *Int. J. Climatol.* **17:** 25–34.

Arbeitskreis Klimaveränderung und Konsequenzen für die Wasserwirtschaft (AK KLIWA), ed., 2002, Langzeitverhalten der Hochwasserabflüsse in Baden-Württemberg und Bayern, *KLIWA- Reports.* **2:** 98.

Arbeitskreis Klimaveränderung und Konsequenzen für die Wasserwirtschaft (AK KLIWA), ed., 2006, Regionale Klimaszenarien für Süddeutschland. Abschätzung der Auswirkungen auf den Wasserhaushalt, *KLIWA- Reports.* **9:** 102.

Association of German Engineers (VDI), 2006, *Richtlinie 6004-1: Schutz der Technischen Gebäudeausrüstung*. Hochwasser. Gebäude, Anlagen, Einrichtungen, Beuth Verlag, Berlin, 64 p.

Büchele, B., Kreibich, H., Kron, A., Thieken, A., Ihringer, J., Oberle, P., Merz, B., and Nestmann, F., 2006, Flood-risk mapping: contributions towards an enhanced assessment of extreme events and associated risks, *Nat. Hazards Earth Syst. Sci.* **6:** 485–503.

Deutscher Wetterdienst (DWD), 2007, Data Acquisition.

Deutsches Institut für Normung e.V. (DIN), 1997, *DIN 19712: Flußdeiche. Ausgabe 1997-11*. Beuth Verlag, Berlin, 32 p.

Erickson, T. R., and Stefan, H. G., 2000, Linear air/water temperature correlations for streams during open water periods. *J. Hydrol. Eng.* **5(3):** 317–321.

Federal Ministry of the Interior (BMI), 2008, *Schutz kritischer Infrastrukturen - Risiko - und Krisenmanagement, Leitfaden für Unternehmen und Behörden*. Self-publ., Berlin, 87 p.

Greiving, S., and Fleischhauer, M., 2006, Spatial planning towards natural and technological hazards, in: *Natural and Technological Hazards and Risks Affecting the Spatial Development of European Regions,* P. Schmidt-Thomé, ed., Geological Survey of Finland, Special Paper **42:** 109–123.

IPCC, 2007, Summary for policymakers, in: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, eds., Cambridge University Press, Cambridge, UK and New York, USA, 19 p.

Jacob, D., 2005, REMO climate of the 20th century run, UBA project, 0.088 degree resolution, run no. 006210, 1H data, World Data Center for Climate, CERA-DB REMO_UBA_C20_1_R006210_1H, http://cera-www.dkrz.de

Jacob, D., Göttel, H., Kotlarski, S., Lorenz, P., and Sieck, K., 2008, Klimaauswirkungen und Anpassung in Deutschland – Phase 1: Erstellung regionaler Klimaszenarien für Deutschland. *Publication of Umweltbundesamt (UBA), research paper 204 41 138 UBA-FB 000969* **11/08,** 154 p.

Kalide, W., 2005, *Energieumwandlung in Kraft- und Arbeitsmaschinen. Kolbenmaschinen - Strömungsmaschinen – Kraftwerke*. Hanser, Munich, Vienna, 421 p.

Kobus, H., and Bürkle, F., 1996, Konkurrierende Ansprüche an ein Fließgewässer – das Beispiel Neckar, in: *Wasser – die elementare Ressource*, H. Lehn, M. Steiner, H. Mohr, eds., Springer, Berlin, Heidelberg, New York, 368 p.

Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW), 2007, Data Acquisition.

Landesanstalt für Umweltschutz Baden-Württemberg (LFU, now LUBW), 2005, *Festlegung des Bemessungshochwassers für Anlagen des technischen Hochwasserschutzes, Guidelines*. Self-published, Karlsruhe, 91 p.

Mackey, A. P., and Berrie, A. D., 1991, The prediction of water temperatures in chalk streams from air temperatures. *Hydrobiologia.* **210:** 183–189.

Maniak, U., 2005, *Hydrologie und Wasserwirtschaft. Eine Einführung für Ingenieure*. Springer, Berlin, Heidelberg, New York, 666 p.

Mohensi, O., Stefan, H. G., and Erickson, T. R., 1998, A nonlinear regression model for weekly stream temperatures. *Water Resour. Res.* **34(10):** 2685–2692.

Moser, H., 2006, Einfluss der Klimaveränderungen auf den Wasserhaushalt des Rheins, presentation, regionale 2010 – Rhine Conference 2006, 14.11.2006, 25 p.

Müller, U., Greis, S., and Rothstein, B., 2007, Impacts on water temperatures of selected German rivers and on electricity production of thermal power plants due to climate change. Poster publication, 8th forum DKKV/CEDIM: Disaster Reduction in Climate Change Karlsruhe, 15. and 16.10.2007, 4 p.

Nuclear Safety Standards Commission (KTA), 2004, Sicherheitstechnische Regel KTA 2207. *Schutz von Kernkraftwerken gegen Hochwasser*. Self-published, Salzgitter, 7 p.

Pedersen, L. N., and Sand-Jensen, K., 2007, Temperature in lowland Danish streams: contemporary patterns, empirical methods and future scenarios. *Hydrol. Process.* **21:** 348–358.

Rothstein, B., Müller, U., Greis, S., Schulz, J., Scholten, A., and Nilson, E., 2008, Elektrizitätsproduktion im Kontext des Klimawandels. Auswirkungen der sich ändernden Wassertemperaturen und des sich verändernden Abflussverhaltens. *KW Korrespondenz Wasserwirtschaft* **10:** 555–561.

Schönwiese, C. D., 2006, *Praktische Statistik für Meteorologen und Geowissenschaftler*, 4th ed. Borntraeger, Berlin and others, 302 p.

Sterman, J. D., 2000, *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Irwin/McGraw-Hill, Boston and others, 982 p.

Umweltbundesamt (UBA), 2007, Neue Ergebnisse zu regionalen Klimaänderungen. Das statistische Regionalisierungsmodell WETTREG. Background paper, 27 p. (October 15, 2008); http://www.umweltbundesamt.de/uba-info-presse/hintergrund/Regionale-Klimaaenderungen.pdf