

# Developing a Graphical User Interface to Improve Learning of Stochastic Theory in Hydrosiences in the Classroom

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**Abstract** –The objective of this paper is two fold: i) to gauge the current state of instruction of stochastic theory for water resources in US universities and thereby identify the potential for curriculum improvement and ii) to demonstrate a proof of concept of a computer-assisted Graphical User Interface (GUI) to improve the current state of learning in the classroom of stochastic theory for hydrosiences. Our study indicates that 84% of the total 241 relevant courses surveyed are available only at the graduate level, while 4.5% and 11.5% were either dual-listed or undergraduate-level courses, respectively. It is worthwhile for the CE educators to consider creating more undergraduate variants of such courses and offer them to students early in their education experience. To further popularize stochastic theory education in context of water resources, more computer-assisted graphics-based schemes should also be used in the undergraduate classroom. The illustration provided herein is a GUI that connects a comprehensive space-time stochastic model for generating rainfall fields that exhibit complex natural variability. Our main finding, based on on-going educational software development, is that effective instructional software building requires evolution from the simplest configuration if its continual upgrade is to continue in liaison with student software developers that are usually available from a computer science department of the university.

**Keywords:** Computer-assisted instruction, graphical user interface, stochastic theory, water resources.

## INTRODUCTION

Stochastic theory is a very important subject matter in any engineering discipline. It helps describe the omni-present uncertainty in man-made or natural systems and further helps us to mathematically model it for prediction. Most engineering curricula have some element of stochastic theory delivered as learning objectives. However, research accumulated over the last two decades indicate that the existing teaching paradigm of stochastic theory that is conventionally adopted in classrooms may be inadequate and in need of modification. Calls for a change in teaching probability theory in the classroom are nowadays gaining widespread recognition (Romero et al., 1995). This change ranges from demonstrating a collection of unrelated methods illustrated by coin tossing or dice-rolling to introduction of theory applied in real-world problems [e.g., Box, 2; Godfrey, 5].

In the modeling of natural water resources systems in civil engineering (CE), stochastic theory receives significant emphasis due to heightened awareness of the limitations of deterministic approaches to modeling [Beven, 1], scale incongruity between input data such as rainfall and hydrologic model grids [Hossain and Lettenmaier, 7], and the wide-spread heterogeneity in naturally occurring variables of the land form (e.g. vegetation, topography, soils, geology, etc.). Thus, it has become increasingly important to use stochastic/statistical concepts to advance the hydrologic science domain of water resources engineering by bridging the gap between current observation capability and the model's predictive uncertainty [Bras and Rodriguez-Iturbe, 3].

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Emerging research in the water resources discipline indicates a fast evolution towards greater use of stochastic methods. This recognition therefore warrants prior knowledge of computational skills for the novice graduate research student. This consequently raises a major demand on the admission criterion for a graduate research program that entering students must be well prepared *a priori* on the computational aspects of stochastic theory for conducting independent research in the hydrosience area. Huddleston et al. [8] however warns that as an applied science, there exists a natural tension between the study of fundamental scientific theory and instruction in the application of analysis and design methodologies within undergraduate engineering curricula. Most engineering courses are structured to emphasize the relevant physical, chemical and biological processes that are then reinforced by studying specific problem solving skills applied to systems of engineering interest. Consequently, the level of application complexity and realism introduced to undergraduates is often limited by students' computational capability. Instructors must diligently balance the need to emphasize the engineering system physics versus instruction in numerical methods used to solve resulting mathematical equations. Student comprehension of basic concepts on stochastic theory may often be impeded by their ability to master archaic computational skills [Hossain and Huddleston, 6].

A computer-assisted graphics-based learning system can potentially enhance the capacity of students to conduct independent research more effectively by training them in computational applications of stochastic theory. Very recently, Stern et al. [15] has demonstrated the importance of integrating computer-assisted learning and simulation technology in undergraduate engineering courses relevant to computational fluid dynamics. Thus, if students are given early exposure to this mode of instruction at the undergraduate-level and allowed to immerse in an intensive research experience, better prepared students could be cultivated for a state-of-the-art graduate research program on water resources involving stochastic theory across institutions nationwide.

However, to assess the validity of our assumption that stochastic theory education can be improved through a GUI-based computer instruction and to further identify if current curricula has an inherent demand for such approaches, there is a need to first survey the curriculum that is adopted by the universities nationwide. The objective of this paper is therefore two-fold: i) to gauge the current state of instruction of stochastic theory for water resources in US universities and thereby identify the potential for curriculum improvement and ii) to demonstrate a proof of concept of a computer-assisted Graphical User Interface (GUI) to improve the current state of learning in the classroom of stochastic theory for hydrosiences.

## **SURVEY OF CURRICULA FOR STOCHASTIC THEORY EDUCATION IN WATER RESOURCES**

### **Methodology of Survey**

Our aim was to perform a broad-based survey and collect baseline data on the universal set of courses in CE that offered any element of stochastic theory or its nearest relative sub-area (numerical methods, quantitative methods) as learning objectives. Using public domain information available on the world wide web, we downloaded information from university websites on CE curricula on the following key parameters: i) Name of University; ii) Course Name in CE; iii) Course details - Number of Credit Hours, Website address (course website), Instructor Name, Instructor Email; iv) Official catalog description of syllabus.

The search for courses was governed by a blanket keyword match in course titles or course catalog descriptions for the following words: 'Stochastic', 'Numerical', 'Statistics', 'Quantitative', and 'Probabilistic'. The courses identified in this manner are therefore subject to the following assumptions: i) Information posted by university course catalog or instructor's website on the world wide web is accurate and up to date; ii) All relevant course content information is available from the world wide web; iii) All courses are actively offered on a routine basis by instructors; iv) The course has a significant amount of stochastic theory component (or a nearest relative discipline) delivered as course content.

## Survey Results

Out of the 67 universities surveyed, we failed to identify any relevant stochastic theory-related course in CE for 10 universities. This can probably be attributed to the inherent limitations of any web-based survey because it is highly unlikely that an accredited CE curriculum would not address the basic elements of statistics and probability. Nevertheless, the 84% of the universities that were found via the web to offer stochastic theory education of some sort demonstrates the general recognition of importance curriculum developers place on this subject matter as part of the overall CE discipline. The total number of courses that were identified in this broad-based fashion was 241. A similar percentage (84%) of these courses were found to be available only at the graduate level, while 4.5% and 11.5% were either dual-listed or undergraduate-level courses, respectively. The current overwhelming proportion of graduate courses perhaps underscores a current need to rethink strategies and strive for a more equitable distribution that would facilitate a smoother learning experience. For example, creating more undergraduate variants of these graduate courses and offering them early in a student's CE education experience are likely to further strengthen the appreciation of the concepts on stochastic methods by the CE student.

## PROOF OF CONCEPT THE GRAPHICAL USER INTERFACE (GUI)

### Novelty of a GUI in Water Resources Education

For the study of water resources in general, there exists a wide body of literature describing various teaching methods based on the use of computer technology. For example, the 2001 December issue of *Journal of Hydraulic Engineering* (American Society of Civil Engineers - ASCE) devoted an entire issue to the subject of teaching hydraulic design. Jewell [10] illustrated the utilization of equation solvers to facilitate instruction in various areas of hydraulic engineering. Other studies include Huddleston [9] on the use of spreadsheet applications, and Whiteman and Nygren [16] on the perspective of maintaining a balance between theory and computer software application. However, little literature seems to exist on potentially effective ways to impart computer-assisted instruction on concepts of stochastic theory for water resources engineering [Hossain and Huddleston, 6]. Hence, it makes sense to pursue the development and application of a GUI tool for instruction.

### The Stochastic Theory Model

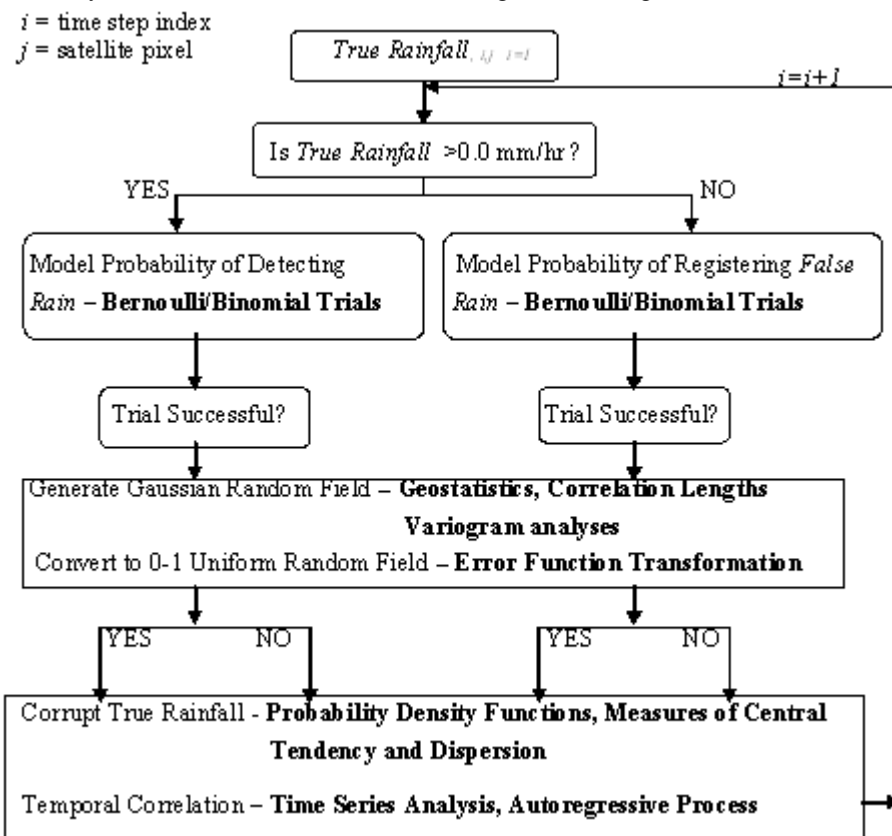
The stochastic model that we considered embedding in our GUI visualization tool is named 'Two-Dimensional Satellite Rainfall Error Model (*SREM2D*)' [6]. *SREM2D* can be used to simulate satellite-rainfall fields from accurate and high resolution reference rainfall data that it corrupts. These simulated satellite rainfall fields can then be visualized graphically according to pertinent stochastic parameters to observe independently the nature of variability of satellite rainfall estimates as function of sensor type, season, regime and location. The students can thus compare their own observations to appreciate the direct link of theory to what they observed in practice. Constructivist theory postulates that such highly interactive learning environments in which the student has an enhanced degree of control should result in greater and deeper learning [Kluger, 11; Smock, 14; Zimmerman, 17]. Furthermore, educational media that utilizes multiple methods of engaging the student in learning activity has a greater potential for meeting the individual learning needs of the student [McCarthy, 12].

At a minimum, *SREM2D* can translate the following concepts of stochastic theory (through a real-world application involving rainfall corruption): (1) General probability theory; (2) Discrete and continuous probability density functions; (3) The concept of a random process; (4) Random trials such as Bernoulli/Binomial trials; (5) Time series analysis; (6) Geostatistics and optimal spatial interpolation (kriging); and (7) Random field generation (unconditional/conditional simulation). *Figure 1* shows a flowchart of the major stochastic concepts that are manifested in *SREM2D*.

### Software Blue-print for the GUI

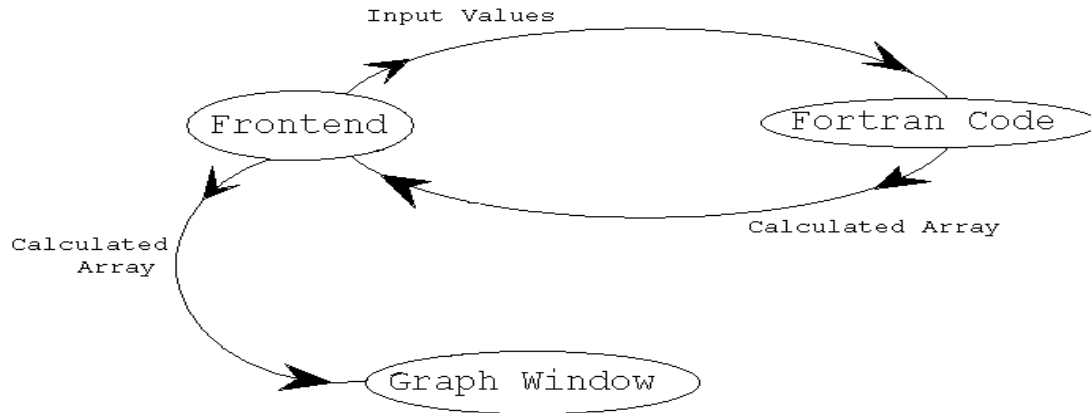
The proposed GUI linking *SREM2D* to a PC visualization environment was developed using the following blueprint. There were three essential software design entities: i) *Frontend*, ii) *Fortran Code*, and iii) *Graph Window* (*Figure2*). The *Frontend* entity was the main source of our software technology program. All calls and receiving were done within this entity. It gets the input from the data provided by the user, and then sends that data to the

*Fortran Code* for calculations. This input data basically comprises various concepts of stochastic concepts and the nature of its implementation in *SREM2D*. *Frontend* receives the calculated data (output) and then finally sends that output to create and display the graph. The *Fortran Code* entity is basically the *SREM2D* algorithm that has already been coded in Fortran 77. Source modifications to this program were minimized to preserve the theoretical consistency of the parent *SREM2D* concept that has been thoroughly verified a priori. This *Fortran Code* accepts input from the *Frontend* and sends back the calculated data for graph processing (Figure2). The *Graph Window* is the program GUI. After *Frontend* sends its inputs to the *Fortran Code* and receives the calculated data, it then sends a signal to the *Graph Window* for rapid visualization. This visualization has two output panels – i) control and ii) experimental. The control panel visualizes the effects at ‘default’ input, thus allowing the experimental (user-defined) panel to be compared with and observe the effect of changing values related to stochastic concepts. For example, a student may be interested in observing the effect of increasing or decreasing the ‘correlation length’ (i.e., a stochastic theory concept) of successful detection of rain by a particular satellite sensor (Passive Microwave or Infrared). The GUI will provide a plot of a two dimensional colored contour field on the randomly generated satellite field for low and high correlation lengths to enhance the student’s ability to understand the actual meaning of ‘spatial structure’ for modeling natural variability. Subsequently, the student can assess the implications of spatial structure on optimal interpolation such as random field generation. Similarly, a student may be curious in understanding the meaning of temporal autocorrelation of estimation error (for time series analysis – a stochastic theory concept) and may choose to use the GUI for contrasting values of lag-one correlation values of



**Figure 1.** Flow-chart for *SREM2D* showing the major concepts of stochastic theory for generation of satellite-like rainfall fields

satellite retrieval bias. The GUI can also plot the time-series (animation) of satellite rainfall fields for the two contrasting conditions thereby assisting the student in appreciating the difference in his/her choice of parameter values. The entity dependency diagram is summarized in Figure2.



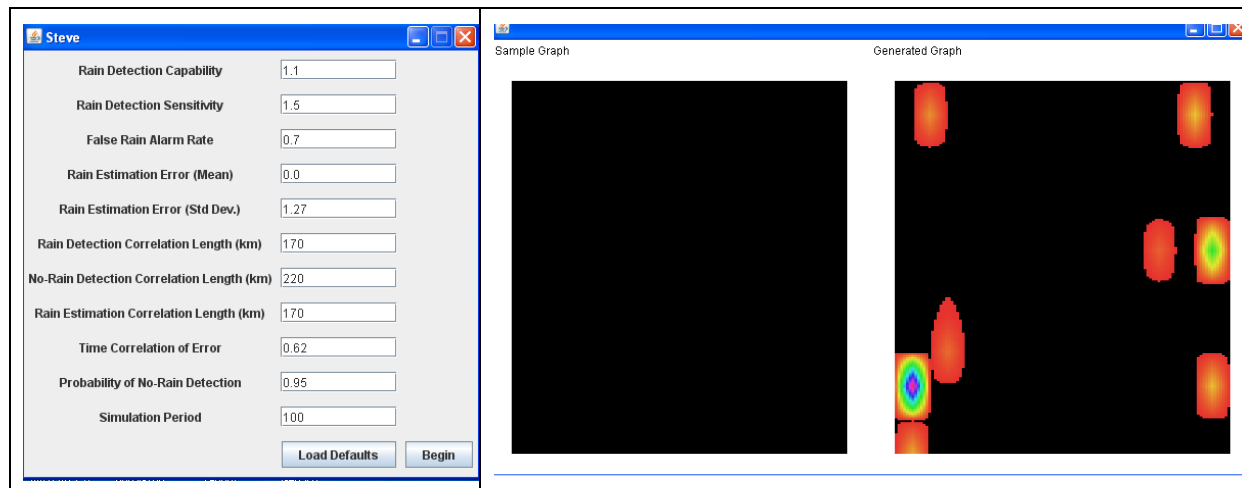
**Figure 2.** Entity dependency diagram for prototyping the *SREM2D*-GUI.

### Proof of Concept of the GUI

A concept demonstration of the technology has been completed at Tennessee Technological University as part of a senior-level software design project by Computer Science Majors. The prototype tool was named **STEVE** ver1.0 (Stochastic Theory Education through Visualization Environment (*Figure3*); see <http://iweb.tntech.edu/fhossain/steve.html>). The STEVE GUI comprises a control panel, (left panel of *Figure3*) where the user can key input parameters on stochastic theory concepts. A Java Native Interface was used for communication between the Fortran code of *SREM2D* and the GUI wrapper. This way, the GUI could be executed on a windows operating system without the requirement of additional softwares or fortran compilers. It would only need to be compiled once before the parent software installation stage. The right hand side represents a screen capture of the output (in this case, animated field sequence of control rainfall fields Vs experimental rainfall fields in time). The software interface is still in development and has not been optimized for performance. Currently, the graphic visualization requires excessive time when the simulation period is long, often leading to a memory overload. More efficient ways of interfacing the *SREM2D* are being investigated. *However, this preliminary implementation and evaluation of the GUI concept clearly demonstrates that the STEVE GUI can indeed be a valuable tool for improving instruction in stochastic theory.* Our main finding, based on on-going educational software development, is that effective instructional software building requires evolution from the simplest configuration if its continual upgrade is to continue in liaison with student software developers that are usually available from a computer science department of the university.

### CONCLUSION

Our study indicates that 84% of the total 241 relevant courses surveyed on stochastic theory for water resources are available only at the graduate level, while 4.5% and 11.5% were either dual-listed or undergraduate-level courses, respectively. We believe that it is probably worthwhile for the CE educators to currently consider creating more undergraduate variants of such courses and offer them to students early in their education experience. To further popularize stochastic theory education in context of water resources, more computer-assisted graphics-based schemes should also be used in the undergraduate classroom. We have demonstrated a proof of concept of once such example. Our adopted example was a GUI that connects a comprehensive space-time stochastic model for generating rainfall fields that exhibit complex natural variability. Our main finding, based on on-going educational software development, has been that effective instructional software building requires evolution from the simplest configuration if its continual upgrade is to continue in liaison with student software developers that are usually available from a computer science department of the university.



**Figure 3.** The STEVE (ver 1.0) GUI currently developed at TTU. Left panel is the control panel where user keys in input parameters for various stochastic theory concepts. Right panel visualizes on the basis of user-driven input. A control visualization for 'default' parameters is also created to visually observe the effect stochastic theory concepts.

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Faisal Hossain received his Ph.D. from The University of Connecticut in 2004. Prior to that, he had earned his M.S. and B.S. from The National University of Singapore and Banaras Hindu University (India), respectively. From 2002-2004, he was the recipient of NASA Earth System Science Fellowship. His education interest is on the development of effective computer-assisted visual instruction schemes to improve the learning of water resources engineering. He is the author of more than 40 archival journal publications and the associate editor of the Journal of American Water Resources Association.

### **David Huddleston**

David Huddleston received his PhD from The University of Tennessee (1989) in Engineering Science and M.S in Engineering Mechanics from Virginia Polytechnic Institute and State University (1978). His research interests are on computational fluid dynamics (CDF), computational design coupling CFD with nonlinear optimization, water resources engineering, open-channel flows, fluid mechanics, applied aerodynamics. His educational interest is on the use of computer technology for the instruction of hydraulic engineering.