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ANALYZING WATER QUALITY CHANGES DUE TO RESERVOIR MANAGEMENT AND CLIMATE CHANGE FOR OPTIMIZATION OF DRINKING WATER TREATMENT

OPTYMALIZACJA PROCESU UZDATNIANIA STOSOWNIE DO ZMIAN JAKOŚCI WODY SUROWEJ SPOWODOWANYCH GOSPODAROWANIEM ZBIORNIKIEM WODY ORAZ ZMIANAMI KLIMATYCZNYMI

Reservoir water for drinking water production may undergo major short-term and long-term quality changes. These are results of natural processes in the water body and of the water's quality entering and leaving the reservoir. Long term quality changes are due to management of catchment areas, but also to a considerable extent by external impacts like climate change. Short term quality changes are impacted by extreme events like rain storms after drought periods, which might also be a result of climate change. Furthermore, short- and mid-term quality changes are impacted by reservoir management, which also influences the ecological state of rivers downstream the reservoir. The purpose of our work is to develop a decision support tool for reservoir management which takes into account short-, mid- and long-term factors for water quality change. With the tool it is intended to simulate not only water quality, but also management impact on flood risk prevention and drinking water quality (treatment efficiency and costs) and to assist decision making for reservoir management. In this paper, water quality changes in reservoirs on the long term and due to extreme events are analyzed, as well as their impact on drinking water treatment. Later further estimations of economic and technological limits of treatment processes will be derived from these data. The analysis provides benchmarks for operation of pilot plants. The approach for pilot scale investigations is presented as well as the concept for development of the decision making tool.

1. Introduction

Drinking water reservoirs predominantly guarantee long-term storage for drinking water supply. Due to continuously ongoing climate change as well as increasing additional demands on drinking water reservoirs, as e. g. flood risk management, energy production and recreational use, water suppliers are permanently facing both sudden and slow raw water quality changes. Despite the numerous conflicts of interest in managing multipurpose reservoirs, raw water has to be provided at not only an adequate amount, but also of high quality. To deal with changes in the nature of reservoir water within the process of drinking water treatment and supply, commonly used treatment technologies have to be optimized or new technologies have to be developed.

Increasing inputs of organic matter into raw waters requires a higher degree of treatment plant efficiency, mostly requiring changes to the whole treatment technology and supply system operation. Increasing concentrations of e. g. humic substances deteriorate the coagulation of water contaminants. The disinfection by-product formation potential and the microbial contamination within the supplying system will increase with decreasing treatment efficiencies. As a consequence of increasing concentrations of particles, algae and organic matter and temporary changes in iron and aluminum concentration within the raw water, more chemicals and flushing water are needed, higher amounts of sludge are produced and there will be a faster breakthrough of filtration plants. Therefore, water suppliers are increasingly confronted with rising costs of operation and waste disposal as well as with sudden and long-term declines in raw water quality. Because of climate change and varying management strategies, drinking water treatment plants will have to be adaptable to changes in raw water quality. Moreover, drinking water supply can be acutely effected by extreme events (e. g. floods), which can even culminate in temporary system breakdowns.

Previous research on reservoir water treatment mainly focused on single boundary conditions like raw water quality, treatment capacity or existent treatment technology. However, these investigations cannot be used as a basis for a decision on how to react in a sustainable manner in cases of changing raw water quality (e. g. caused by floods, intense rain, snowmelt, climate change or changes in catchment area management). For that purpose, besides conventional treatment processes, especially efficient processes to remove dissolved organics and particles are to be applied and optimized using varying raw water qualities. Additionally, a novel technique in water treatment (direct nanofiltration of reservoir water) is considered. The results of the investigations will provide input in a decision making tool to describe the treatment capacity of different process combinations at given raw water qualities.

2. Analysis of Water Quality Changes and Drinking Water Treatment optimization Potentials

Detailed data analysis with respect to real raw water qualities are the basis of technology optimizations. Possible extreme events have to be considered as well as long-term trends. These investigations showed that changes in water quality (concerning organic substances and particles) of drinking water reservoirs in the south-eastern part of Germany have been observed since the early 90s (Heß, 2004; Wolf, 2005; Nitzsche, 2005; Jehmlich, 2005). Such changes are caused by the interaction of extended periods of vegetation and shortened frost periods with frequent extreme events (e. g. intense rain) as well as changes in catchment area management and a decline of emissions from industry. Moreover, declines of reservoir water levels to improve flood protection all over Germany can negatively influence raw water quality.

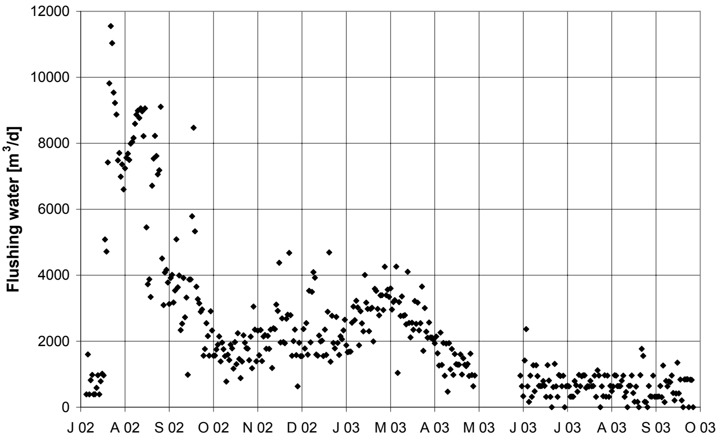

Fig. 1. Amount of flushing water needed in the drinking water treatment plant Dresden-Coschuetz (Germany) during and after the extreme flood in August 2002.

Data analysis concerning the material consumption of drinking water treatment facilities proved expected increases in chemical dosing, amounts of flushing water and sludge production during the last years. These issues could be attributed to sudden changes in raw water quality caused by e. g. extreme events (Fig. 1) and general tendencies regarding rising costs of operation and waste disposal were identified (Tab. 1).

Tab. 1. Amounts of coagulant and flocculant needed and lime sludge produced in the drinking water treatment plant Dresden-Coschuetz (Germany).

	1998	1999	2000	2001	2002	2003	2004	2005	2006
coagulant [t]	244	299	325	391	690	598	515	550	534
flocculant [t}	0,30	0,25	0,30	0,63	0,63	0,63	0,55	0,63	0,63
lime sludge [m^3]	x	1826	1683	1617	1809	2196	2216	2330	2062

The tremendous impacts of extreme events could exemplary be outlined by means of the intense rain event in August 2002 (local 400 mm rain within 2 days) in the eastern Ore Mountains (Germany). This event caused an abrupt rise of inflow to the drinking water reservoirs followed by high increases in turbidity, organic load and iron concentration (Fig. 2). Fig. 2 also shows that the reduction of the Altenberg reservoir peak values was greatly time-delayed, for the values of organic contamination, turbidity and total iron still remaining high or even increasing till the beginning of the following year.

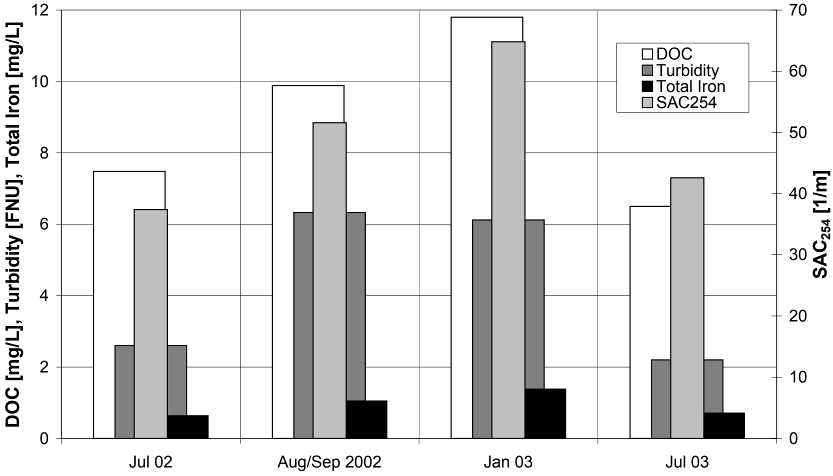

Fig. 2. Development of the parameters DOC, turbidity, SAC and total iron in the drinking water treatment plant Altenberg (Germany) during and after the extreme event in August 2002.

The consequences for drinking water treatment were: increase in coagulant dosage (Fig. 3), flushing water (Fig. 1) and amounts of sludge produced as well as decreases in filter run time. Treatment facilities were running at maximum capacity and dosing limits of iron coagulants were multiple exceeded.

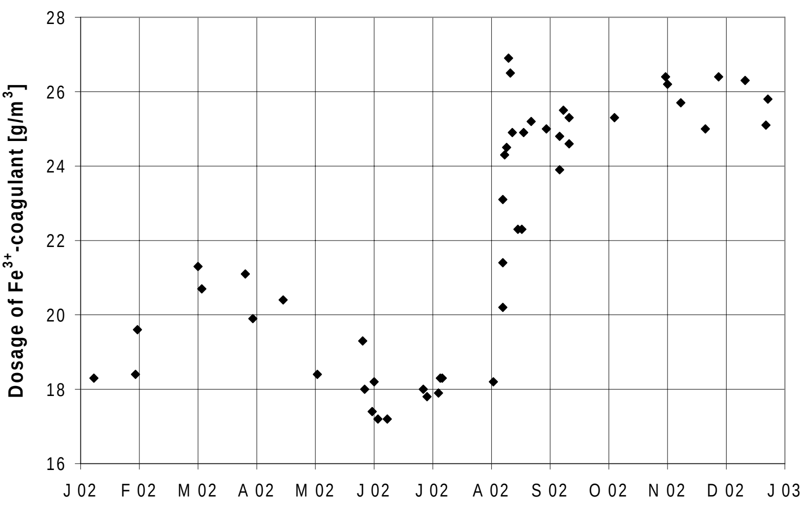

Fig. 3. Dosage of Fe^{3+}-coagulant from January 2002 to January 2003 of the drinking water treatment plant Altenberg (Germany).

The results of this analysis show a high potential for optimizing drinking water treatment with respect to treatment efficiency and costs.

3. Materials and Methods for Optimization of Drinking water Treatment

Analyzing the extreme values and trends of raw water quality reveals considerable need for action with respect to optimization of drinking water treatment. To develop universal methods to treat different raw waters with respect to the particularly relevant parameters turbidity and dissolved organic substances, waters with respectively low and high organic loads have to be investigated. Therefore, the reference raw waters from the reservoir Klingenberg (low organic load and turbidity) and the reservoir Altenberg (high organic load and turbidity) were chosen. To investigate qualities differing from those reference waters, particles can be added or removed and dilutions can also be performed, (Tab. 2).

Tab. 2. Approach and benchmark data to simulate different raw water qualities; ww = water works.

Organic load	**low**		**medium**		**high**	
DOC [mg/L]	1 – 5		5 – 9		9 – 13	
SAC [1/m]	0 – 15		15 – 30		30 – 75	
Particle load	**low**	**high**	**low**	**high**	**low**	**high**
Turbidity [FNU]	0 – 2	2 – 15	0 – 2	2 – 15	0 – 2	2 – 15
Raw water source	ww Coschütz	ww Coschütz	ww Altenberg	ww Altenberg	ww Altenberg	ww Altenberg
Variation by:		dosing of particles	mixing with clear water	mixing with clear water; dosing of particles	elimination of particles	dosing of particles if necessary

Using the investigation results for the raw water, important benchmark data for the test program can be derived. From a qualitative classification of surface water pollution loads, values were estimated (Tab. 2).

To optimize the experimental work, the assignment of values was performed based on the method of statistic test planning. Using this method, experimental design and evaluation plans can be arranged in such a manner that the predetermined objectives can be optimally achieved. In this case, treatment capacity is described as a function of organic load and turbidity. It should be possible to determine required information with maximum accuracy from as few as possible experiments. Using the method of statistic test planning, simultaneous variation and investigation of all variables within a single experimental plan will be possible. Thus, distinction of significant variables from insignificant as well as the identification of expected trends in the optimum values will be possible.

The classification of organic loads was performed based on the parameter DOC. Appropriate SAC values are additionally given in Tab. 2, but are only providing a reference and not being taken into consideration for statistical analysis. To ideally analyse the results of the statistic test planning method, the classification of organic loads (as DOC) was performed using equal intervals of DOC-values.

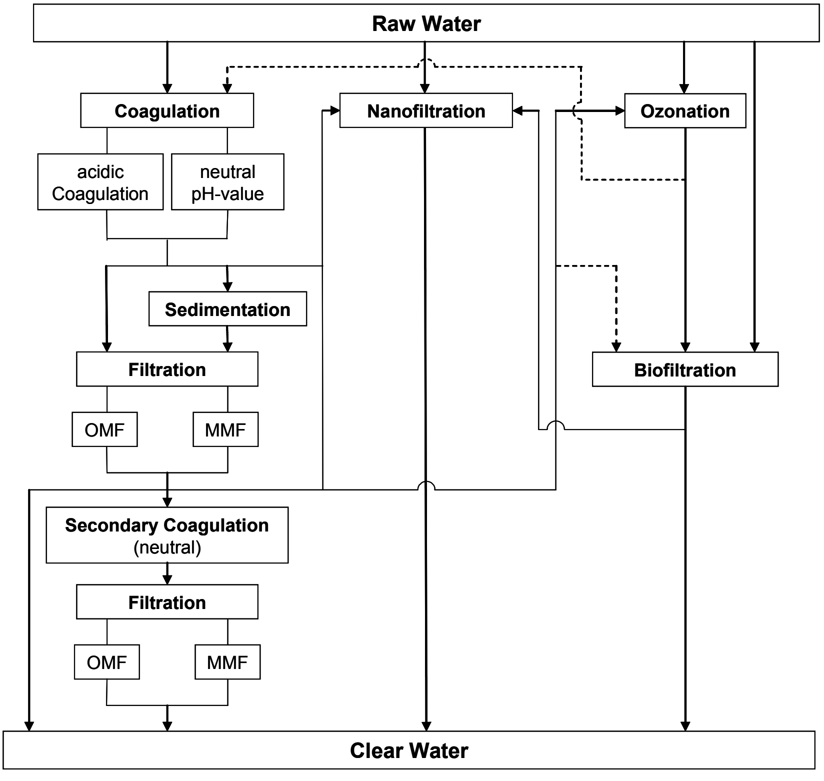

Fig. 4. Experimental process combinations. OMF = one-media filter, MMF = multi-media filter.

Coagulation and filtration are the chosen technologies to treat raw water with low organic loads and variable particle concentrations. To treat raw water with high concentrations of organic compounds, increased requirements exist. Therefore, process combinations of oxidation/biofiltration and nanofiltration (with and without pre-treatment) have to be applied in addition to the conventional processes of coagulation and filtration. Fig. 4 shows all potential process combinations. These technologies will be investigated to determine efficiencies and limits. From these investigations, required operation parameters (dosing chemicals, degree of treatment efficiency, sludge production, filter run, flushing intervals, etc.) will be determined.

The investigation on eliminating turbidity at low concentrations of organic compounds is performed using a steady state pilot plant for coagulation and filtration within the treatment plant Dresden-Coschuetz (Germany). This pilot plant consists of 2 filter columns with a diameter of 0.15 m, which are connected to upstream flocculation tanks. Particles and chemicals can be dosed at these upstream flocculation tanks. The effluent turbidity is continuously measured with a digital device; the head loss is visually read. The filter outlet flow to provide constant flow rates is regulated by float-operated tanks.

The treatment of raw water with medium to high particle and organic loads is performed using a steady state pilot plant for coagulation and filtration within the treatment plant Altenberg (Germany). This pilot plant is equipped for classic coagulation and filtration, but can also perform as biofilter. Filtration takes place using 4 filter columns with a diameter of 0.2 m. A partial automation of this plant is performed by mechanic effluent flow regulation and coupled inductive flow-through measurement as well as pressure measurement using differential gages to continuously record head loss. The parameters pH, oxygen concentration, conductivity, turbidity, SAC_{254} and TOC are measured quasi-continuously using a digital system. Fig. 5 shows the process and flow chart.

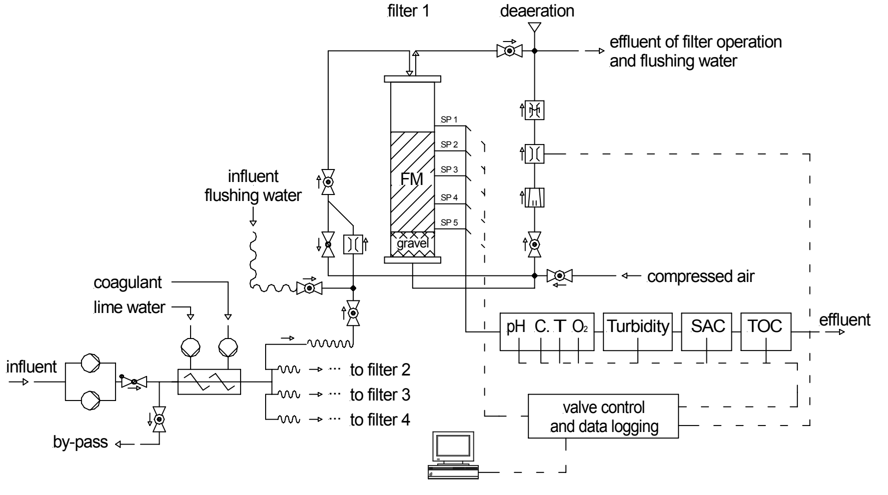

Fig. 5. Process and flow chart of the pilot plant in the Altenberg (Germany) treatment facility.
FM = filter media; SP = sample point; C. = conductivity; T = temperature; O_2 = oxygen concentration.

In preparation for the small-scale investigations, coagulation jar tests were performed. These investigations provide a basis for determining the optimization potential of the conventional technologies and operation methods depending on pH, coagulant and flocculant concentration. It was investigated whether, and under which settings, acidic conditions for coagulation can be applied to treat raw waters with high organic loads. The operation of the pilot plant will be based on the results of those lab-scale investigations.

4. Development of a Decision making tool

The conclusions and results of the drinking water treatment optimization analysis can be used as basis for the development of a computer model describing the effects of different reservoir management strategies on reservoir water quality and quantity, flood retention capacity, the ecological state of the rivers downstream and drinking water treatment. Users of this decision support tool should be able to predict certain states of reservoir water quality and quantity and the ecological quality of the rivers downstream the reservoir as well as their effects on drinking water treatment. This technological model should offer the possibility to find optimal reservoir management strategies for current or prospective incidents using definite target values and limits as input data (Fig. 6).

The secondary focus of this tool's development is aimed at the description of the impact of varying raw water qualities on drinking water treatment and supply. Water suppliers may use this tool to determine the optimal reaction to changing raw water conditions (e. g. during extreme rain events or droughts, because of modified management strategies or climate change) to guarantee a secure and sustainable water supply. The objective is to make separate predictions of treatment capacity and costs of different treatment technologies for various possible raw water qualities.

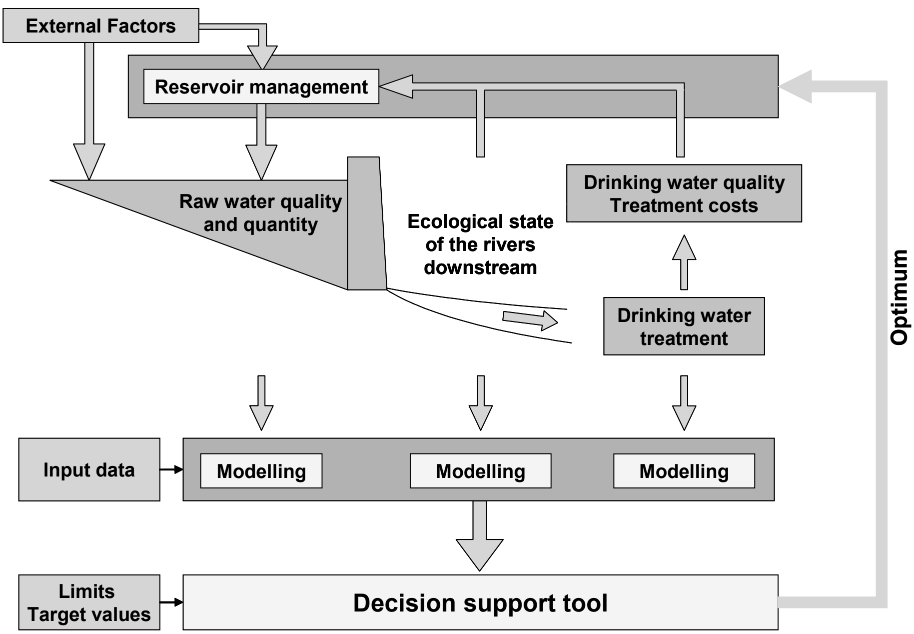

Fig. 6. Scheme of approach to develop a decision-making tool to optimize reservoir management and consequently drinking water treatment.

5. Conclusion

The intensive literature research provided a database of numerous raw water parameters in south-east German drinking water reservoirs. Factors influencing raw water quality could be determined by analyzing the literature and raw water data. Climate change, decreasing emissions from industry as well as management strategies in the catchment area or reservoir, respectively, are regarded as major causes of changing raw water qualities. The results of the literature research also provided benchmark data for operating pilot plants. Estimations of economic and technological limits of the conventional treatment processes and alternative technologies will be based on these results. For this reason, it is essential to extensively analyze not only raw water data but also operating data from treatment plants. This is to determine treatment capacities and effluent water qualities of different conventional technologies under varying raw water qualities and to calculate resulting costs of operation.

As a result of these considerations the authors seek to attain information about optimizing potentials, limits and deficiencies of applied technologies and operating methods using present and especially predicted raw water qualities. The results of the experimental investigation will provide a basis for technological models, in which all essential operating data will be integrated. These models are meant to become part of a decision-making tool to optimize reservoir management (Fig. 6). All required actions to guarantee safe and economic drinking water treatment in the future will be derived from this tool.

6. Nomenclature

C.		Conductivity
DOC	mg/L	dissolved organic carbon
FM		filter media
MMF		multi-media filter
O_2		oxygen concentration
OMF		one-media filter
SAC_{254}	1/m	spectral absorption coefficient at 254 nm
SP		sample point
SSAC		specific spectral absorption coefficient
T		temperature
TOC	mg/L	total organic carbon

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References

[1] **DREWAG – Stadtwerke Dresden GmbH:** Parameters of reservoir Altenberg raw water, 2007.

[2] **Enke, W., Kuechler, W., Sommer, W.:** Climate forecast for Saxony – Recapitulatory report: Regionalization of climate model results of the weather classification statistical method and subordinated multiple regression analysis for Saxony. Engl. of: „Klimaprognose für Sachsen - Zusammenfassender Bericht: Regionalisierung von Klimamodell-Ergebnissen des statistischen Verfahrens der Wetterklassifikation und nachgeordneter multipler Regressionsanalyse für Sachsen.“, 2001.

[3] **Heß, K.:** Investigations on the effect of changing raw water conditions in reservoirs on drinking water treatment; exemplary demonstrated for the reservoirs Carlsfeld and Sosa. Engl. of: „Untersuchungen zu den Auswirkungen der veränderten Rohwasserbeschaffenheit von Trinkwassertalsperren auf die Trinkwasseraufbereitung am Beispiel Carlsfeld und Sosa.“ Diploma thesis at Technische Universität Dresden, Institute of Urban Water Management, 2004.

[4] **Jehmlich, R.:** Treatment of humic substances containing waters by coagulation and filtration. Engl. of: “Aufbereitung huminstoffhaltiger Waesser durch Flockung und Filtration.“ Diploma thesis at Technische Universitaet Dresden, Institute of Urban Water Management, 2004.

[5] **Landestalsperrenverwaltung des Freistaates Sachsen (LTV):** Parameters of reservoir Klingenberg raw water, 2007.

[6] **Nitzsche, P.:** Investigations on optimizing coagulation and filration under acidic conditions. Engl. of: “Untersuchungen zur Optimierung der Flockenfiltration im sauren pH-Bereich.“ Diploma thesis at Technische Universitaet Dresden, Institute of Urban Water Management, 2006.

[7] **Wolf, C.:** Trends in raw water conditions of dystrophic drinking water reservoirs and effects on treatment processes as well as possibilities of taking influence; exemplary demonstrated for the reservoir Carlsfeld. Engl. of: “Trends in der Rohwasserbeschaffenheit von dystrophen Trinkwassertalsperren und Auswirkungen auf die Wasseraufbereitung am Beispiel der Talsperre Carlsfeld sowie Möglichkeiten der Beeinflussung.“ Final report. Technische Universitaet Dresden, Institute of Urban Water Management, unpublished, 2005.

[8] **Wolf, C.; Uhl, W.; Heiser, A.:** Needs for adaptions in catchment area management and drinking water treatment as consequence of climate change (oral presentation). In: Proc. IWA World Water Congress, Beijing/China, Sept. 10 – 14, CD-ROM, 2006.