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A DECISION SUPPORT TOOL FOR FLOOD MANAGEMENT UNDER UNCERTAINTY USING GIS AND REMOTE SENSING TECHNOLOGY

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ABSTRACT

Historical flood events have shown that the level of damage does not solely depend on exposure to flood waters. Vulnerabilities due to various socio-economic factors such as population at risk, public awareness, and presence of early warning systems, etc. should also be taken into account. Federal and state agencies, watershed management coalitions, insurance companies, need reliable decision support tools to evaluate flood risk, to plan and design flood management and mitigation systems. In current practice, flood damage evaluations are generally carried out based on results obtained from one dimensional (1D) numerical simulations. In some cases, however, 1D simulation is not able to accurately capture the dynamics of the flood events. The present study describes a decision support tool, which is based on 2D flood simulation results obtained with CCHE2D-FLOOD. The 2D computational results are complemented with information from various resources, such as census block layer, detailed survey data and remote sensing images, to estimate loss-of-life and direct damages (meso or micro scale) to property under uncertainty. Flood damage calculations consider damages to residential, commercial and industrial buildings in urban areas, and damages to crops in rural areas. The decision support tool takes advantage of fast raster layer operations in a GIS platform to generate flood hazard maps based on various user-defined criteria. Monte Carlo method based on an event tree analysis is introduced to account for uncertainties in various parameters. A case study illustrates the uses of the proposed decision support tool. The results show that the proposed decision support tool allows stake holders to have a better appreciation of the consequences of the flood. It can also be used for planning, design and evaluation of future flood mitigation measures.

1. INTRODUCTION

Due to rapid population increase, urbanization, and climatic changes, floods are causing considerable damages every year around the globe. From many historical flood events, it is observed that the level of damage during a flood event does not solely depend on exposure to flood waters, or the presence and degree of protection measures. Vulnerabilities that involve consideration of various socio-economic factors such as population at risk, public awareness, and early warning systems, etc.

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should also be taken into account in assessing damages due to flood events. The recent practice defines flood management as a broad spectrum of water resources aimed at reducing the loss of life and property damage, and at the same time obtaining the social, environmental and economic benefits from the floodplains (Simonovic, 1998). Federal and state agencies, watershed management coalitions, insurance companies, consultant engineers need reliable decision support tools to evaluate flood risk, to plan and design flood management strategies and mitigation systems, to prepare emergency management plans which may involve both structural and non-structural measures. Such decision support tools can also be used to evaluate and compare cost-effectiveness of alternative solutions, to assess loss-of-life and property damages, and to plan for emergency management operations.

In current practice, the Hydrologic Engineering Center's Flood Damage Reduction Analysis (HEC-FDA, or FDA) program developed by US Army Corps of Engineers has been widely used to estimate flood damages (California Department of Water Resources, 2004). This program uses risk-based analysis method to integrate hydrologic, hydraulic, and economic relationships. The two primary outputs from HEC-FDA include expected annual damage estimates and project performance statistics. Expected annual flood damage is the average of all possible damage values, taking into account all expected flood events and associated hydrologic, hydraulic, and economic uncertainties. Project performance statistics provide information concerning the risk within an area of annual (or long-term) flooding and the ability to survive flood events of given magnitudes.

However, HEC-FDA program is generally carried out based on results obtained from one dimensional (1D) numerical simulations (i.e., HEC-RAS). 1D simulation results are then converted almost manually into two-dimensions using rather crude interpolations. Except for floods in well defined narrow valleys, however, such interpolations could lead to significant errors in capturing the dynamics of the flood events, i.e. flow velocities, flood-wave arrival time, and flood duration, which may result in serious errors in subsequent flood damages evaluation. In addition, various analyses in HEC-FDA undertake highly inefficient procedures which require the user to input numerous information, i.e. all the structural survey data along various river reaches. Recent developments in GIS and remote sensing technologies, which facilitate data preparation, and the advances in robust, fast numerical schemes, make it feasible to develop decision support tools based on two dimensional (2D) hydrodynamic computations for flood simulations. The present research describes a decision support tool, which is based on 2D flood simulation results obtained with CCHE2D-FLOOD. The 2D computational results are complemented with information from various resources, such as census block layer, detailed surveyed data, and remote sensing images, to estimate loss-of-life and direct damages to property under uncertainty.

Loss of life due to flood is mainly influenced by the number of people occupying the floodplain (which is also called Populations at Risk - PAR), the escape time between the initiation of the warning and the arrival of the flood waters, and the severity level of the flooding. Urban and agricultural flood damage assessments rely on both Remote Sensing (RS) information and surveyed property information. The satellite images at different wavelengths can provide information on various urban land cover features, such as vegetation, residential area, or water bodies. Surveyed property database complement this information at a more detailed level. Using pre-established relationships for percentage property damage vs. water depth and/or velocity, or a combination of these, the urban flood damage (including infrastructural damage), and agricultural damage (crops, farmlands, etc.) are then calculated. The decision support tool uses Monte Carlo simulation method to account for uncertainties in various input variables and parameters. Loss-of-life computation considers uncertainties in flood severity, warning time, PAR value, and fatality rate relationship. Urban and agricultural damage computations consider uncertainties in number of structures (residential, commercial and industrial), value of a given structure, content value of a structure, and value of a farmland or cropland, quantities of the crop yield, depth vs. % damage relationships, etc.

In addition, an event tree is used to cover the uncertainty with regard to the season, day and time of the flood event.

The decision support tool takes advantage of fast raster layer operations in a GIS platform to generate flood hazard maps based on various user-defined criteria. Other supplementary information, such as stage-damage curves, is specified via a user-friendly graphical interface. A case study of a catastrophic dam break flood of Oconee River near Milledgeville, GA is carried out to illustrate the potential uses of the proposed decision support tool. The results of the case study clearly show that this new approach based on 2D simulation results allows the stake holders to have a better appreciation of the consequences of the flood. The developed flood management tool can be efficiently used in planning, design and evaluation of various flood mitigation measures.

2. FLOOD SIMULAION USING CCHE2D-FLOOD MODEL

CCHE2D-FLOOD is a state-of-art numerical model, which solves 2D shallow-water equations with a very robust, shock capturing finite-volume scheme that accepts both regular Digital Elevation Maps (DEM) based or triangular unstructured grids. A special version of this model is currently used by USACE for military and civil applications. The conservative form of the two-dimensional shallow water equations (Saint-Venant Equations) is solved in conservative form (Ying et al., 2003):

$$\frac{\partial \mathbf{U}}{\partial t}+\frac{\partial \mathbf{F}}{\partial x}+\frac{\partial \mathbf{G}}{\partial y}=\mathbf{S} \quad \text{with } \mathbf{G}=\begin{bmatrix} hv \\ huv \\ hvv \end{bmatrix} \quad \mathbf{F}=\begin{bmatrix} hu \\ huu \\ huv \end{bmatrix} \quad \mathbf{U}=\begin{bmatrix} h \\ hu \\ hv \end{bmatrix} \quad \mathbf{S}=\begin{bmatrix} 0 \\ -gh\dfrac{\partial Z}{\partial x}-g\dfrac{u\sqrt{u^2+v^2}}{C^2} \\ -gh\dfrac{\partial Z}{\partial y}-g\dfrac{v\sqrt{u^2+v^2}}{C^2} \end{bmatrix} \tag{1}$$

Where in Eq (1) $\mathbf{U}$, $\mathbf{F}(\mathbf{U})$, $\mathbf{G}(\mathbf{U})$ and $\mathbf{S}(\mathbf{U})$ are respectively the vectors of conserved variables, fluxes in the x and y directions, and source terms. Other variables are h = water depth; u = velocity component in the x direction; v = velocity component in the y direction; g = gravitational acceleration; Z = water level; C = Chezy's channel resistance coefficient. Eq (1) is written in a coordinate system where x and y define the horizontal plane and z the vertical direction.

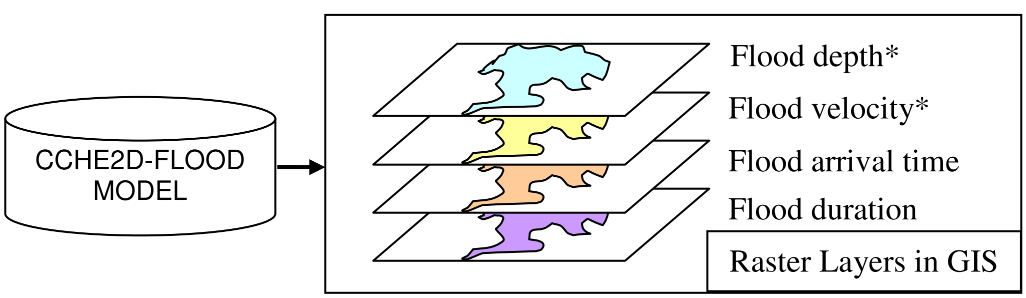

Figure 1 Set of Results Provided by CCHE2D-FLOOD Model.
(*: values are stored at each time step during simulations)

The numerical model provides the information about the extent of the flooded area, spatial distributions of flood depth and flood velocities in two horizontal directions, arrival time of the flood and its duration at each point of the computational domain (Figure 1). The numerical code is extremely stable, oscillation free near discontinuities, robust, and conserves rigorously mass and momentum. It has been tested and validated using both laboratory and field measurements (Ying and Wang, 2004). A special version of this model has also been used for solving complex real life problems related to dam-break floods (Jorgeson et al., 2005).

3. DECISION SUPPORT TOOL FOR INTEGRATED FLOOD MANAGEMENT USING GIS AND REMOTE SENSING TECHNOLOGY

This research aims to develop an innovative decision support tool for integrated flood management that allows a detailed evaluation of the consequences of a flood event based on two-dimensional realistic, reliable numerical simulations with various GIS, RS information and etc. The organizational structure of the proposed decision support is depicted in Figure 2. A state-of-the-art 2D numerical model, CCHE2D-FLOOD, and a collection of GIS based decision support modules constitute the core of the proposed system. The decision tool can be used for urban/ rural flood damage analysis, loss-of-life analysis, risk and uncertainty analysis, emergency response planning and analysis and alternative analysis by Spatial Compromised Programming (SCP).

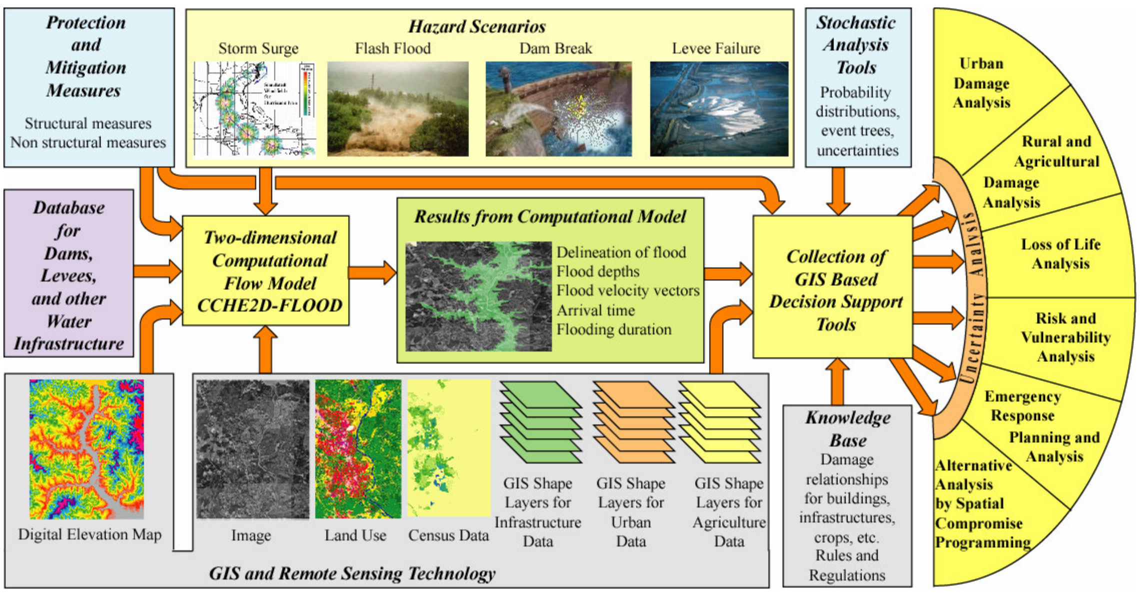

Figure 2 Organizational Structure of the Decision Support Tool for Integrated Flood Management.

Using either regular DEM-based or triangular unstructured grids, the numerical model provides the information about the extent of the flooded area, spatial distributions of flood depth and flood velocities, arrival time of the flood and its duration at each point of the computational domain. To carry out the simulation, the model receives information from various sources. The topography is supplied from DEMs. The data on the water infrastructure to be analyzed is retrieved from a special database. In addition, information on structural or non structural (Simonovic, 1998) flood protection and mitigation measures, if any, should be provided.

The Geographic Information System (GIS) approach has been extensively used for spatial decision making of integrated flood management. GIS technology brings to the user the ability to integrate, store, process, and output geographic information. This system takes a multitude of data from numerous sources and graphically displays the information. A detailed review of GIS applications in civil engineering and environmental modeling can be found by Miles and Ho (1999). These applications allow us to not only reach information about the geographical, geophysical, and socioeconomic characteristics of the research area, but also, more importantly, to determine, visualize, and analyze the possible extent of flood disasters (Gunes and Kovel, 2000). Based on the

2D flow simulation results computed by CCHE2D-FLOOD, which are converted into raster layers, the collection of GIS based decision support tools carry out analyses of loss of life, urban damage, rural and agricultural damage, and risk and uncertainty, which is explained in detail in the followings. To carry out these tasks, the GIS decision support tool needs complementary information regarding various geospatial information, such as land use, census data, infrastructure data, urban data, agricultural data, economic data, etc. It also allows evaluation of the efficiency of emergency response plans, structural and non structural flood protection and mitigation measures, etc. Engineering alternatives for flood control and management, emergency response, etc. can be comparatively evaluated and ranked using recently developed SCP technique, which takes into account spatial variations of the relative efficiency of the alternatives (Qi et al., 2005a).

3.1 Loss of Life Estimation with Census Block Information

Loss of life due to a flood event is usually estimated by determining a fatality rate, which is defined as the fraction of mortalities among the exposed population (Jonkman et al., 2003). According to Graham (1999), fatality rate resulting from flooding is highly influenced by three major factors: 1) The number of people occupying the floodplain, which is also called population at risk (PAR); 2) The amount of warning that is provided to the people exposed to dangerous flooding and 3) The severity level of the flooding. In order to determine the PAR value, the census block data, which is usually a vector polygon layer, are used in GIS environment. Census blocks are areas bounded on all sides by visible features, such as streets, roads, streams, and railroad tracks, and by invisible boundaries, such as city, town and county limits, property lines, and short, imaginary extensions of streets and roads. After importing this layer into GIS, the population density is first calculated by using the total population of each census block and its area. Then this feature polygon layer is converted to a raster layer which has the same cell size as the flood computation results. The cell value, which represents the PAR living and working inside each cell, is reclassified according to the product of population density and the cell area. This operation would obtain a raster layer showing the PAR distribution (Qi et al. 2005a).

The typical definition of warning time of a flood is the length of time from when the first public warning is issued until the flood wave reaches the first person in the PAR (Aboelata et al., 2002). Since the time that the flood event occurs is defined as time “0”, warning time can be either positive which indicates warning is issued after the flood event, or negative which means warning is issued before the flood event. The flood severity definition is usually associated with the flood depth. Low, medium and high severity can be categorized according to Graham (1999). Using the flood severity based method for estimating life loss, the intersection of modified census block information with inundation depth and warning time in raster layers can produce a map showing the spatial distribution the loss of life information shown in Figure 3 (Qi et al. 2005a).

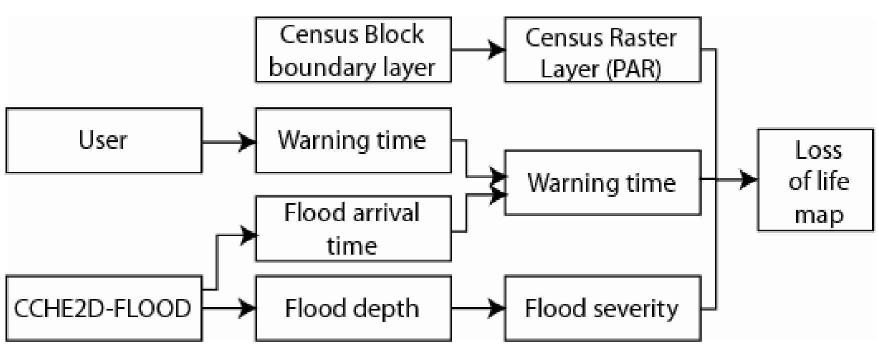

Figure 3 Loss of Life Estimation with Census Block Information in GIS.

3.2 Flood Damage Calculation for Urban and Rural Area

The actual amount of flood damage generated by a specific flood event refers to all types of hazards caused by flooding. It encompasses a wide range of harmful effects on humans, their properties and belongings, on public infrastructure, cultural heritage, ecological systems, industrial production and the competitive strength of the affected economy (Messner and Meyer, 2005). Flood damage effects can be further categorized into direct and indirect effects. Direct flood damage covers all varieties of harm which relate to the immediate physical contact of flood water to humans, property and the environment, which includes, for example, damage to buildings, loss of standing crops and livestock in agriculture, economic goods and dykes, and contamination of ecological systems. Indirect or consequential effects comprise damage, which occurs as a further consequence of the flood and the disruptions of economic and social activities (Green et al. 1994). This damage is usually more difficult to evaluate, and thus is often unjustly neglected.

In current practices, there are two integral parts in the state-of the-art estimation of flood damages (Messner and Meyer, 2005). Firstly, the flood hazard needs to be determined by means of exposure indicators, using flood parameters like inundation area and depth, velocity and flood duration. For this research, these indicators are provided by the simulation model. Secondly, the expected damage needs to be estimated. In order to do this, all valuable property located within the endangered area, i.e. the damage potential, needs to be quantified. The expected damage is generally calculated using %-damage functions versus depth (or velocity) relationships. Based on the analysis of damages occurred during past flood events, such curves are prepared for different types of structures (residential, commercial, industrial, etc.) and their contents, infrastructures (bridges, highways, etc.), crop lands, agricultural installations, etc.

Over the past decades, a great variety of methods emerged for the estimation of flood damages. Each method is suitable for a specific purpose. Gewalt et al. (1996) roughly divides these methods into three categories based on their scale and goal: macro-, meso- and micro-scale analyses. Macro-scale analyses consider areas of national or international scale and should provide decision support for national flood mitigation policies. These generally yield very rough estimates and can be used in analyzing the effect of large flood on the national economy, for example. Meso-scale analyses deal with research areas of regional scale, i.e. river basins or coastal areas. For Meso-scale analyses, the planning level corresponds to design of flood mitigation strategies for large-scale flood events. Finally, the aim of micro-scale analyses is the assessment of flood protection measures at a local level. Characteristics of macro, meso and micro approaches of flood damage analysis for different spatial scales are listed in Table 1. For this research, meso-scale flood damage analysis is performed for urban area with the aid of RS images, while micro-scale flood damage analysis for crops of rural area based on detailed survey database is carried out.

Table 1 Characteristics of Macro, Meso and Micro Approaches of Flood Damage Analysis.
(adapted from Messner and Meyer, 2005)

Scale	Size of the Research Area	Management Level	Demand on Accuracy	Possible Data Resource	Applied for This Research
Macro-	(Inter)-National	Comprehensive flood management practices	Low	Feature maps	No
Meso-	Regional	Large scale of flood management strategies	Medium	RS images	Yes, for urban area
Micro-	Local	Single or small scale flood protection works	High	Detailed survey database	Yes, for rural area

3.2.1 Meso-Scale Urban Flood Damage Calculation with Remote Sensing Image

Within meso-scale analyses, the damage potential is derived from aggregated data (Klaus et. al, 1994). As in the macro-scale approach, the data on valuables stem from official statistics at the municipality level. However, in order to enable a more realistic localization of the valuables within the municipalities, each of the categories for the valuables is assigned to one or more corresponding land-use categories. For example, residential capital is assigned to residential areas, fixed assets and inventories of the commercial sector are assigned to industrial areas, and livestock is assigned to grassland. This approach allows a differentiation between areas of high value concentration, such as urban areas and especially city centers on the one hand, and areas with very low damage potential like non-urban land or forests on the other hand.

Today, digital land-use data like Remote Sensing image (RS) is the recently developed science and technology of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact under investigation. The satellite image can provide important information by showing various urban land cover features, like vegetation, residential area or water body. Since different land feature types have their inherent spectral reflectance and emitance properties, the RS image is usually classified so that all the pixels in this image fall into certain land over classes or themes. Each class of the land features manifests a unique Digital Number (DN) value. Three DN values of urban land features are considered in this research: high intensity residential area, low intensity residential area and commercial /industrial/transportation area. The estimated dollar value for the above three category, and the depth - % damage relationship can be entered via a user friendly interface and stored in the knowledge base. With overlaying of this classified RS image with the flood inundation image, the flood damage calculation can be achieved in GIS as showed in Figure 4 (Qi et al., 2005).

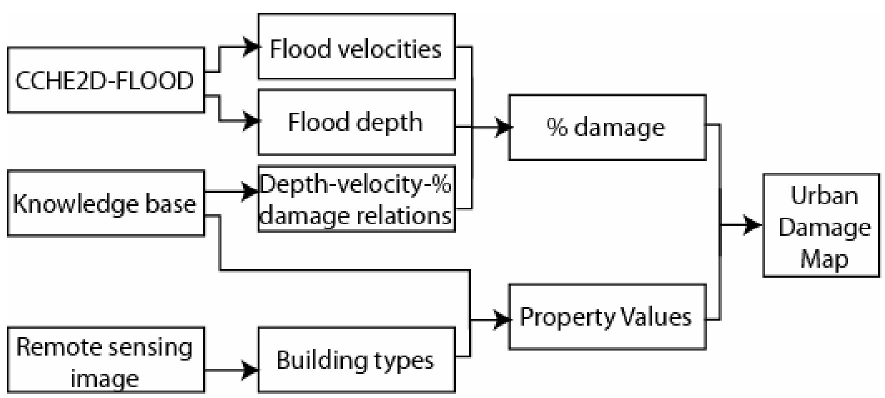

Figure 4 Urban Flood Damage Calculations with RS Image.

3.2.2 Micro-Scale Rural Flood Damage Calculation with Detailed Survey Database

Within micro-scale analyses, damage potentials and expected damages are evaluated on an object level, i.e. single valuables of one category, such as specific types of residential for urban flood damage calculation or non-residential properties, i.e. farms for rural area flood damage evaluation, are differentiated. Field surveys or interviews with the property owners are the two primary sources of the data used to develop detailed survey database. The survey database table includes the following items, farm/owner name, geographical locations (x/y coordinates), area, crop types, unit crop yield quantities, etc. Crop prices are also obtained for the research area. According to the general procedure developed by National Resources Conservation Services (NRCS), damage calculations are based on stage-yield-% damage functions which are derived either from past flood data analysis, or through analytical descriptions of flood damage to various crops considering the possible damage ratio to a given flood depth, the crop yield quantity and the time that flood occurs. Table 2 shows the detailed floodwater damage percentage per acre by month, yields, and depths of for northern US (NETSC Technical Note – Watersheds-16 Rev. 2, 1978). It is interesting to note that negative numbers in the table mean some flood event could even increase the potential production return of certain crops.

Table 2 Crop Floodwater Damage Percentages Per Acre by Months, Yields and Flood Depth.

Crop and Depth of Flooding	Yield*	Damage Per Acre as a Percent of Flood-Free Gross Return by Months							
		April	May	June	July	August	September	October	November
Corn Grain 0-2’	75 bu	0	4	30	31	14	9	10	3
	125 bu	0	3	29	32	15	9	10	4
	175 bu	0	3	28	32	15	9	10	4
Corn Grain over 2’	75 bu	0	5	41	60	38	27	23	8
	125 bu	0	4	41	62	39	27	24	8
	175 bu	0	4	39	63	39	28	24	8
Soybeans 0-2’	25 bu	0	3	40	67	64	45	33	10
	40 bu	0	2	40	70	66	46	34	11
	60 bu	0	2	40	71	68	47	35	11
Soybeans over 2’	25 bu	0	4	54	86	86	65	38	11
	40 bu	0	3	53	89	89	67	40	11
	60 bu	0	2	51	91	91	69	40	11
Oats 0-2’	50 bu	15	16	46	54	24	0	0	0
	70 bu	12	0	46	53	21	0	0	0
	90 bu	11	- 9	46	52	20	0	0	0
Oats over 2’	50 bu	23	25	75	81	38	0	0	0
	70 bu	19	0	75	78	33	0	0	0
	90 bu	16	- 14	75	77	31	0	0	0

(*) in units of bushels (bu)

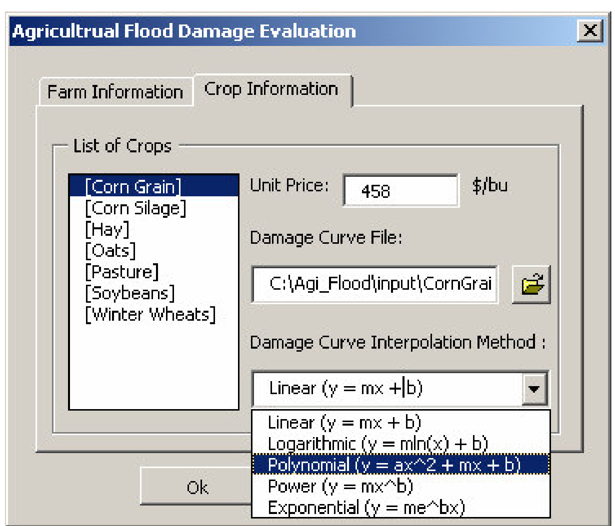

Figure 5 Dialog Box for Setting up Micro-scale Rural Damage Calculation.

In this research, detailed survey database of the farms is first converted and imported in GIS as a point feature layer. Figure 5 shows the graphical interface developed to set up the computation of crop damage. The user is prompted to enter parameters for different crops entering into the computation, i.e. crop price, damage curve files (MS excel format) and one of five interpolation methods (linear, logarithmic, 2nd order polynomial, power or exponential). Based on the parameters supplied by the user, the farm damage is estimated by using the interpolated flood depth at each farm location from the raster layers of computational results, crop yield and event happened time in the region of interest. Finally the result is displayed as a point feature layer, which is drawn with different symbol sizes to show damage quantities.

4. RISK AND UNCERTAINTY ANALYSIS FOR FLOOD MANAGEMENT

As a spatial decision making problem, integrated flood management problem is subject to multiple sources of uncertainty (Qi et al. 2005b). The first type of uncertainty arises from the natural variability (inherent randomness) of the variables entering into analysis, and can be spatial or temporal. The second type of uncertainty, the epistemic uncertainty, encompasses the knowledge uncertainty due to lack of sufficient knowledge in modeling the physical processes and the parameters involved, as well as the decision model uncertainty. The proposed decision support tool takes into uncertainties by means of Monte Carlo method, which uses stochastic sampling based on user defined probability distributions of uncertainties to compute the expected values of loss of life and flood damage and their standard deviation.

4.1 Natural Variability of Various Input Parameters

The effect of parameter uncertainty on the total flood damage is taken into account in this research, because it may have large effects on the output, and it is relatively easy to quantify and important in the context of the decision support system. Parameter uncertainty derives from statistical considerations and is usually described by either confidence intervals or probability distributions. It relates to accuracy and precision with which parameter can be inferred from field data, judgment and technique literature (CRA, 2000). The uncertainty of eighteen dominant parameters is considered in loss of life estimation and flood damage calculation (Table 3).

Table 3 Input Parameters with Uncertainties

Loss of Life Estimation	Flood Damage Calculation	
	Urban Flood Damage	Rural Flood Damage
flood severity, warning time, census data, fatality rate	number of structures, structural value, content value, other value, first floor height, depth - % damage relationship	crop prices, crop yield, depth – yield - % damage relationship

Uncertainties may be defined in the knowledge base as none (no uncertainty), or commonly used probability distributions, e.g. normal, logarithmic, triangular, uniform, etc (Qi et al. 2005b). Selection of an appropriate probability distribution for each uncertain parameter requires collecting and evaluating all available data, facts and knowledge regarding these parameters, and is often a trade-off between theoretical justification and empirical evidence. However, in absence of the available data, the probability distributions are often chosen as uniform distribution for flood management practices.

4.2 Event Tree Analysis for PAR Distribution

The date and time of the flood are important parameters that significantly affect the PAR distribution (Dise 2002). For example, campgrounds located on the floodplain may be unused in the winter but heavily populated in the summer, especially during the weekends. Traffic density on a highway and occupancy in residential, commercial and industrial building varies seasonally, daily and even hourly during a given day. In order to take this into account, it would be necessary to prepare population dynamics models. Unfortunately, at the present such models are not available. In the current practice, a simplified event tree can be used to estimate the PAR variation with date and time. The event tree is a graphical representation of the logic model that identifies and quantifies the possible outcomes resulting from a given event. Event tree analysis provides an inductive approach to reliability assessment as they are constructed using forward logic. In the present case, this logic diagram would have four branches for the seasons. Each seasonal branch would have two branches one for weekdays and one for weekends. In turn, each of these could have two branches one for the daytime the other for the nighttime. Ranges for PAR could then be estimated for each of the 16 end branches. Each PAR associated with the given time frame would be stored as database file (raster layer) separately. The user is prompted to specify season of the year, day of the week and time at the beginning of the analysis. This information is then used by the decision support system to retrieve the associated PAR database for loss of life estimation.

4.3 Spatial Monte-Carlo Simulation Method

Monte Carlo simulation refers to a mathematical technique that is used to determine the outputs from a model represented by a complex set of equations that cannot be readily solved analytically (Charalambous, 2004). In this study, the Monte Carlo simulation approach is first used to draw samples of n different uncertainty parameters from their predetermined probability distribution. Then, the flood management tool is run with those samples. The whole procedure is repeated for a large number of runs and the final results (mean, min/max and standard deviations) are then calculated from the results obtained in each run. The number of runs required to achieve convergence can either be determined by using Kolmogorov-Smirnov and Renyi statistics, or, more arbitrarily, by experience (Beck, 1987). Theoretically, the greater the number of simulations, the better resemblance between generated and parent distribution of each random variables. However, for a complex flood management decision support system with many uncertainty parameters running on a GIS platform, the computational time to achieve convergence may become prohibitively high. Therefore, often a trade-off between desired accuracy and affordable computational burden is necessary.

As it should be noticed here, the results of Monte Carlo simulation shows the spatial variances of loss of life and flood damage for each geographical location of the research area. This method is, therefore, named as "*Spatial*" Monte Carlo simulation method. The final results can be displayed in the form of raster/vector maps as an aid for better decision making related to flood hazard management (Qi et al. 2005b). It can also be used to evaluate the cost effectiveness of alternative approaches to strengthening flood control measures.

5. CASE STUDY

A hypothetical floodplain management analysis for Oconee River in the state of Georgia is chosen to illustrate the capability of the proposed decision support tool. This river has a total basin area of 3.4×10^6 acre. The study area includes the City of Milledgeville in the downstream of Oconee River and the surrounding rural area of Baldwin County with an area of around 1.65×10^5 acre (Figure 6). In 2000, Milledgeville had a population of about 44,220 with a median family income of about

$35,856 (U.S. Census). DEM of study area is 60m × 60m data that was obtained from USGS website. There are a total of six major land cover classes within the study area namely, forest, wetland, crops, water body and urban, as classified from the LANDSAT 7 RS data of 30m resolution (Qi et al. 2005a and 2005b). Datasets required for loss of life estimation are available from the 2000 population census from state office of Georgia, and various agricultural data on farms of Milledgeville were obtained from the census report of Georgia Department of Agriculture. About 30 % of the total agricultural land cover patterns are corn, 20 % are soybeans, and the rests are oats, hay and winter wheat.

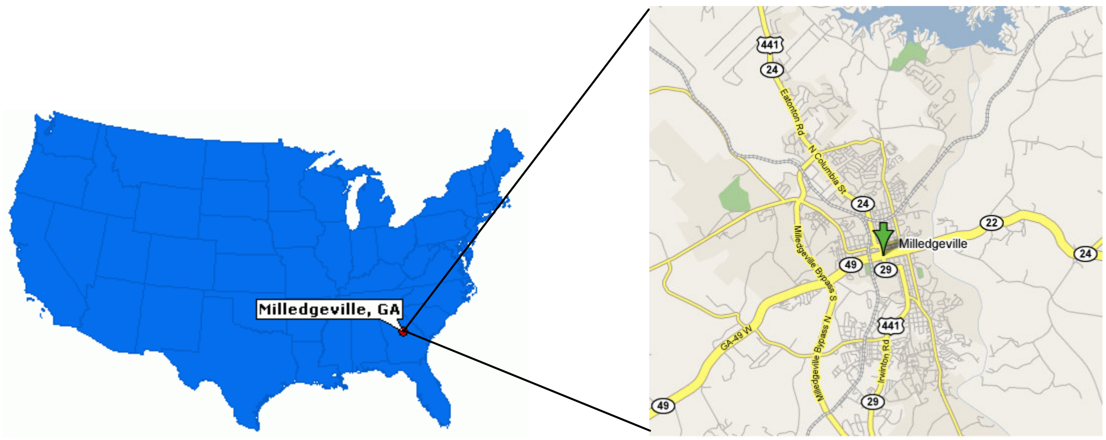

Figure 6 Study Area: Milledgeville, GA in Southeastern United States.

The flood event is assumed to occur during the night on a weekend in spring. Flood simulation is carried out using CCHE2D-FLOOD (Ying et al., 2003, and Qi et al., 2005a, 2005b) based on a 60m × 60m DEM, and the computed flood depths, velocity components, arrival times and flood durations are saved for further analysis. The number of Monte Carlo runs is set to 5000 for each analysis. The input data used for the spatial Monte Carlo Analysis of loss of life and flood damage for both urban and rural areas are presented in Tables 4, 5 and 6.

Table 4 Input Data for Loss of Life Estimation with Probability Distribution Functions.

Category	Name	Primary Value	Probability Distribution	Related Parameters
Flood Severity	High	> 20 ft	Normal	*variance* = 0.35
	Low	< 15 ft	Normal	*variance* = 0.5
Warning Time	Initial	20 min (after flood)	Uniform	*Range* (15, 35)
	Adequate	> 70 min	Uniform	*Range* (60, 80)
	No	< 25 min	Uniform	*Range* (15, 35)
Census	PAR	census raster	Normal	*Variance = 6% PAR*
Fatality Rate	FR	default value	N/A	N/A

Figure 8 (a) shows map showing the distribution of expected value of loss of life (number of people) and urban flood damage (in US dollars) resulting from the Monte Carlo Analysis. Figure 8 (b) shows the detailed farm damage in selected regions on the inundation map resulting from the Monte Carlo Analysis. Estimated different categories of flood damage by the tool are shown in Table 7. The results indicate that levels of loss of life and economic damage greatly vary spatially over the floodplain, which can be used effectively for enhancing integrated flood management decision making process, as well as for designing future flood protection measures.

Table 5 Input Data for Urban Flood Damage Analysis with Probability Distribution Functions.

Category	Name	Primary Value	Prob. Distribution	Related Parameters
High Intensity Residential Area (HIRA)	No of houses	10 Units	Triangular	*min* = 8, *max* = 14
	Structure value	$ 98,000	Normal	*variance* = 0.45
	Content value	$ 75,000	Normal	*variance* = 0.35
Low Intensity Residential Area (LIRA)	No of houses	6 Units	Triangular	*min* = 4, *max* = 10
	Structure value	$ 120,000	Normal	*variance* = 0.45
	Content value	$ 90,000	Normal	*variance* = 0.35
Commercial Industrial Transportation Area (CITA)	No of houses	8 Units	Triangular	*min* = 6, *max* = 12
	Structure value	$ 150,000	Normal	*variance* = 0.25
	Content value	$ 100,000	Normal	*variance* = 0.35
	Other value	$ 30,000	Normal	*variance* = 0.4
Depth – % Damage Relationship	HIRA	$f = -0.68h^4+7.78h^3-34.52h^2+78.7h+4.95$	Triangular	*min* = - 5%*f*, *max* = + 5%*f*
	LIRA	$f = -2.61h^4+25.37^{h3}-78.42h^2+95.89h+4.31$	Triangular	*min* = - 5%*f*, *max* = + 5%*f*
	CITA	$f = -0.81h^4+9.25h^3-38.13h^2+71.20h+4.77$	Triangular	*min* = - 5%*f*, *max* = + 5%*f*

Table 6 Input Data for Rural Flood Damage Analysis with Probability Distribution Functions.

Crop Name	Items	Primary Value	Probability Distribution	Related Parameters
Corn Grain	Yield *(bu/acre)*	75	Normal	*variance* = 0.25
	Price *($/bu)*	458	Normal	*variance* = 0.35
	% Damage	from Table 2	Triangular	*min* = - 5%*v*, m*ax* = + 5%*v*
Corn Silage	Yield *(bu/acre)*	65	Normal	*variance* = 0.35
	Price *($/bu)*	557	Normal	*variance* = 0.25
	% Damage	from Table 2	Triangular	*min* = - 5%*v*, m*ax* = + 5%*v*
Soybeans	Yield *(bu/acre)*	45	Normal	*variance* = 0.30
	Price *($/bu)*	655	Normal	*variance* = 0.40
	% Damage	from Table 2	Triangular	*min* = - 5%*v*, m*ax* = + 5%*v*
Hays	Yield *(bu/acre)*	100	Normal	*variance* = 0.40
	Price *($/bu)*	152	Normal	*variance* = 0.35
	% Damage	from Table 2	Triangular	*min* = - 5%*v*, m*ax* = + 5%*v*
Oats	Yield *(bu/acre)*	60	Normal	*variance* = 0.25
	Price *($/bu)*	536	Normal	*variance* = 0.30
	% Damage	from Table 2	Triangular	*min* = - 5%*v*, m*ax* = + 5%*v*
Winter Wheat	Yield *(bu/acre)*	50	Normal	*variance* = 0.30
	Price *($/bu)*	469	Normal	*variance* = 0.30
	% Damage	from Table 2	Triangular	*min* = - 5%*v*, m*ax* = + 5%*v*

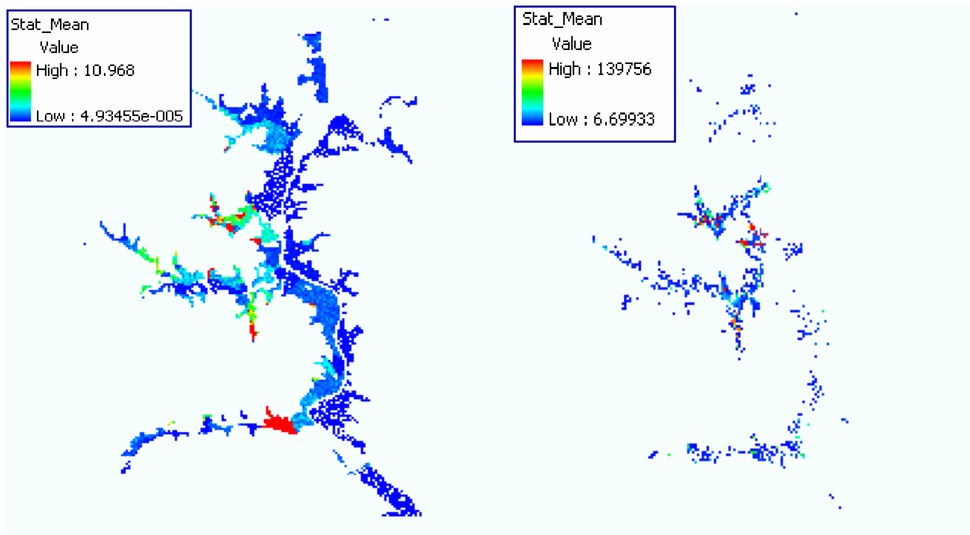

Figure 8 (a) Expected Value of Loss of Life and Flood Damage from Monte Carlo Analysis.

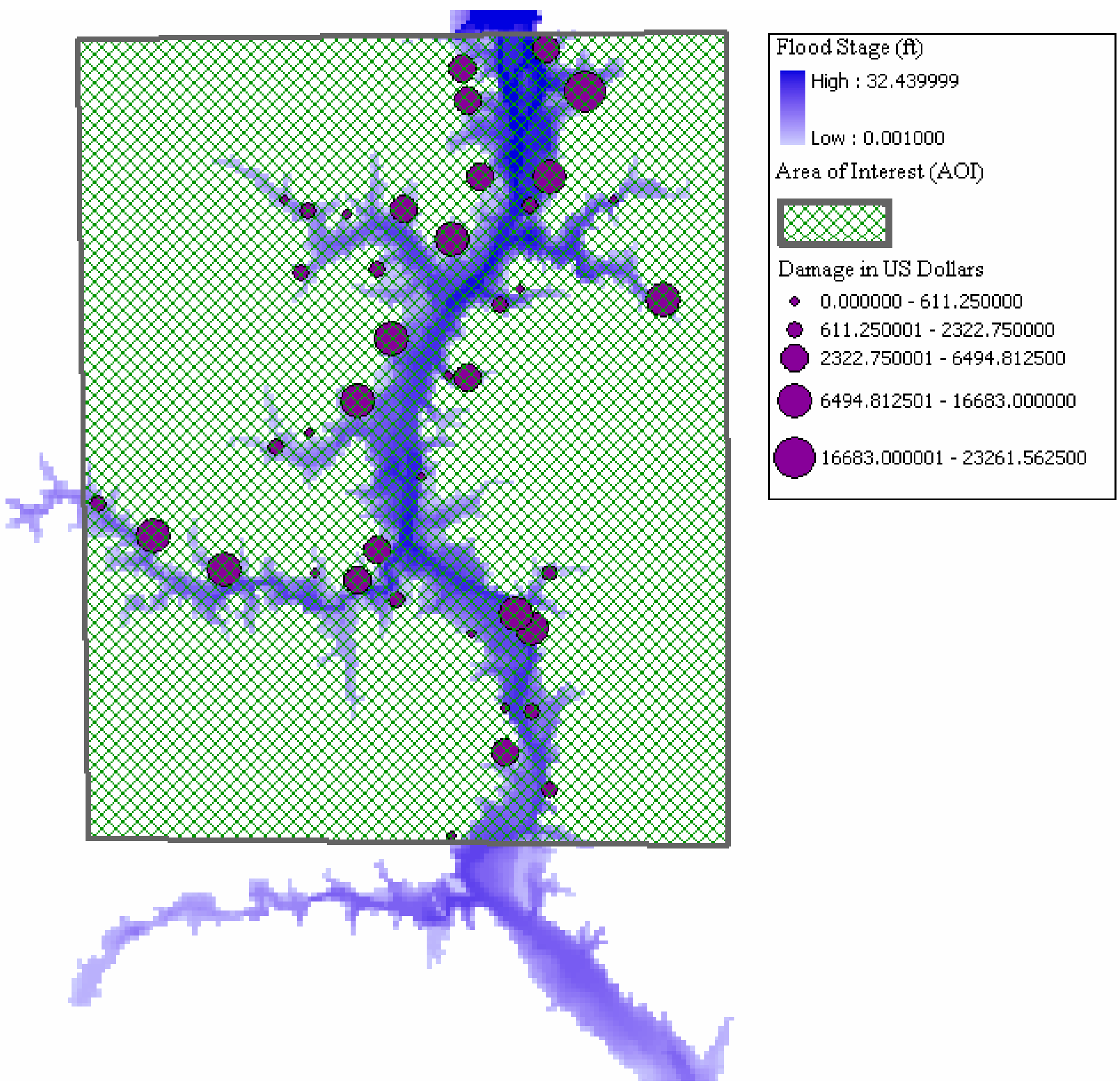

Figure 8 (b) Expected Value of Rural (Farm) Damages from Monte Carlo Analysis.

Table 7 Estimated Flood Damage by Category.

Category	Items	Results
Loss of Life	Number of Fatalities	147 person
Urban Flood Damage	High Intensity Residential Area	3.45×10^8 $
	Low Intensity Residential Area	2.62×10^8 $
	Commercial, Industrial Transportation Area	5.81×10^8 $
	Total	1.18×10^9 $
Farm Flood Damage	Total	1.60×10^6 $

6. CONCLUSIONS AND FINAL REMARKS

An estimate of losses from future floods is essential to preparing for a disaster and facilitating good decision making at the local, regional, state, and national levels of government. Flood loss estimates provide public and private sector agencies with a basis for planning, zoning, and development regulations, and policy that would reduce the risk posed by floods (Dutta and Herath, 2001). This research introduces a new system-based approach to flood management and flood damage analysis, which makes use of the advantages offered by the state-of-the-art numerical modeling capabilities of CCHE2D-FLOOD, GIS and Remote Sensing technologies, and data- and knowledge-base type information systems. In this respect, the proposed tool significantly improves the current practice by providing simulation and analysis capabilities with unprecedented realism and robustness. Table 8 compares the unique features offered by the proposed new methodology with the currently used used flood damage evaluation software - HEC-FDA, which is based on 1D simulation.

Table 8 Comparison between the Proposed Flood Management Decision Support Tool with HEC-FDA .

	HEC-FDA (US Army Corp of Engineers)	Proposed Flood Management Decision Support Tool
Flood Simulation	HEC-FDA uses discharge-frequency, stage-discharge relationships and water surface profiles computed from a 1D hydraulic model such as HEC-RAS.	Flood propagation computations are carried out using a 2D model, CCHE2D-FLOOD. Flood depths, velocities, flood arrival time and duration are stored in raster format that can be imported into ArcGIS.
Data Source	Damage reaches, structure inventory from survey database are defined. Hydrologic and economic information are entered in tabular forms via graphical user interfaces (GUI).	GIS feature layers (census block layer, infrastructure layer, surveyed database and etc) and Remote Sensing image are used. User defined depth – percentage damage relationship and various other digital data resources can be used.

Cont. (Table 8)

Flood Protection Alternatives	A study in HEC-FDA model allows formulating and evaluating several plans.	Each plan requires an individual run of CCHE2D-Flood and the results are used for evaluation.
Risk and Uncertainties Analysis	Risk-based analysis in HEC-FDA considers uncertainty in discharge-frequency, elevation-discharge, and elevation-damage relationships and various economic information. Monte Carlo analysis is used for computing expected damage.	Uncertainties in various economic data, depth-% relationship, number of population at risk, and date and time the event occurs enter into the computation of loss-of-life and flood damage. Spatial Monte Carlo simulation is performed for a single event case.
Results	HEC-FDA provides final results as equivalent annual damage report and plan performance in forms and charts. Results of various plans can be compared and evaluated.	Various maps showing spatially distributed loss of life and flood damage information and statistical analysis are provided. Spatial Compromised Programming toolbox is used to comparing various flood mitigation plans.

The present study shows risk and uncertainty analysis based on 2D numerical simulation results, GIS and remote sensing technologies can significantly improve the accuracy of flood hazard assessment. This approach efficiently assists in evaluation and ranking of flood control management strategies, and future design of flood proofing works. The resulting raster/vector maps of the case study showing spatial distribution of loss of life and flood damage can greatly enhance decision making process for future planning of emergency management operations. Currently, the studies are underway to incorporate the discharge-exceedance probability functions and flood frequency probability functions into the spatial risk and uncertainty analysis.

It is also important to underline the fact that the currently available relationships used for estimating property damage are generally expressed as a function of flood depth only. The accuracy of predictions can probably be improved by taking into account other detailed information provided by 2D flood modeling, such as flood velocity and duration. Research is needed to develop such improved damage relationships.

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