MONITOR AVANÇADO DE ENCHENTES (MAVEN): A HYDROCLIMATOLOGIC COMPUTATIONAL FRAMEWORK FOR EARLY FLOOD ALERT SYSTEMS

E. R. Silva[1]; E. O. Oficialdegui[2]; J. A. Cirilo[3]; A. R. Neto[1]; C. E. Dantas[4]; K. Almeida[4]
1. *Universidade Federal de Pernambuco, Brazil.*
2. *Conselho Nacional de Desenvolvimento Científico e Tecnológico, Brazil.*
3. *Secretaria de Recursos Hídricos e Energéticos, Brazil.*
4. *Companhia de Pesquisa de Recursos Minerais, Brazil.*

ABSTRACT: The phenomena associated with water management issues show a level of complexity that requires the knowledge of many experts in addition to the use of modern computational tools, both in what concerns the use of powerful equipment as in the development of integrated and flexible information systems. This work presents the MAVEN system (Monitor AVançado de ENchentes - Advanced Floods Monitor), a computational structure designed and built specifically to monitor hydro-climatological conditions in watersheds, inserting manually or automatically the data monitored in hydrological and hydrodynamics modeling procedures, with the aim of generating values for the water level variation in riparian towns. MAVEN is an application developed for the studied basins. Basically, the operating logic of the system uses a server computer that, running the MAVEN system continually, searches for hydrological current conditions and regional weather forecasting (on Web services and FTP databases), running both automated and manual simulation procedures, for rainfall-runoff transformation integrated with the spread of water level, corresponding to a flood wave along the river. MAVEN provides the results according to four user profiles, associated with their functions within the operating system strategy, these are: the system administrator; the watershed models team; the water administrators; and civil defense officers. The implementation of this system is the result of interagency cooperation (UFPE / SRHE / CPRM) on research in hydrological and hydrodynamics modeling, driven by the Water Resources Group of UFPE, after the 2010 floods in the southern coastal forest of the state of Pernambuco, Brazil. Computational infrastructure and grants were provided by CNPQ, through RedeClima project.

Key Words: Decision Support System, Early Flood Alert System, Integrated Modeling.

1. INTRODUCTION

The phenomena associated with water issues requires the knowledge of many experts and the use of modern computational tools, both with regard to the use of powerful machines as well as the development of advanced and flexible information systems. In recent decades, technologies have provided a variety of mechanisms and procedures, used alone or together, to provide water managers a large set of information sources, well-qualified and quantified, temporally and spatially distributed. Some of these are the advancement in human-machine interfaces, new and more precise satellite imagery sets, use of supercomputers, intelligent software and more accurate sensors for mapping.

This set of factors that have improved the water resources management process is associated with a more environmental vision of the context of the problem and has led to better planning strategies as well as the identification of preventive procedures for the treatment of extreme events such as droughts and flooding, rationalizing the distribution of activities to provide flexibility in the implementation of hydraulic structures. Partnerships have been formed between government organizations, universities and research institutes in order to develop the necessary technological mechanisms (Figure 1).

Figure 1: Partnership established to cope with floods in Pernambuco, Brazil.

In building a set of information that can effectively support water managers, computer scientists have been working with simulation models. These models (Figure 2) seek to represent the main physical phenomena involved in the events being studied. These phenomena fall into three main groups: climatological phenomena; hydrologic phenomena; and hydrodynamic phenomena. As these phenomena occur simultaneously, a computational procedure which designed to represent them should implement, at some level, an integration of models that represent them. This model integration can be achieved by building an information system that is flexible and adaptable to environmental conditions of each basin, working with a set of common data.

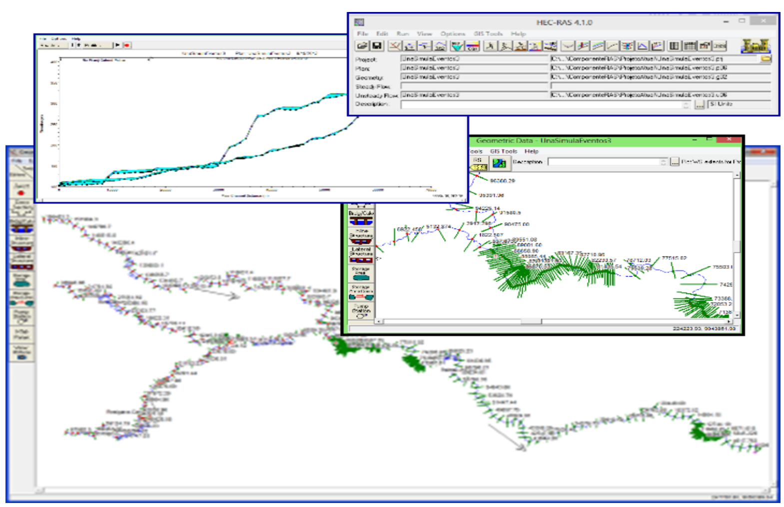

Figure 2: Hydrodynamic model (HEC-RAS) developed for the basin of the river Una.

An information system for advanced monitoring of flood events, using data from the three groups of phenomena and the mechanisms involved in the integration of models has been designed and is being constructed at the Federal University of Pernambuco (UFPE).

1.1 Theoretical and Practical References

Human beings solve problems with the use of information and intellectual concepts, trying to understand how things and phenomena work, as well as the interaction between causes and consequences. In this process naturally we make use of models, applying some degree of cognition and perception of the interrelationships of structure and dynamics of the researched environment to our study (Porto and Azevedo, 1997). Models are representations of reality, resulting from the skills and limitations of the type of modeling used and the influence the perspective of the modeler agent as well. Modeling allows generation of subsets of things and phenomena observed in the environment, with a greater or lesser degree of approximation to the actual aspects (Christofoletti, 1999).

For (Tucci, 2005), a model is a representation of system behavior. Models are commonly classified into physical, analogical and mathematical. The physical model is a prototype system to a lesser extent in most cases. The analogical models draw on the analogy of the equations governing the environmental phenomena to model the desired process in the most convenient way. The mathematical models, also called digital models, represent the system using mathematical equations.

To understand and work on the solution of problems related to water resources management, it is necessary to consider the quantitative and qualitative aspects in an integrated manner, using modeling diagrams that represent the dynamics of ecosystems, (Silva, 2010). To do this, so that the water management procedures are efficient, models of both availability and demand are needed (Welsh et al., 2013). .

The hydrological model HEC-HMS (Hydrologic Modeling System), used in this work, is a distributed type of rainfall-runoff model developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers (USACE). The model has been applied to solve many problems in a wide variety of basins with different characteristics, and including a wide variety of methods to simulate the hydrological behavior of river basins and channels. (Santos, 2013). The hydrodynamic model used in this study is the HEC-RAS (River Analysis System), also developed by USACE. The HEC-RAS simulates flows in natural or artificial channels. This software enables the calculation and hydraulic analysis of one-dimensional flows in continuous and non- continuous situations, (Dantas, 2012). Studies have been carried out showing the use of the HEC-HMS model in conjunction with the HEC-RAS model, with positive results for the representation of variations in water levels for specific regions, i.e, in inhabited areas along the banks of the Una River, in Pernambuco, Brazil. These results led the Federal University of Pernambuco to develop a working group to improve the integration of these models (Cirilo et al., 2011) and (Neto, Cirilo and Dantas, 2011).

In general, Decision Support Systems (DSS) are computational tools that provide mechanisms for obtaining, processing and presenting information for a specific field of knowledge, providing simulations of scenarios with the aim of improving decision-making and assisting people responsible for resolving conflicting situations (GRH, 2004). (Alcoforado and Cirilo, 2001) describe a decision support system for forecasting and flood control that uses hydrodynamic simulation applied in conjunction with techniques of neural networks, using a case study on the Capibaribe River basin in Pernambuco, Brazil.

(Demir and Krajewski, 2013) present a system of information on hydro-meteorological conditions developed for the state of Iowa in the United States, employing a well-developed user interface to provide various types of data, relating to the risk of flooding. In (Thielen et al., 2009) the details of the European Flood Alert System are described. This is a complex computational mechanism created to integrate the predictions of flooding within the European community. This case was particularly complex because of the political issues regarding trans-national rivers. The database was able to reflect this.

2. THE MAVEN PROJECT

The advanced monitoring and integrated modeling system for flood alerts (Monitor AVançado de ENchentes) "MAVEN" (Figure 3) is a computational structure of the type "middleware", that is, it connects and activates software programs that run hydrological and hydrodynamic simulations on watersheds, in an integrated and synchronized way. The emphasis is on the observation of changes in the river levels in areas of interest, which are the riparian towns.

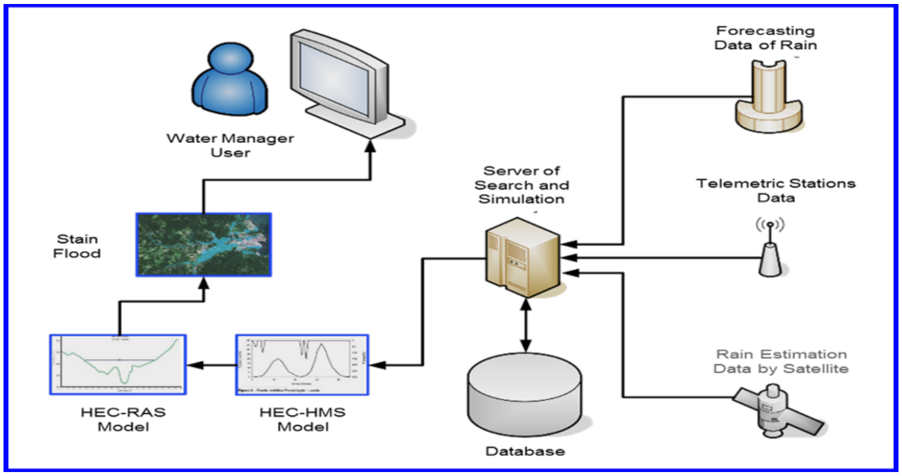

Figure 3: Basic Structure of the Advanced Floods Monitor System (MAVEN).

The main capabilities of this system are: (1) Analyzing data sets and procedures relating to the integration of simulation models and the state of monitoring indicators of conditions which are positive for extreme hydrological events; (2) Checking of possibilities for synchronous and asynchronous connections between models within an integrated decision support system for managing extreme hydrological events and; (3) Collecting and aggregating structural information, processes and other elements necessary for data processing activities, with means to its use as an integrated computational tool for flood forecasting.

2.1 Features of the System

MAVEN uses multiple data sources and formats simultaneously, such as: automatic hydro climatologic gauges; hydro climatologic conventional gauges; estimates of rainfall from satellite images; estimates of precipitation by radar; rain forecasts made by regional or global models. There are five types of users who are responsible for the functioning of the system, namely: the general population; civil defense teams; administrators for flood situations; modelers and basin researchers; and system administrators.

Furthermore, the system is able to perform simulations of hydrological and hydrodynamic behavior for various basins simultaneously; present data and results in tables and charts on web pages through FTP sites and also as direct export; store rainfall patterns related to the floods; facilitate the identification of areas of interest for generation of flood plains; generate flood plains in areas of interest; serve as a platform for the development of hydrological and hydrodynamic models for river basins anywhere in the world, provided that they can be simulated by the models used.

2.2 System Architecture

The system architecture (Figure 4) is formed by the interconnection of blocks. The main ones are:

- Data Searching Control: has the responsibility for access and retrieval of external data provided by systems from their organizations. This component consists of parsing interfaces and data consistency processing;
- Automatic Processes Control: integrates and controls all the automatic processing system, whether in the search data, simulation, verification, data analysis or presentation;
- Data Presentation Control: is responsible for all screens and Web-based windows, keeping the interaction with the system in all its modules, providing user information simultaneously;
- Simulation Main Control: controls models and simulation projects, allocates data, activates models, defines parameters and deals with the results of simulations, while maintaining the integrity of the process;
- MAVEN Access Control: keeps track of system users, controls permissions and responsibilities, establishing work areas for each and joint actions between the user and the system, depending on the characteristics of their activities.
- System Setup Control: is represented by the main administrative tasks, with respect to users, the simulation projects and automated simulation parameters.
- Models Interface: controls the execution of the models based on the guidelines of the main simulation control.

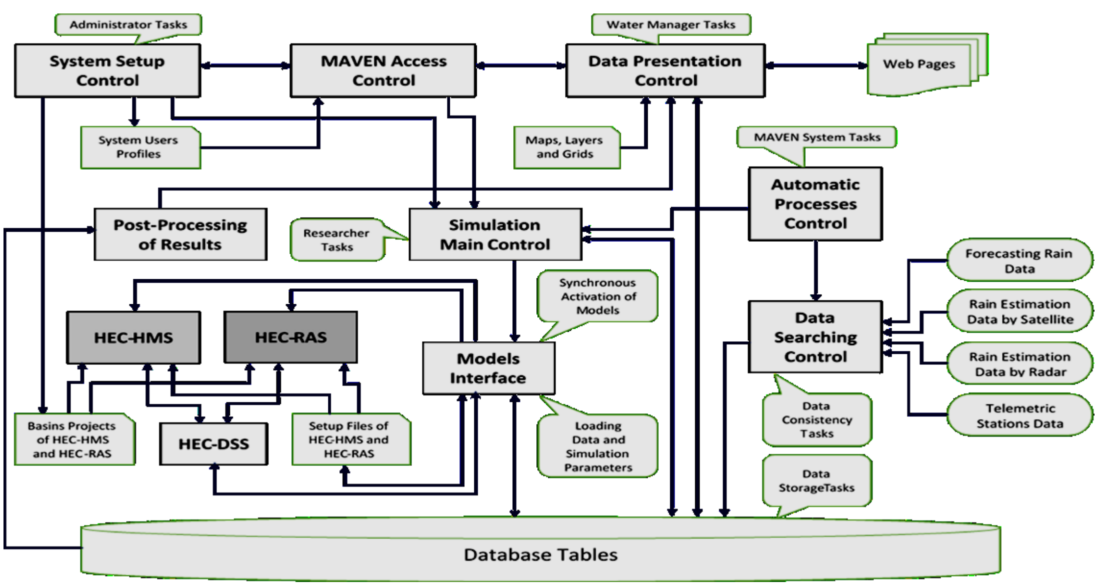

Figure 4: Detailed architecture of the MAVEN system, with modules, activities and tasks.

2.3 System Operating Structure

The MAVEN system is designed to monitor conditions in watersheds, thus its main operation is monitoring. Furthermore, MAVEN performs rainfall-runoff simulations and calculates the behavior of a flood wave, based on rainfall data observed or expected.

2.3.1 Monitoring

MAVEN performs the monitoring of rainfall data, water level, and stream flow through an automatic search of Web services and ANA (National Water Agency) FTP, and CPTEC (Center for Weather Forecasting and Climate Studies). The frequency with which this data arrives is analyzed to understand the situation of the system station operations (Figure 5) on the main monitoring screen. The states of a station can be: red, indicating an emergency event; blue, the station is operating normally; yellow represents failure in the data, or partial data coming from the station; and gray, the station is out of service. The station data can be queried by clicking on it. Monitoring of the MAVEN also performs capture of data grids for rainfall forecast. These data are presented as the arrangement of bars in Figure 6

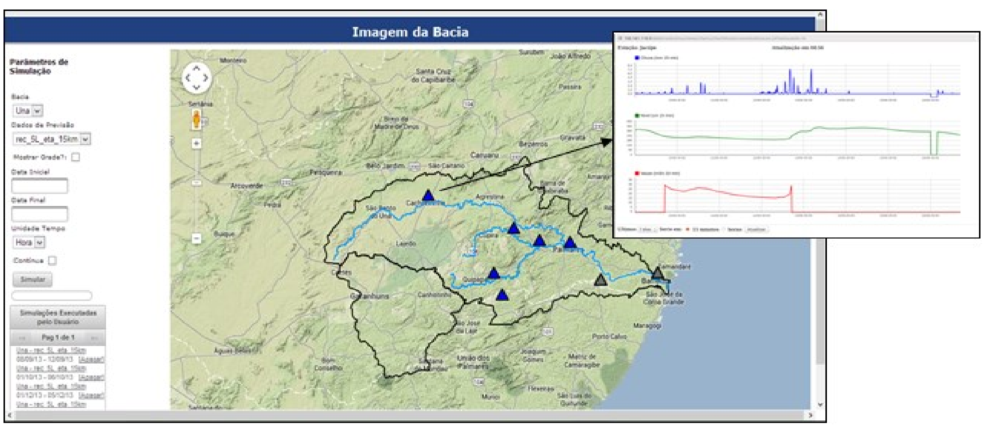

Figure 5: Screen monitoring of the MAVEN, with window for hydrological data.

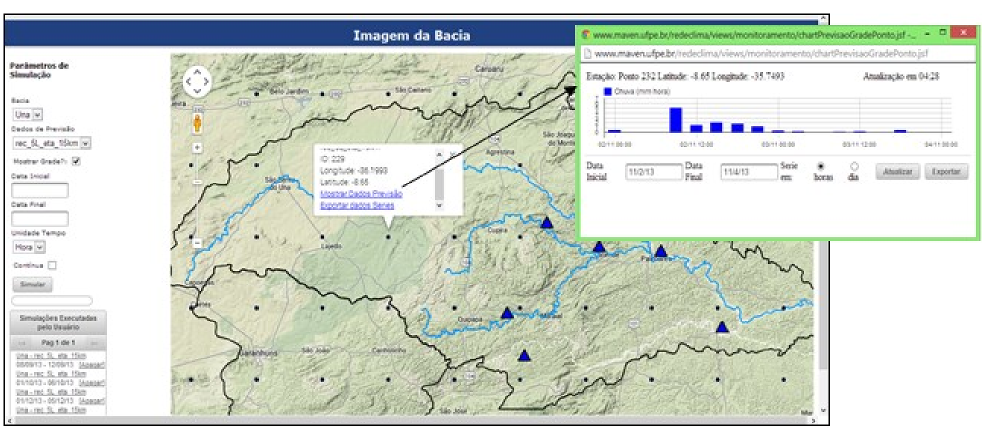

Figure 6: Screen monitoring of the MAVEN, presenting data query prediction window.

2.3.2 Simulations

One goal of the system is to simulate threatening situations related to the flooding of rivers and canals, as well as consequences for the areas surrounding them, so it is necessary to integrate hydrological and hydrodynamic simulations in order to generate predictions of water levels expected in certain parts of the rivers, under extreme events such as heavy rains.

To implement the HEC-HMS and HEC-RAS integrated simulation models, MAVEN first obtains the input data from the hydrological simulations, which are loaded from the data set of precipitation. This data can be the observed data, the estimated and/or the forecasted. The results of the hydrologic model are then provided as input to the hydrodynamic model, obeying interconnection schemes defined by the researchers who created the models.

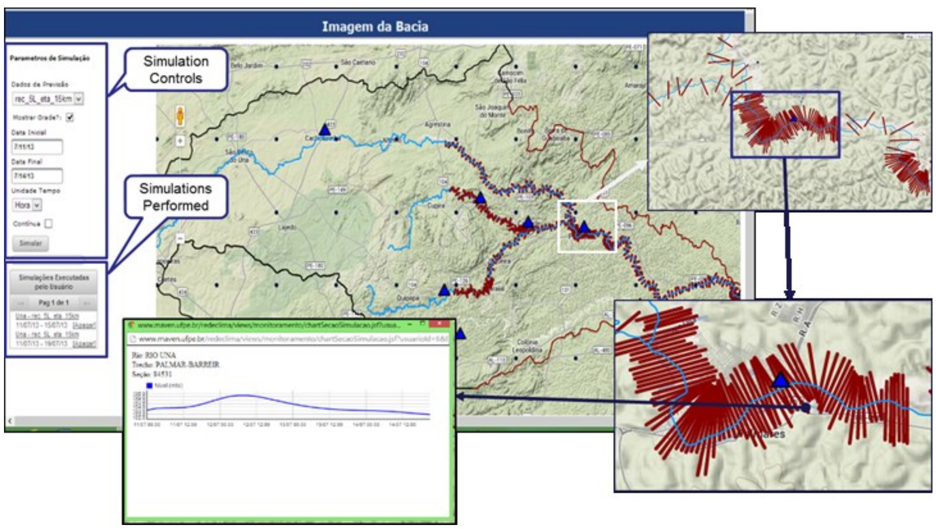

Figure 7: MAVEN main screen simulation with the simulation results window (HEC-RAS).

The manual simulations are performed by defining the parameters on the left side of the MAVEN monitoring main screen and the simulation results are found for each section of the HEC-RAS model, by clicking directly in the sections (Figure 7). MAVEN also has the ability to perform automatic daily simulations, or even shorter periods, depending on the setting in which it is implemented. These simulations are also used by the system as tools for model validation.

2.4 Period of Use of System

The main period of use of MAVEN is directly related to the period of heavy rains in the region to which it has his basin models associated. In the case of the version that is currently under development at UFPE, the region of the southern forest of the state of Pernambuco is being studied. The rains that cause flooding in this area of Pernambuco are concentrated in the winter months, i.e., from May to July. Thus, during these three months, the system will be in full operation: monitoring the basins, performing simulations and automatically reporting to managers and other credentialed users about any patterns, in their data, which could cause flooding rains. During other months of the year, the system will undergo adjustments, model development, improvement of functions and maintenance tasks.

2.5 Technologies Used

The operational features of the system are based on client-server structure, being built on open technologies, the main are: JAVA, PostgreSQL and Google Maps. Table 1 presents a summary of the technologies used in the development of the MAVEN system.

Requirement	Component	Tecnology Name
Web access	Primefaces (Complex Components, AJAX, etc)	PrimeFaces
	JSF CSS	Java Server Faces
	Spring MVC (Model View Controller) Spring Web Flow	Spring Framework
Required authentication	Spring Security	
Execution of scheduled tasks	Scheduling annotation support	
Execution of batch processes	Spring Batch	
Transaction management		
Local storage database	PostgreSQL JDBC pgAdmin (Management) PostGIS (Spatial Data)	PostgreSQL
Script Integration	JSON (JavaScript Object Notation)	Java
Shapes processing (KML)	JAK (Java API for KML)	
Maintenance tasks	Java2EE	
Sending email with notifications	JavaMail	
Object Oriented Programming	JavaSE	
Connecting to other systems on the Internet (FTP)	Jsoup(Java library for working with real-world HTML)	
	Appache Commons net	Apache Software Fundation
Information availability and graphics	Google Maps (Mapas e georeferencing)	Google Web Technologies
	Google Charts (Graphics)	
Data extraction format GRIB e GRIB2	NetCD	Unidata NetCD

Table 1: Technologies used in the development of MAVEN, so far.

3. CURRENT STAGE OF DEVELOPMENT

The development of the system has been carried out according to the research involved in the determination of data formats and procedures necessary to connect this data, to construct the interfaces. Most monitoring functions have been implemented, with automatic and continuous access to hydro-climatic data, provided by the ANA and the CPTEC, as well as with forecasts of rainfall data available on the CPTEC FTP website.

Structures of interfaces between the monitored data, forecast data and models have been developed. This part is in the testing and adjustment stage. Mechanisms for integrating different data formats are being developed and should be ready for testing soon. The next phase will be the generation of the flood plains. The MAVEN system can be accessed at: http://www.maven.ufpe.br/redeclima.

4. FINAL CONSIDERATIONS AND CONCLUSIONS

Details of design, construction and operation of the advanced flood monitoring system MAVEN were presented. This system consists of an integrated computational structure that compiles information from multiple sources of hydro-climatologic data, for use in hydrologic and hydrodynamic simulation models. The system is designed to work on any watershed, for which HEC-HMS and HEC-RAS models have been built, offering an interactive tool using these models for simulating current and future weather conditions, as well as a platform for development and improvement of these same models.

Thus, the MAVEN constitutes a mechanism for constant observation of the hydro-climatic situation of the basins under study, as well as a tool to verify the behavior of river levels in inhabited areas subject to flooding. The Water Resources Group of the Federal University of Pernambuco designed the MAVEN system after study and experimentation with HEC-HMS/RAS model projects in the southern rain forest area of the state of Perambuco, Brazil. The basis for obtaining satisfactory results in the modeling of the hydrodynamic behavior of the basins in the study process was provided by the use of LIDAR (Light Detection and Ranging) digital terrain models (DTM), sponsored by the Secretary of Water Resources and Energy of the state of Pernambuco. This partnership was essential for the research results.

The system presented in this work is in the development stage and its trial version has recently become available. Some operational adjustments still need to be made, but its functionality can now be proven, with verification of the results of simulations and notifications to the managers for hydro-climatologic conditions that deserve attention. The main features of monitoring and simulation have been integrated using a decentralized mechanism, that is, it can be used via the web from a server computer located anywhere, providing freedom for managers to access information, both in central decision-making, as in areas subject to flooding.

The level of detail offered here does not reveal the complexity of the issues involved, leaving these details to the Masters Dissertations and Doctoral Theses which formed the foundations of the system, but constitutes the presentation of a computer application, the result of the study and development of hydrological and hydrodynamic modeling procedures. These were then used to minimize real catastrophic situations that happened, or could happen, in the Southern rain forest area of the state of Pernambuco. Use of the data and algorithms of MAVEN represents our desire to create better models of a hydrodynamic reality for the hydrologic basins involved, decreasing their human and material losses when floods occur.

5. ACKNOWLEDGEMENTS

The authors wish to acknowledge the support received from partner institutions in this project, which are: Secretary of Water Resources and Energy of the State of Pernambuco (SRHE-PE); National Council for Scientific and Technological Development (CNPq), through RedeClima Project; Water and Climate Agency of Pernambuco (APAC); Institute of Technology of Pernambuco (ITEP); Geological Survey of Brazil (CPRM); Center for Weather Forecasting and Climate Studies, of National Institute for Space Research (INPE/CPTEC); and the Coordination of Improvement of Higher Education Personnel (CAPES).

6. REFERENCES

Roberta G. Alcoforado and José A. Cirilo, 2001: "Sistema de suporte à decisão para análise, previsão e controle de inundações" *Revista Brasileira de Recursos Hídricos* 6:4, 133-153.

Antônio Christofoletti, 1999: *Modelagem de sistemas ambientais*. Edgard Blücher Publications, São Paulo, Brazil.

José A. Cirilo et al., 2011: "Controle e Previsão de Cheias no Estado de Pernambuco, Brasil: Estrutura Geral do Sistema de Suporte à Decisão" *14th IWRA World Water Congress*, Porto de Galinhas, Pernambuco, Brazil, September 25-29, 2011.

Carlos E. de O. Dantas, 2012: *Previsão e controle de inundações em meio urbano com suporte de informações espaciais de alta resolução*. PhD thesis, Universidade Federal de Pernambuco/PPGEC, Recife, Brazil.

Ibrahim Demir and Witold F. Krajewski, 2013: "Towards an integrated Flood Information System: Centralized data access, analysis, and visualization" *Environmental Modelling & Software* 50, 77-84.

GRH – Grupo de Recursos Hídricos, 2004: *Sistema de apoio à decisão para o gerenciamento dos Recursos hídricos da bacia do rio Paraguaçu: Instrumentos de apoio à decisão*. Executive Report, Universidade Federal da Bahia/DEA/GRH, Salvador, Brazil.

Alfredo R. Neto, José A. Cirilo and Carlos A. de O. Dantas, 2011: "Integração de Modelos Chuva-Vazão e Hidrodinâmico para Simulação de Cheias" *14th IWRA World Water Congress*, Porto de Galinhas, Pernambuco, Brazil, September 25-29, 2011.

Rubem L. L. Porto and Luiz G. T. Azevedo, 1977: *Técnicas quantitativas para o gerenciamento de recursos hídricos*. UFRGS/ABRH Publications, Porto Alegre, Brazil.

Keyla A. dos Santos, 2013: *Modelagem do acompanhamento e controle de cheias em bacias hidrográficas de grande variação de altitude. Estudo de caso: bacia do rio Mundaú*. Master dissertation, Universidade Federal de Pernambuco/PPGEC, Recife, Brazil.

Edilson R. Silva, 2010: *Abordagem multicriterial difusa como apoio ao processo decisório para a identificação de um regime de vazões ecológicas no baixo curso do rio São Francisco*. Master dissertation. Universidade Federal da Bahia/MEAU, Salvador, Brazil.

Jutta Thielen et al., 2009: "The European Flood Alert System – Part 1: concept and development" *Hydrology and Earth System Sciences* 13, 125–140.

Carlos E. M. Tucci, 2005: *Modelos Hidrológicos*. UFRGS/ABRH Publications, Porto Alegre, Brazil.

Wendy D. Welsh et al., 2013: "An integrated modelling framework for regulated river systems" *Environmental Modelling & Software* 39, 81-102.