

**A2.2 - Modelling and Optimisation of Water Resources  
Management Systems**  
Time: Tuesday, 14.09.2010  
Location: Humboldt-Building, Lecture Room 010  
Chairman: Th. Rauschenbach (DE-Ilmenau)

9:00 a.m.	A. Gnauck (DE-Cottbus)
<p><b>A Simulation Framework for Freshwater Eutrophication Management</b></p> <p>Eutrophication of freshwater ecosystems is characterised by an intensive increase of dissolved nutrients in water bodies, by excessive growth of green plants, mainly algae, by decreasing transparency, by anoxic conditions of deeper water layers, by loss of biodiversity, by restricted water uses as well as by taste and odour problems. Man-made impacts have been caused shifts in the states of freshwater. To obtain control options for the eutrophication management of a river basin a modelling and simulation framework was developed. It consists on a MATLAB based stationary 1D-eutrophication model for shallow water bodies combined with an optimisation tool. Modern time series analysis methods were used for process identification. Model state variables are given by algal biomass, zooplankton, orthophosphate phosphorus, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen as well as by dissolved oxygen and biochemical oxygen demand. The phosphorus remobilisation from sediment was included in the phosphorus balance equation. Dependencies of ecosystem state variables of external driving forces are modelled by analytical and regression type functions. For parameter optimisation the software tool ISSOP was used. For simulation and eutrophication management the river basin of the Lower Havel was divided into several river segments of different length's and hydraulic characteristics. Basic Simulation runs for algal biomass (<math>y_1</math>), orthophosphate phosphorus (<math>y_2</math>) and nitrate nitrogen (<math>y_3</math>) are carried out. To compute optimal management strategies options the following goal functions are used: Algal biomass <math>f_1(t) = \sum_x \sum_t y_1(x, t) \rightarrow \min.</math>, orthophosphate phosphorus <math>f_2(t) = \sum_x \sum_t y_2(x, t) \rightarrow \max.</math>, nitrate nitrogen <math>f_3(t) = \sum_x \sum_t y_3(x, t) \rightarrow \max.</math> Two management strategies are considered: (i) Natural strategy according to limiting nutrient concept (LNC). (ii) Impact strategy according to LAWA concept. Management options according to LNC lead to a diminished phytoplankton maximum in late summer by optimised nitrate concentrations. No effect of optimised orthophosphate phosphorus concentration can be stated. On the other hand, management options according to LAWA regulations lead to nearly the same behaviour of algal biomass in spring but to smaller differences of phytoplankton maxima and to low nutrient concentrations in late summer. As a result the LAWA concept leads to significant lower nutrient concentrations but to a slight increase of phytoplankton biomass. In opposite of that an eutrophication management according to the LNC results in lower phytoplankton concentrations but higher admissible nutrient inputs.</p>	

9:20 a.m.	D. Karimanzira, Th. Rauschenbach, H. Linke, Th. Bernard, O. Krol, M. Jacobi (DE-Ilmenau)
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**A Simulation-Optimization-Based Decision Support System for Water Allocation**

Water is critical, but often overlooked element in sustainable development. The paradigm encapsulated in the "Beijing water allocation decision support system" (BjWDSS) explicitly challenges conventional, fractional water development and management systems and places emphasis on integrated approach with more coordinated decision making across sectors and scales. Recognizing that exclusively top-down, supply-led, technically-based and sectoral approaches to water management are imposing unsustainably high economic, social and ecological costs on human and on the natural environment. BjWDSS utilize optimization techniques to facilitate optimal decision making in the planning and management of especially large scale water resources systems. A water system involves several stakeholders with different, often conflicting objectives, and thus the proper framework for the statement of the decisional problem under consideration should be that of multi-objective decision analysis. Therefore, BjWDSS couples a simulation model based on the RiverMod-Library with numerical search methods IPOPT/HQP for optimizing relevant decision variables. The concept is tested and now in application on the large scale Beijing water supply system, where all challenges of water resources management come together. Beijing is in a temperate zone with a semi-humid monsoon climate. Rainfall varies geographically, seasonally and yearly. Eighty-five percent of rainfall falls between July and September. At times, 40-70% of rainfall falls within 3 days. Beijing's total population has topped 17.4 million. With population growth and expansion of the economy, water demand has increased dramatically. Aside from problems such as excessive withdrawal and water quality deterioration of surface waters, the lack of regional coordination leads to issues such as uncoordinated withdrawals and upstream water contamination. The results of the DSS show that the concept significantly improves the water system's performance in terms of sustainability, efficiency and survivability.

**Modelling of Algae Growth by combining Fuzzy Logic and Finite Element Method**

One of the main challenges for modelling of spatial distributed phenomena is the estimation of the model parameters. For many environmental processes (e.g. biochemical or biophysical processes) the physical phenomena like flow and mass transport can be described by partial differential equations (PDEs) of fluid dynamics, but for parameters like growth rates often no analytic models are available or the existing models require a large number of parameters which are hard to determine. However, in many cases experts have knowledge about the system behaviour that can be formulated by a set of IF...THEN rules. As this kind of knowledge can easily be handled by so-called Fuzzy models we propose the coupling of Finite Element models with such Fuzzy models. By this means one or more parameters of the classical PDEs are estimated by Fuzzy Models. Besides the natural inclusion of expert knowledge a second benefit of this approach consists in the fact that Fuzzy Models can describe even very nonlinear phenomena. The calculation of the Fuzzy model consists in the steps (1) Fuzzyfication, (2) inference and (3) defuzzyfication. Within step (1) the considered input/output variables are transformed to linguistic variables. In the inference unit (step (2)) the actual processing of the linguistic variables is performed whereby IF...THEN rules have to be formulated by experts that describe the interdependence of the input parameters to the output parameter(s). The defuzzyfication (step (3)) generates crisp physical output values of the Fuzzy model. The concept of coupled Fuzzy and FEM models is demonstrated by the modelling and simulation of algae growth in flat water bodies and related eutrophication effects. The proposed approach is very suited for this problem as the hydrodynamics is well understood whereas the biochemical processes are still a topic of research and the developed models are very complex and require a big number of parameters. Since in general the required parameters (e.g. growth rates) are not measurable for the entire model domain the idea raised to estimate them by taking the main variables (e.g. temperature, fluid velocity, nutrients concentration) into account and estimate the algae growth rate by Fuzzy model.

10:00 a.m. | Th. Westerhoff, B. Scharaw (DE-Ilmenau)

**Sensor based Leak Detection in Urban Water Supply Systems on the example of the drinking water distribution network of the city of Darkhan, Mongolia**

Leakages and the water loss caused by them are one of the most important problems in urban water distribution systems. Because water supply networks are located below the surface it is very difficult to detect leakages. Only large leaks generate through the ground. Currently leak detection happens manually by pacing off the pipes and listening to the typical noise produced by leakages. Therefore one has to know the approximate position of the leak. Another method to detect the leak position on one single pipe is the use of acoustic correlators. Fraunhofer AST takes part at an IWRM (Integrated Water Resource Management) project in Mongolia. In the city of Darkhan, the largest city in the project area, the water loss is about 45% of the fed in water. The positions of the leaks are unknown. The use of correlators is difficult because the pipes are installed very deep into the ground. The intention of the project is to install a pre-defined amount of some combined pressure-/flow-/noise-sensors at selected nodes in the supply network. There are two goals in the project. First is to estimate the position of the leak by pressure measurement. Network outflow (consumer demands, leakages) produces a typical pattern of hydraulic head over the network caused by the head loss in the pipes. Because the consumer demand will change with a typical profile during the day and the amount of leakages depends on the net pressure it is possible to estimate the position of leaks by using evolutionary optimization algorithms in combination with a hydraulic simulation using the software tool HydroDyn. The disadvantages of this approach are the requirement of exact demand profiles as well as very accurate pressure and flow measurements. To increase the accuracy another approach with additional acoustic sensors which measure the noise in the water network will be developed. When a leakage occurs then a typical noise propagates through the network with the speed of sound. That speed varies with the water temperature, the flow directions and the structure of the network. With the knowledge of these parameters a very fast detection of the leak position will be possible short after the leakage occurs.

10:20 – 10:40 a.m. Coffee break

10:40 a.m. | D. Schwanenberg, G. Verhoeven, L. Raso (NL-Delft)

**Nonlinear Model Predictive Control of Water Resources Systems in Operational Flood Forecasting**

We present a Nonlinear Model Predictive Control (NMPC) algorithm for real-time decision support on the management of water resources systems in operational flood forecasting. The algorithm consists of an iterative, finite horizon optimization of the system over a short-term control horizon. The underlying process models are a set of nonlinear ordinary differential equations. Depending on the physical properties of the specific system, these equations are solved numerically either by an explicit or implicit time stepping scheme. Objectives of the control, i.e. the desired damping of flood peaks, and constraints such as the water level dependent capacity of a structure are mathematically formulated by a set of objective functions and inequality constraints. The resulting optimization problem is solved by Sequential Quadratic Programming (SQP). For enabling the real-time application of the algorithm, we present the derivation of adjoint systems on the discrete level of the process models for computing the gradient of the objective function related to the controlled variables at the computational costs of a single model execution. The algorithm is applied to i) the control of a reservoir system of four reservoirs and ii) to the control of six hydraulic structures and two major flood detention basins along the bifurcation points of the Rhine River in the Netherlands.

11:00 a.m.	A. Gnauck, B. Luther (DE-Cottbus)
<p><b>Parameter Optimisation and Sensitivity of an Eutrophication Simulator</b></p> <p>Modern environmental management decisions are based on simulation models of ecosystems or ecological processes. To get suitable results for management purposes the process of setting up of parameter values and initial conditions is of high importance. Options for eutrophication management will be obtained by scenario analyses with changing parameter values. For the determination of quantitative values of parameters three different approaches can be taken: A preliminary estimate is obtainable from laboratory and field observations of processes and effects by means of correlation analysis or by parameter estimation techniques. Combinations of parameters in keeping with a modelled situation may be obtained by means of estimation from parameter optimisation techniques. Estimates of parameter importance of a simulation model may be obtained by sensitivity analysis which is important for model validation. Investigations of parameter changes are carried out for an eutrophication simulator of a lowland river basin. Three classical approaches to sensitivity analysis can be distinguished: Sensitivity to major parameter changes (The values of some parameters are arbitrarily changed within the expected limits of their validity, and the response of system investigated). Experimental sensitivity analysis (The parameter values <math>p_i</math> are changed by a finite amount <math>\Delta p</math>, the model rerun and model outputs for nominal and changed parameter vectors abstracted. The result depends on <math>\Delta p</math>). Analytical sensitivity analysis (Sensitivity functions are calculated representing partial derivatives of state variables <math>u_j</math> to parameters: <math>S(p_i) = \partial u_j / \partial p_i</math>. This method of sensitivity analysis is based on linearisation around the nominal solution). Estimating sensitivity to external parameters, those connected with driving variables or site constants, a picture is getting how a given freshwater ecosystem would behave under different conditions. For internal parameters, the goal is too determine the importance of parameters for the adaptability of the model to reality. Eutrophication is referred to algal growth and intensive increase of dissolved nutrients within the water body. These man-made impacts influence matter fluxes and biological activity of a freshwater ecosystem. Therefore, those parameters connected with algal growth are of special interest for eutrophication management. In the paper, results of a parameter optimisation and sensitivity analysis of an eutrophication simulator are discussed. The influences of internal and external driving forces on parameter changes are demonstrated. The importance of parameters is visualised by ranking with Hasse diagram technique. The output of the eutrophication simulator investigated is most sensitive for parameters characterising algal growth and dynamics. A second level of sensitivity is given by parameters describing nutrient cycles within the water body. In opposite of that, the food chain based influence of zooplankton to phytoplankton was found very stiff.</p>	
12:00 noon – 1:30 p.m. Lunch	
End of Lecture Session	