Report as of FY2007 for 2006FL144B: "Cooperative Graduate Research Assistantships Between the Florida Water Resources Research Center-South Florida Water Management District UF/ABE in Critical Water Resources Areas for South Florida"

Publications

- Conference Proceedings:
  - Lagerwall, Kiker, Muñoz-Carpena. 2007. TaRSE-ECO: Ecological algorithms for the RSM model. FL-Section of ASABE, MAy 31, 2007, St. Pete Beach, FL.
  - Zajac, Z., R. Muñoz-Carpena, Y-M. Kuo. 2007. Application of Global Sensitivity and Uncertainty Analysis Techniques to the Vegetative Filter Strip Model (VFSMOD). University of Florida, Department of Agricultural and Biological Engineering. FL-Section of ASABE, MAy 31, 2007, St. Pete Beach, FL.
  - Muller. S., R. Muñoz-Carpena and G. Kiker. 2007. Global Sensitivity and Uncertainty of a Wetland Phosphorus Water-Quality Model, Accounting for Variable Model Structure. FL-Section of ASABE, May 31, 2007, St. Pete Beach, FL.
  - Muller. S. and R. Muñoz-Carpena. 2007. Towards an objective framework for evaluation of hydrologic models: state-of-the-art methods. ASABE Paper No. 072212. St. Joseph, Mich.: ASABE.
- Other Publications:
  - Jawitz, J.W., R. Muñoz-Carpena, K.A. Grace, S. Muller, A.I. James. 2007. Spatially Distributed Modeling of Phosphorus Reactions and Transformations in Wetlands. Scientific Investigations Report 2006-XXXX. U.S. Department of the Interior. U.S. Geological Survey (under review).
- Articles in Refereed Scientific Journals:
  - Muller. S. and R. Muñoz-Carpena. 2007. Effect of variable model structure in modelling wetlands phosphorus water quality in South Florida. (in review, Adv. Water Resources).
  - Muñoz-Carpena,R. Z. Zajac, Y.-M. Kuo. 2007. Evaluation of water quality models through global sensitivity and uncertainty analyses techniques: application to the vegetative filter strip model VFSMOD-W. (in review, Trans. of ASABE)

Report Follows

Cooperative Graduate Research Assistantships Between the Florida Water Resources Research Center-South Florida Water Management District UF/ABE in Critical Water Resources Areas for South Florida

Project Description

Two specific research projects have been agreed and contracted with South Florida Water Management District (SFWMD). The status of each research project is presented followed by more specific program details and long-term objectives.

Topic 1: Sensitivity Analysis Of South Florida Regional Modeling
Topic 2: Addition of Ecological Algorithms into the RSM Model

Progress report: Topic 1

Sensitivity Analysis for the SFWMM

PI: Dr. Rafael Muñoz-Carpena[1], Co-PI: Dr. Wendy Graham[2]

[1] *Department of Agricultural and Biological Engineering, University of Florida*

[2] *Water Institute, University of Florida*

1. Review of Previous Sensitivityy Analysis of the SFWMM

We conducted a detailed review of the sensitivity analysis performed on the South Florida Water Management Model (SFWWM), as presented in the Model Documentation of SFWMM Version 5.5). The traditional approach of varying one parameter at a time was used for this analysis. The results indicated that most geographical regions, of the model's domain were most sensitive to WPET (Wetland Potential ET) and that, coastal areas were strongly influenced by CPET (Coastal Potential ET). However, this review found that the methods applied for the different inputs and modeling subdomains are often inconsistent and at times subjective. Examples of this are the different and insufficiently explained variational ranges applied to the parameters (which changed for the different regions where the model is applied), or the varying criteria selected to identify a parameters as sensitive or not. As a result, the sensitivity analysis performed appears too simplistic and not appropriate for the level of complexity and importance of the SFWMM as a regional management tool. Our findings are in agreement with those of the "SFWMM Peer Review Panel", which recommended a more thorough approach towards sensitivity analysis of SFWMM, including global sensitivity techniques.

2. Review of Alternative Global Sensitivity and Uncertainty Methods

We performed a review of modern global sensitivity analysis techniques suitable for application to SFWMD models. Hydrological and water quality models are often

complex and require a large number of parameters and other inputs. Mathematical models like these are built in the presence of uncertainties of various types (input variability, model algorithms, model calibration data, and scale). The role of uncertainty analysis is to propagate all these uncertainties, using the model, onto the model output of interest. Complementarily, sensitivity analysis is used to determine the strength of the relation between a given uncertain input and the output. As a result of these analyses, the model user can learn what model input factors affect the output of interest the most, and possibly quantify the uncertainty of the model due to the most sensitive inputs. This knowledge is critical to efficiently guide the model calibration as well as to document the validity of the model outputs for management or decision tasks. In spite of their importance, these analyses are not usually performed in many model development and application efforts today. Even if they are performed, the procedures used are often arbitrary and lack robustness. Usually derivation techniques (variation of the model output over the variation of the model input) are employed. These methods are applied just over a prescribed (and usually small) parametric range, only can handle one-parameter-at-a-time (OAT techniques), and can consider efficiently but a few parameters. When the model output response is non-linear and non-additive, as with most complex model outputs, the derivative techniques are not appropriate. As an alternative, new global sensitivity and uncertainty techniques are available that evaluate the input factors of the model concurrently over the whole parametric space (described by probability distribution functions). So far, two modern global techniques, a screening method (Morris method) and an analysis of variance one (Fourier Analysis Sensitivity Test-FAST) were identified as potentially suitable for performing the sensitivity analysis of the SFWMM. An initial application of these techniques to the new water quality component of the SFWMD RSM model has been recently performed (Jawitz et. al. 2007), as well as to the water quality model VFSMOD (Muñoz-Carpena et. al. 2007).

3. Publications

Jawitz, J.W., R. Muñoz-Carpena, K.A. Grace, S. Muller, A.I. James. 2007. Spatially Distributed Modeling of Phosphorus Reactions and Transformations in Wetlands. Scientific Investigations Report 2006-XXXX. U.S. Department of the Interior. U.S. Geological Survey (under review)

Muñoz-Carpena, R. S. Muller, and Z. Zajac. 2007. Application of Global Sensitivity and Uncertainty Analyses Techniques to a the vegetative filter strip model VFSMOD (Invited paper for Soil and Water Centennial Collection, Trans. of ASABE, in preparation)

Progress Report: Topic 2
Addition of Ecological Algorithms into the RSM Model

CoPIs: Gregory Kiker, Rafael Muñoz-Carpena, Wendy D. Graham,
SWFMD Coordinator: Naiming Wang
Ph.D. Student: Gareth Lagerwall
Collaborator: Andrew James

Progress to Date:

This research project aims to systematically review, design and develop selected ecological algorithms for the RSM model using a similar methodology to the development of recent water quality algorithms (RSM-WQ).

Activities for this project have included the usual startup related activities including formation of Mr. Lagerwall's supervisory committee and the design/submission of a coursework plan. The graduate committee consists of the following persons:

Dr G A Kiker (Dept of Agr. & Bio. Engineering) Chair

Dr R Munoz-Carpena (Dept of Agr. & Bio. Engineering) Co-Chair

Dr K Hatfield (Civil and Coastal Engineering)

Dr A James (Soil and Water Sciences)

Dr N Wang (SFWMD) (to be added shortly)

Research activities have been primarily focused on a review of the RSM and RSM-WQ models (including their fundamental designs, code layout/design and input/output structures). Weekly meetings were conducted with Dr Andy James, Prof Munoz-Carpena and Prof Kiker to understand and explore potential design challenges in adding ecological components to the RSM structure. In addition, other integrated regional models (FT-LOADS/SICS/TIME) were included in review discussions to provide a variety of design viewpoints for upcoming object/code design discussions. It is expected that increased communications/discussions with SFWMD modelers will be required to establish upcoming design and implementation strategies for code expansion.

Program Details and long-term objectives:

Cooperative Graduate Research Assistantships Between the Florida Water Resources Research Center-South Florida Water Management District UF/ABE in Critical Water Resources Areas for South Florida

As mentioned previously, two specific research projects have been agreed and contracted with South Florida Water Management District (SFWMD): ***Topic 1: Sensitivity Analysis Of South Florida Regional Modeling and Topic 2: Addition of Ecological Algorithms into the RSM Model.***

Topic 1: Sensitivity Analysis Of South Florida Regional Modeling

CoPIs: Rafael Muñoz-Carpena, Wendy D. Graham, Gregory Kiker
SWFMD Coordinator: Jayantha Obeysekera
Ph.D. Student: Zuzanna Zajac

Introduction

Mathematical models are built in the presence of uncertainties of various types (input variability, model algorithms, model calibration data, and scale) (Haan, 1989; Beven, 1989; Luis and McLaughlin, 1992). Propagating via the model all these uncertainties onto the model output of interest is the job of uncertainty analysis. Determining the strength of the relation between a given uncertain input and the output is the job of sensitivity analysis (Saltelli et al., 2004). The evaluation of model sensitivity and uncertainty must be an essential part of the model development and application process (Reckhow, 1994; Beven, 2006). Although sensitivity analysis is useful in selecting proper parameters and models, and model uncertainty provides much needed assessment of results, they are rarely used in most water quality modeling efforts today (Muñoz-Carpena et al., 2006). If uncertainty is not evaluated formally, the science and value of the model will be undermined (Beven, 2006). The consideration of model uncertainty should be linked to the availability or efficient collection of data. This combination will allow: a) to improve the representation of the inputs and boundary conditions; b) refine the evaluation of the model complexity structure; c) indicate what models are adequate for specific applications; and d) constrain feasible sets of effective parameter values at particular applications (Beven, 2006).

"Input factor" in a broad sense refers to anything that changes the model prior to execution. This not only includes the model parameters, but entirely different conceptualizations of the system. Input parameters of interest in the sensitivity analysis are those that are uncertain; that is, their value lies within a finite interval of non-zero width. Traditionally, model sensitivity has been expressed mathematically as model output derivatives; these are normalized by either the central values where the derivative is calculated or by the standard deviations of the input parameter and output values. These sensitivity measurements are "local" because they are fixed to a point or narrow range where the derivative is taken. Local sensitivities are used widely and are the basis

of many applications, such as the solution of inverse problems. These local sensitivity indexes, used in "one parameter at a time" methods, quantify the effect of a single parameter by assuming all others are fixed (Saltelli et al., 2005). Sometimes a crude variational approach is selected in which incremental ratios are taken by moving factors one at a time from the base line a fixed amount (for example, 5 percent). This is often done without prior knowledge of the factor uncertainty range or the linearity of the output response.

Techniques that vary one parameter at a time relative to a chosen initial value have some inherent drawbacks. Using such local sensitivity indexes for the purpose of assessing relative importance of input factors can only be effective if the effects of model parameters are all linear, unless some kind of average over the parametric space can be made (Saltelli 2004). Often, the models are non-additive (non-linear) and an alternative "global" sensitivity approach is more appropriate. Exploring the entire parametric space of the model may answer questions such as (1) which of the uncertain input parameters largely determine uncertainty of a specific output, or (2) eliminating uncertainty in which input parameter would reduce output uncertainty by the greatest amount (Saltelli et al., 2005).

Different types of global sensitivity methods can be selected based of the objective of the analysis. For computationally expensive models or if a large number of parameters need to be evaluated simultaneously, it is usually more efficient to apply a screening method. This type of method provides a parameter ranking in terms of relative effect over output variation. Screening tools yield a qualitative parameter ranking that allows the user to focus the calibration or development effort on the most sensitive parameters. If quantitative information is desired, an analysis of variance technique is usually required.

The South Florida Water Management Model (SFWMM) is a regional-scale computer model that simulates the hydrology and the management of the southern Florida water resources system from Lake Okeechobee to Florida Bay. The model simulates all the major components of the hydrologic cycle in southern Florida on a daily basis using climatic data for the 1965-1995 period. The SFWMM is widely accepted as the best available tool for analyzing regional-scale structural and/or operational changes to the complex water management system in southern Florida (http://www.sfwmd.gov/org/pld/hsm/models/sfwmm/index.html). A derivative based local sensitivity analysis was performed by the South Florida Water Management District (SFWMD) for 8 parameters of the SFWMM for a number of sites to which the model was differentially calibrated based on land use characteristics and availability of historical hydrological data (SFWMD, 2005). As parameters ranges characteristic for South Florida conditions were not found in the literature, they were assessed in an unconventional way: “for each parameter, a series of model runs were completed to determine the range of acceptable values such that each parameter within the range can be used without significantly affecting the calibration”. A recommended permissible variation of the parameters was thus determined to be ±10% for WPET (Wetland PET), ±20% for CPET (Coastal PET) and ±50% for other parameters.

Such derivative-based techniques as were applied in this work were found inadequate by the “SFWMM Peer Review Panel” and in a recent report (Bras et al., 2005). The panel recommended that the District adopts effective and quantitative measures of sensitivity.

Objectives

In the proposed research, global sensitivity approaches and alternative sensitivity techniques will be undertaken. Global sensitivity measures will provide a measure of the overall model sensitivity to a parameter across the entire distribution of its possible values. Choice of sensitivity analysis techniques will depend on the following criteria: 1) the computational cost of running the model, 2) the number of input parameters, 3) the degree of complexity of model coding, 4) the amount of time available to perform the analysis and 5) the ultimate the objectives of the analysis. For computationally expensive models, or when large numbers of parameters need to be evaluated simultaneously, a screening technique can prove more efficient. These kind of methods provides a qualitative measure of the relative importance of each of the parameters. For quantitative comparisons of parameter sensitivity variance-based methods will be used

Scope of Work:

Year 1

- Literature review on sensitivity analysis methods and theory
- Understanding the fundamental principles, inputs and parameter requirements of the model
- Selection of an application case (domain/subregion) for sensitivity analyses

Year 2

- Identification parameters and the distribution of each parameter from existing data at the application site and literature (for the intended area of application i.e. South Florida).
- Selection of sensitivity analysis method(s) to be applied, tools and training.
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Years 3

- Carry out the sensitivity analysis.
- Interpretation of results.

D**eliverables:**

These are proposed to permit the evaluation of the project by the three partners of this project as included in the UF/SFWMD Cooperative Agreement:

1) One-page quarterly reports summarizing the progress in recruiting, enrolling, developing supervisory committees, developing plans of study, developing research proposals, courses taken, and research conducted by the Ph.D. student.
2) Annual summary report.
3) Regular progress meetings at UF and/or SFWMD.
4) A final report at the completion of each students degree program (the content of this report will be close to that of the students dissertation).

5) One or more papers submitted to a peer-reviewed journal, co-authored with the student's adviser and the South Florida Water Management District Staff that actively works with the student in his research study. The paper(s) should cite the financial, in-kind, and technical support received from the South Florida Water Management District and the Water Resources Research Center.

References:

Beven, K. (1989), Changing Ideas in Hydrology -- The Case of Physically Based Models. Journal of Hydrology, 105: 157.

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SFWMD (2005), Final Documentation for the South Florida Water Management Model (v5.5). South Florida Water Management District and the Interagency Modeling Center West Palm Beach, Florida, November, 2005.

Topic 2: Addition of Ecological Algorithms into the RSM Model

CoPIs: Gregory Kiker, Rafael Muñoz-Carpena, Wendy D. Graham,
SWFMD Coordinator: Naiming Wang
Ph.D. Student: Gareth Lagerwall
Collaborator: Andrew James

Introduction

Alterations to the natural delivery of water and nutrients into the Everglades of the southern Florida peninsula have been occurring for nearly a century. Major regional drainage projects, large-scale agricultural and urban development, and changes to the hydrology of the Kissimmee River-Lake Okeechobee-Everglades watershed have resulted in substantial changes in ecological components of all these systems. The highly connected nature of groundwater and surface water systems over large spatial areas has necessitated the development of integrated regional modeling approaches to adequately represent the unique hydrological and ecological conditions of southern Florida.

The Regional Simulation Model (RSM) was developed to provide an integrated surface and subsurface hydrological model for the development and exploration of water management and habitat restoration objectives (SFWMD, 2005). One of the primary challenges in developing RSM and its concomitant implementation within southern Florida (SFRSM) is to provide a flexible and adaptable framework for new code additions and expanded functionality while maintaining stable simulations for management analysis. Recent RSM code addition projects have successfully added generic water quality components into the model structure (RSM-WQ: Jawitz et al., 2006). This approach used an innovative mixture of conceptual model design, XML implementation and global sensitivity analysis to provide water quality algorithm designs for multiple modeling platforms while being implemented and tested within RSM. Given the initial success of the RSM-WQ module additions, interest has been growing to utilize elements of this approach to add ecological algorithms with a similar methodology. Ecological components and their representation within modeling platforms present a significant challenge as a variety of algorithm designs exist ranging from simplified Habitat Suitability Indices (USFWS, 1981; Tarboton et al., 2004) to Spatially Explicit Species Index (SESI) and individual models (DeAngelis et al., 1998; Curnutt et al., 2000) to more complex, high resolution, individual-based models (Goodwin et al., 2006).

Objectives

This research project aims to systematically review, design and develop selected ecological algorithms for the RSM model (RSM-ECO) using a similar methodology to the development of water quality algorithms (RSM-WQ). To this end, the objectives of this research are the following:

- Review of relevant ecological models, design concepts and code implementation tools for development of RSM-ECO ecological algorithms.

- Selection of ecological species (habitat, plant and/or animal) to be included in the initial development and testing of RSM-ECO.
- Development of the conceptual model of RSM-ECO organisms
- Prototype model development and testing on the "10x4" mesh (Jawitz et al., 2006)
- Selection of a test site for model calibration and testing
- Model implementation and testing on selected test site
- Systematic global sensitivity analysis

Scope of Work:

Evolution of the RSM-ECO model and its associated simulation results will be posted on-line with reports and deployed software (Years 1-3). A basic schedule is listed as follows:

Year 1: Review of relevant models and concepts

- Review current RSM and RSM-WQ design and code structure
- Current ecological model designs/algorithms (*i.e.* HSI models, ATLSS, ELM, ELAMS)
- Object-oriented design and code implementation (Java and C++)

Year 2: Development of conceptual models for selected organisms

- Selection of organisms for initial RSM-ECO inclusion and testing.
- Development of the "10x4" site with selected organisms for prototype testing
- Selection and development of parameters for a South Florida test site for RSM-ECO

Year 3: Model implementation on selected test site

- Sensitivity Analysis
- Calibration/Validation with SFWMD ecological data
- Development of technical documentation

D**eliverables:**

These are proposed to permit the evaluation of the project by the three partners of this project as included in the UF/SFWMD Cooperative Agreement:

6) One-page quarterly reports summarizing the progress in recruiting, enrolling, developing supervisory committees, developing plans of study, developing research proposals, courses taken, and research conducted by the Ph.D. student.
7) Annual summary report.
8) Regular progress meetings at UF and/or SFWMD.
9) A final report at the completion of each students degree program (the content of this report will be close to that of the students dissertation).

10) One or more papers submitted to a peer-reviewed journal, co-authored with the student's adviser and the South Florida Water Management District Staff that actively works with the student in his research study. The paper(s) should cite the financial, in-kind, and technical support received from the South Florida Water Management District and the Water Resources Research Center.

References:

Curnutt, J.L., J. Comiskey, M.P. Nott, and L.J. Gross. 2000. Landscape-based spatially explicit species index models for Everglades restoration. *Ecological Applicat*ions 10:1849-1860.

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Related research.

As described above, these training efforts will complement existing research conducted by the PIs. Currently this includes work with NSF, FDEP, FDACS, USGS and SFWMD that will provide a foundation for the new assistantships. Within the first year the PIs, with the close cooperation of SFWMD staff, have recruited the listed students and have developed supervisory committees, plans of study and Ph. D. research proposals that match the interests formulated by the SFWMD. These research areas encompass, but are not limited to, global sensitivity analysis and uncertainty of hydrologic/water quality models, ecological modeling in South Florida. These research proposals are co-funded with matching funds from SFWMD.

Training potential.

Two Ph.D. graduate students will be trained through this effort.

Investigator's qualifications.

Resumes from the project PIs and collaborator are included in the next pages.