MODELING FLOOD EVENTS IN THE US

Charles Scawthorn
EQE International
1111 Broadway
Oakland CA 94607 USA

Abstract: Floods are an increasingly significant hazard for the US, causing financially greater losses per annum on average than any other natural hazard. Recent floods in the Mississippi (1993), Northwest (1996) and North Dakota (1997) were all regional catastrophes. The Federal Emergency Management Agency, US Army Corps of Engineers, National Weather Service and others have engaged in extensive efforts over the last several decades to develop a National Flood Insurance Program, build and maintain levees and other protective structures, and develop a flood early warning system. US Flood Insurance Maps may be unique in covering a large fraction of the population at risk, and forming the basis for land and structure use controls. FEMA is currently supporting development of a HAZUS Flood Loss Estimation program, for free and wide dissemination, which will include default data for all parts of the US.

Key words: floods, simulation, modeling, damage risk, software

Introduction

Flooding of all types (riverine, flash flooding, coastal, fluctuating lake levels and other sources) is a major hazard in the US, accounting for the single largest total property losses, and major life loss, of any one hazard. Flooding has a long history in the US, including the infamous Johnstown flood of 1889[1], and the Mississippi floods of 1927. Recent floods have included the Mississippi Flood of 1993, the Northwest floods of 1996, and the North Dakota flood of 1997. Figures 1 and 2 show US fatalities due to flooding, with a an increasing trend which however, if normalized for population growth, appears to be relatively steady (FEMA, 1997).

Figure 3 shows US financial losses due to flooding for the period 1988-1997, with a significant increasing trend. With adjustment for population and inflation, the average annual damage was $902 million for the 1916-to-1950 period, and $2.15 billion for the 1951-to-I 985 period. In other words, annual flood damage was almost 2.5 times more

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[1] Johnstown PA, the victim of a disastrous flood in 1889, is one of the greatest natural disasters in US history. At 3:10 PM on May 31, the South Fork Dam, a poorly maintained earthfill dam holding a major upstream reservoir, collapsed after heavy rains, sending a great wall of water rushing down the Conemaugh Valley at speeds of 20 to 40 miles per hour (32 to 64 km/h). At 4:07 PM, the 30-foot high wall of water smashed into Johnstown, which lay on the floodplain of the Conemaugh River. The flood swept away most of the northern half of the city, killing 2,209 people and destroying 1,600 homes. After another disastrous flood in 1936, a flood-control program was completed (1943), but this did not prevent heavy flooding in July 1977 in which 68 people were killed

during the latter period (FEMA, 1997). Currently, flooding losses are estimated to average about $4 billion per year in the US.

Prominent in Figure 3 are the losses in the Mississippi floods of 1993, the largest series of floods to affect the US in recent decades. The Mississippi River is the sixth largest river in the world in terms of discharge, with an annual average flow rate of 14,000 m3/s and a freshwater discharge onto the continental shelf of 580 km3/yr. In the summer of 1993, severe flooding occurred along large portions of the Mississippi and Missouri river valleys. The cause of the flood was the movement of the jet stream in the early summer of 1993, which dipped down into the Midwest and trapped weather systems in place over North America, producing storms that lashed the upper Mississippi Valley. In one month some areas of the Midwest absorbed five times their normal amount of rainfall - as the Mississippi and Missouri rivers reached record heights, the slow moving flood rolled over at least 15,600 square miles, through 55 towns, killed 50 people, damaged or destroyed 55,000 homes, stole at least 30,000 jobs, and destroyed 12 billion dollars worth of property.

In order to reduce flood losses in the US, local, state and federal authorities have engaged in flood mitigation for decades. Because knowledge of these efforts may be of value for other regions, this paper briefly summarizes some of the major US flood risk mitigation programs, and a new effort to develop a national flood loss estimation model.

An overview of US Flood Risk Assessment and Mitigation

For many years, the U.S. Army Corps of Engineers (USACE) has been involved in floodplain management studies. Figure 4 shows for example losses avoided (ie, prevented) by USACE flood projects, for the years 1988-1997. Bulletin 17B (IACWD, 1982) is used by USACE and most other government agencies in undertaking flood flow frequency and floodplain mapping studies.

For streams with recorded annual peak flows, the 10-, 2-, 1and 0.2-percent-annual-chance (10-, 50-, 100-, and 500-year) floods are determined using Bulletin 17B procedures. The flood discharges are used in evaluating flood hazards for the National Flood Insurance Program (NFIP), with the 1-percentannual-chance flood used as the base flood for regulatory purposes. For streams where there is insufficient statistical data, frequencies are estimated by regional regression equations based on watershed and climatic characteristics or watershed models (FEMA 37, 1995).

The water depths and areas inundated by the 1 and 0.2% annual chance floods are determined through the use of hydraulic models that reflect topographic characteristics. Most often, a one-dimensional, steadystate model (a step-backwater model) is used to convert charges to water surface elevations, with the most widely used model being the USACE Hydrologic Engineering Center's HEC-RAS model or its predecessors (HEC-River Analysis System; *USACE, 1997b*). Computed water surface elevations are combined with topographic mapping data to develop flood hazard maps for the NFIP, termed Flood Insurance Rate Maps (FIRMs).

FIRMs are produced using traditional cartographic practices and digital techniques. An example of a FIRM panel, adapted from the digital map for El Paso County, CO and Incorporated Areas, is shown in Figure 5. Figure 6 indicates areas of the US where digital FIRMS, termed "Q-3"'s, are currently available. An ambitious program to update FIRMS for the entire US is currently under development by the Federal Emergency Management Agency (Frengs et al, 1999).

Floods occur in all 50 States and the U.S. territories. FEMA has estimated that over 9 million households and $390 billion in property are at risk from the 1-percent-annual-chance flood (analyses based on Donnelley, 1987). Based on a composite risk score accounting for floodplain area and the number and value of households, Florida ranked as the State with the highest risk, followed by California, Texas, Louisiana, and New Jersey. Figure 7 shows the estimated distribution by county of households in the 1-percent-annual-chance annual floodplain (FEMA, 1997).

Figure 8 indicates the framework employed by USACE, NFIP and most others, for estimating flood losses. It consists of three basis steps, involving

1. Define the Hazard, usually accomplished by determining an exceedance probability, and determining the associated discharge.
2. For each sub-area of interest, determine the depth of flooding (termed the stage), based on hydrologic and topographic considerations – the resulting curve is termed the *rating* curve.
3. For each structure or sub-area of interest, determine the damage associated with the stage for that structure or sub-area. Damage is determined from depth-damage curves, developed by various USACE district offices, by the NFIP based on claims data, and by others.

National Flood Insurance Program (NFIP)

The U. S. Congress established the NFIP with the passage of the National Flood Insurance Act of 1968. The NFIP was broadened and modified with the passage of the Flood Disaster Protection Act of 1973 and other legislative measures. It was further modified by the National Flood Insurance Reform Act of 1994, signed into law on September 23, 1994. The NFIP is administered by the Federal Insurance Administration (FIA), and the Mitigation Directorate (MT), components of the Federal Emergency Management Agency (FEMA), an independent Federal agency.

Under the NFIP, flood insurance is made available at rates that are intended to be affordable in return for community adoption of ordinances to regulate development in mapped flood hazard areas. The NFIP enables property owners in participating communities to purchase insurance protection against losses from flooding. This insurance is designed to provide an insurance alternative to disaster assistance to meet the escalating costs of repairing damage to buildings and their contents caused by floods.

In support of the NFIP, FEMA has undertaken a massive effort of flood hazard identification and mapping to produce Flood Hazard Boundary Maps (FHBMs), Flood

Insurance Rate Maps (FIRMs), and Flood Boundary and Floodway Maps (FBFMs). Several areas of flood hazards are commonly identified on these maps. One of these areas is the Special Flood Hazard Area (SFHA), which is defined as an area of land that would be inundated by a flood having a 1-percent chance of occurring in any given year (also referred to as the base or 100-year flood). The 1-percent annual chance standard was chosen after considering various alternatives. The standard constitutes a reasonable compromise between the need for building restrictions to minimize potential loss of life and property and the economic benefits to be derived from floodplain development. Development may take place within the SFHA, provided that development complies with local floodplain management ordinances, which must meet the minimum Federal requirements. Flood insurance is required for insurable structures within the SFHA to protect Federal financial investments and assistance used for acquisition and/ or construction purposes within communities participating in the NFIP.

The Federal Insurance Administration reported at the end of 1994 that 18,561 of over 20,000 flood-prone communities were participating in the National Flood Insurance Program and administering floodplain management ordinances. In those communities, over 2.8 million flood insurance policies were in effect, providing financial protection in the event of flood damage.

Tables 1A and 1B present information on the program's current status, showing that there are approximately 4 million policies in force with total sums insured of $483 billion, and premiums of $1.6 billion per annum (0.3% of TSI). In 20 years, there have been 929,903 claims experienced, for an average total loss per year of $420 million.

Real-time warning

Early and real-time warning offer major benefits for flood loss reduction, in that emergency floodfights can be mounted, population and livestock evacuations can occur, and property can be protected. The US Geological Survey, National Weather Service and FEMA have combined to develop various tools for early and real-time warning systems.

The concept of the *Integrated Flood Observing and Warning System* (IFLOWS) has been developed extensively since the creation of the National Flash Flood Program Development Plan in 1978. The goals of the IFLOWS Program are to substantially reduce the annual loss of life from flash floods, reduce property damage, and reduce disruption of commerce and human activities. To develop the IFLOWS concept, the National Weather Service (NWS) began a joint effort with selected states in the Appalachian Region of the United States to undertake the establishment and development of a flash flood warning system to improve flood warning capabilities in that Region.

In 1979 the NWS first began development of a prototype IFLOWS system to use as a model for expansion into other areas. A 3-state, 12-county area along the borders of Virginia, West Virginia, and Kentucky was selected for the prototype because of its susceptibility to flooding and its lack of existing flood warning systems and available communications circuits to tie this 3-state area together.

The NWS completed the prototype IFLOWS system in 1981, and work began on expanding the system in the three original states and on developing IFLOWS in Pennsylvania and Tennessee. The expansion program was targeted to implement IFLOWS equipment inapproximately 120 counties of the multistate area.

In 1985, Congress approved an amendment to a continuing resolution which earmarked additional funds specifically for expansion of IFLOWS in the areas hardest hit by the devastating floods of November 4-5, 1985. This area encompassed 29 new counties in West Virginia and numerous counties in Virginia and Pennsylvania which were declared disaster areas. It was also expanded to include counties in North Carolina and New York with a history of serious flooding problems in the past.

While resource limitations have restricted additional expansion of direct NWS support for new IFLOWS installations, IFLOWS technology has now spread well beyond the seven original states. Numerous communities, state and federal agencies are now linked in a wide area communications network using this technology. This Automated Flood Warning Systems (AFWS) network connects numerous local flood warning systems, and integrates and shares information from approximately 250 computers and 1500 sensors in 12 states.

ALERT is an acronym for *Automated Local Evaluation in Real Time*, which is a method of using remote sensors in the field to transmit environmental data to a central computer in real time. This standard was developed in the 1970's by the National Weather Service and has been used by the National Weather Service, U.S. Geological Survey, Army Corps of Engineers, Bureau of Reclamation, numerous state and local agencies, and international organizations.

There are a number of types and manufacturers of ALERT hardware and software, but they are all designed to meet a common set of communications criteria. Because of this, most equipment and programs are interchangeable, which has allowed for competition to improve performance and reduce cost. ALERT systems have become a standard in real time environmental data collection because of their accuracy, reliability, and low cost.

HAZUS Flood Loss Estimation Model

HAZUS is a nationally applicable standardized methodology and software program for estimating potential losses from earthquakes, floods, and wind, being developed by the National Institute of Building Sciences (NIBS) under a Cooperative Agreement with the Federal Emergency Management Agency (FEMA). At the present time, HAZUS has the capability to estimate Earthquake losses, and Flood and Wind models began development in 1998. NIBS has established an expert committees to provide technical oversight and guidance to the contractors selected to develop each of the models. EQE International with Michael Baker Corporation is the contractor selected to develop the Flood Model.

HAZUS Flood is anticipated to operate at three Levels:

- Level 1 is the default level, in which analyses are performed using hazard and exposure data, together with algorithms, damage functions and software, all of which comes with the model. Level 1 is anticipated to have two kinds of users:
    - Local users, who wish to examine their risk or the potential benefits of a mitigation measure, without investing any time for data collection or processing. Local users, who might be floodplain managers, emergency responders, land use planners or others, are expected to understand that the default data furnished with the model may be inaccurate in detail, and are expected to go to Level 2, if the default Level 1 analysis is promising.
    - Non-local users, typically policy-makers, who are not local and are not expected to have local knowledge. Such users, who might be state emergency responders, legislative analysts or others, have a different perspective than local users, and the Level 1 analysis and results are anticipated to have sufficient accuracy (in the mean) for their needs.
- Level 2 is anticipated to be employed mainly by local users, and uses the HAZUS software for all calculations, differing from Level 1 in the input data. Instead of employing default DEM, discharge-frequency and/or exposure data, in Level 2 more accurate data developed by or available to local users can be input.
- Level 3 is similar to Level 2 in that it is intended for local users only, but differs in that results of hydrologic or other analyses will be importable, via standardized format. An example of this would be importing rating curves from the HEC-RAS model, rather than generating them using the HAZUS software.

The HAZUS Flood Model is being developed in several phases, with Phase 1 completed in the period August 1998 to April 1999. As part of the initial phase, a comprehensive review of the flood loss estimation studies, models, and data was conducted. Based on that review, an idealized flood estimation methodology and model were developed as represented in Figures 9. Methods for estimating each component of the methodology (i.e., characterization of flood hazard, inventory representation and classification, direct damage, direct economic loss, etc.) were then identified and evaluated through a *Proof-of-Concept* exercise in six communities representing various flood conditions.

The findings from the proof-of-concept methodology were the following:

- Discharge frequencies can be determined for all river reaches in the United States where digital elevation models (DEM) and regional regression relations are available (i.e., most of the US).

- Flood depths can be determined for all river reaches in the United States where DEM and Q3 data is available.
- Base flood elevations (BFEs) along coastal shore-perpendicular transects can be estimated and provide reasonable results.
- The application of U.S. Census and Dunn & Bradstreet data at the census block level provide the resolution required for flood loss estimation.
- The Federal Insurance Administration “credibility-weighted” depth-damage functions are the most viable to use at present, since they are based on the best available damage data, representing more than 20 years of losses.
- Lifeline depth-damage functions can be developed using a combination of historical data, component based modeling and expert opinion.
- USACE’s AGDAM model can be modified to produce reasonable results of agricultural damage.

Phase 2 of the HAZUS Flood Loss Estimation Model development process began in May 1999 is currently scheduled to provide a Preview Model in the summer of 2002. Phase 2 consists of the following four tasks:

1. Development of Flood Loss Model
2. Development of Software
3. Calibration and Pilot Testing, and
4. Model Revisions, based on pilot testing.

Concluding Remarks

Floods are a significant hazard for the US, causing financially greater losses per annum on average than any other natural hazard. Agencies at all levels of US government have engaged in mitigation since the last century. The US may be unique in having developed over the last two decades a standardized flood mapping program covering a large fraction of the population at risk, and using that program in support of land and structure use controls, and a national flood insurance program. FEMA is currently supporting development of a standardized flood loss estimation program, for free and wide dissemination, which will include default data for all parts of the US.

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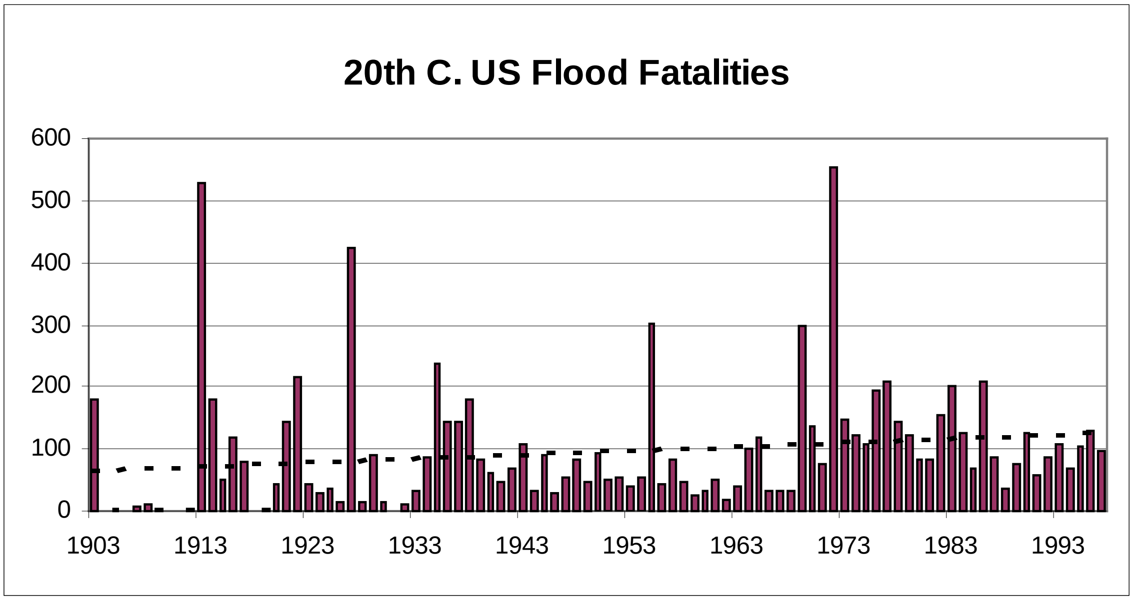

Figure 1 – 20th Century US Flood Fatalities

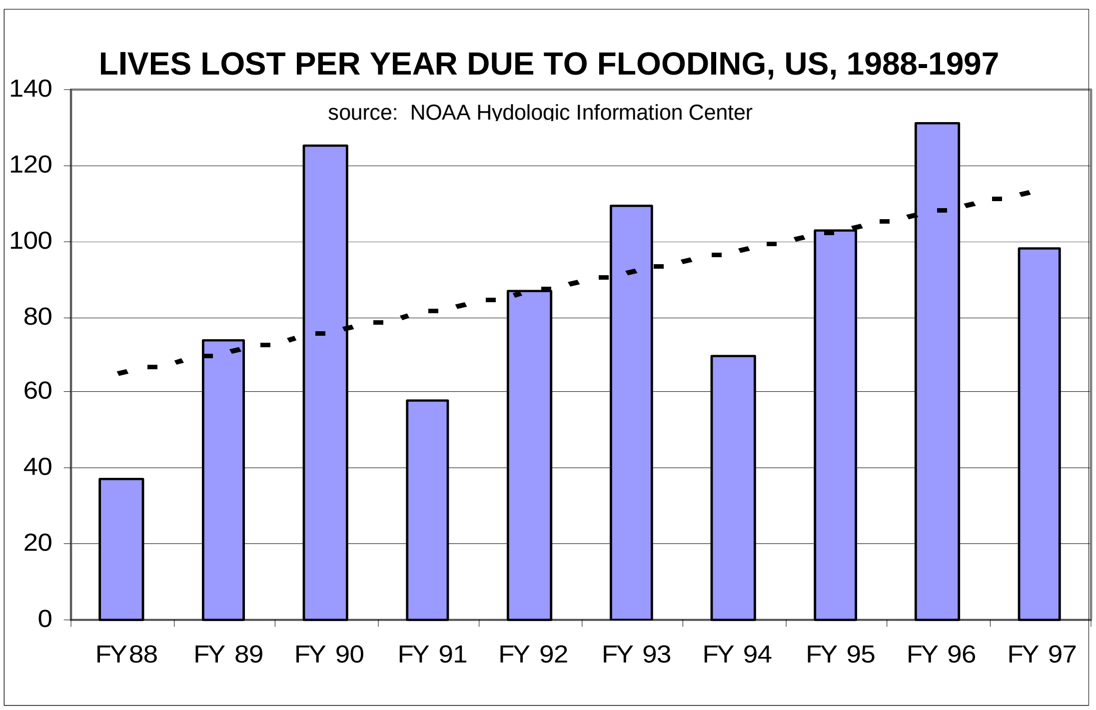

Figure 2 –US Flood Fatalities, 1988-1997

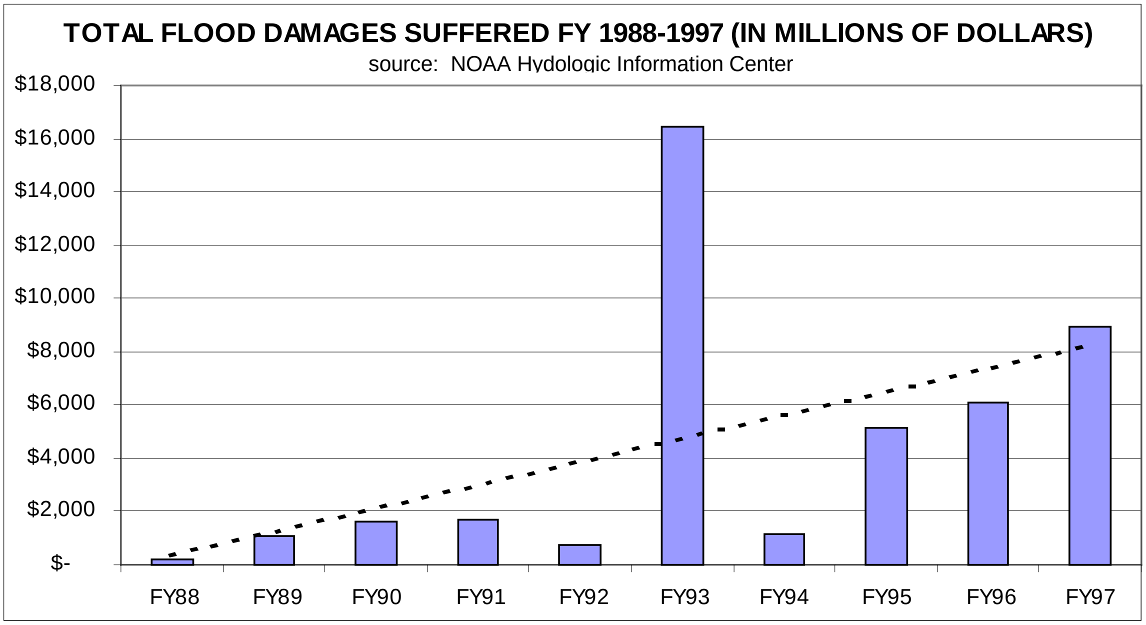

Figure 3 – Total US Flood Damages 1988 - 1997

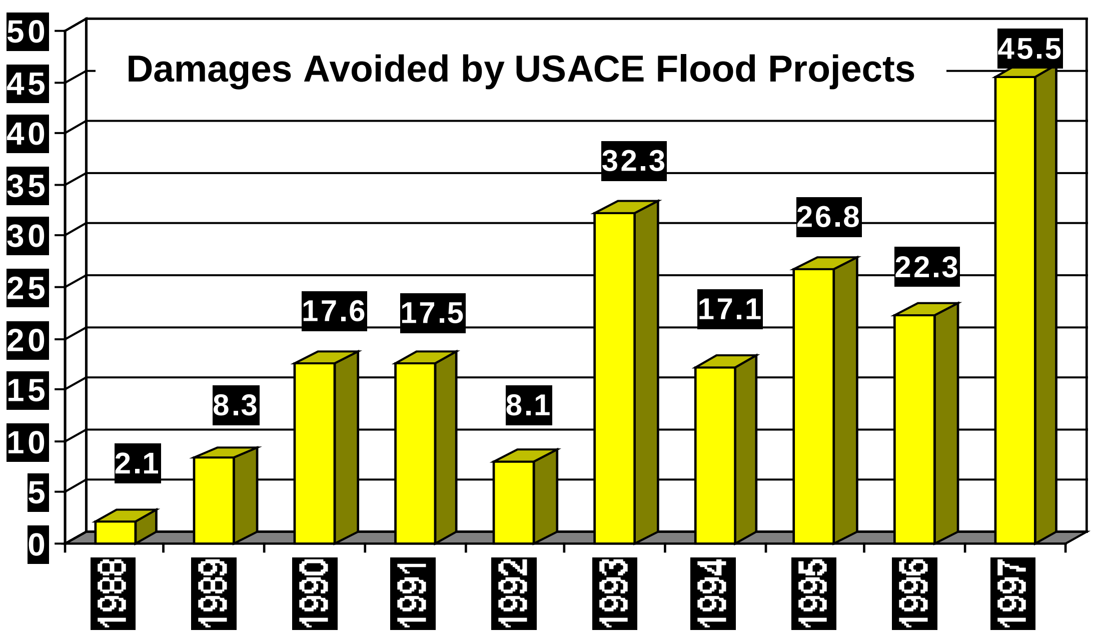

Figure 4 –US Flood Losses Avoided by USACE Flood Projects, 1988 - 1997

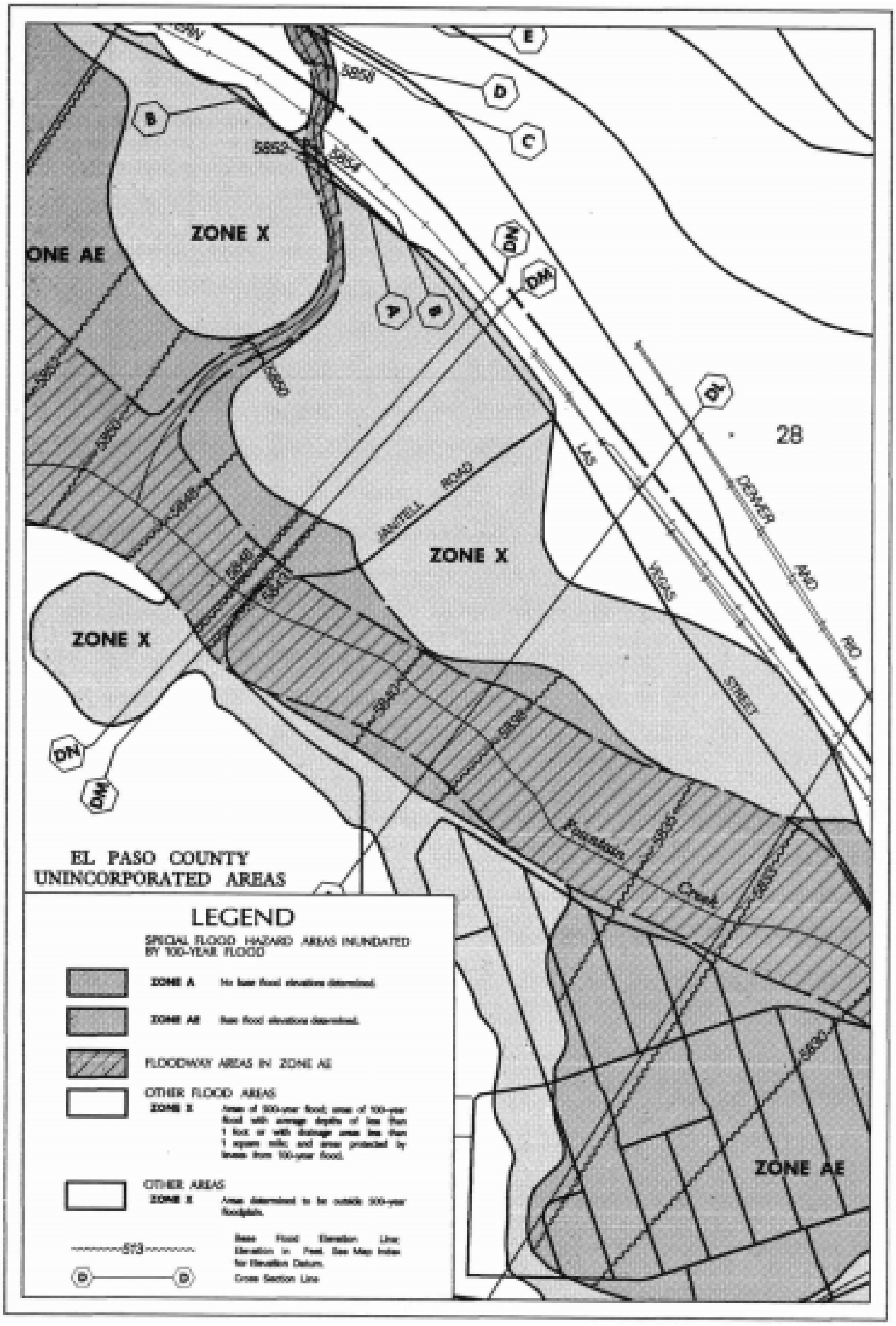

Figure 5 – Example Flood Insurance Rating Map (FIRM)

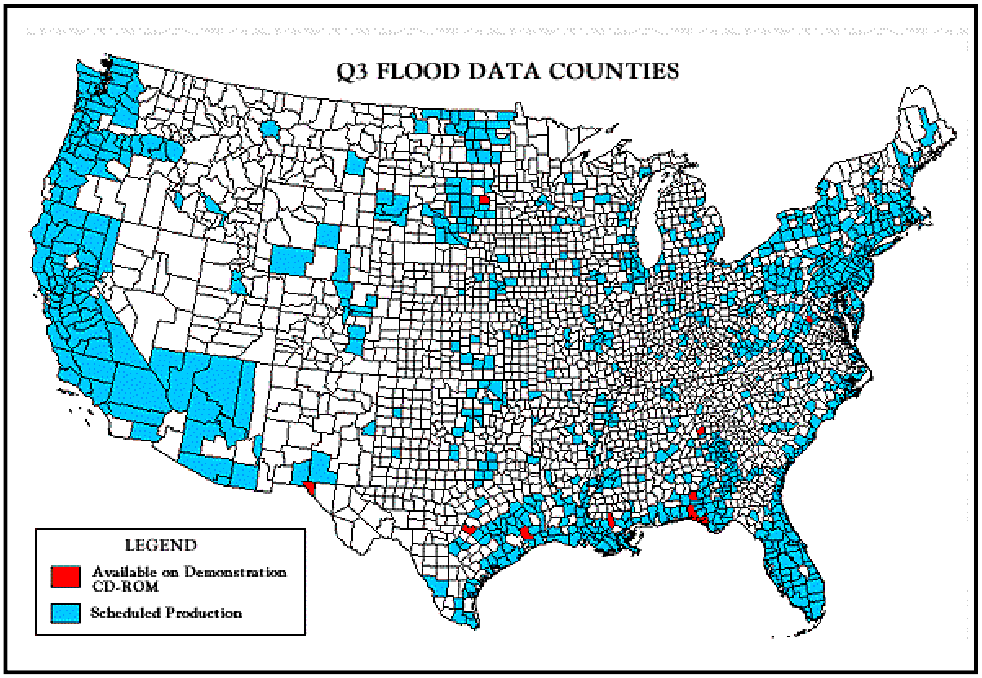

Figure 6 – US Counties with Q3 Flood Data

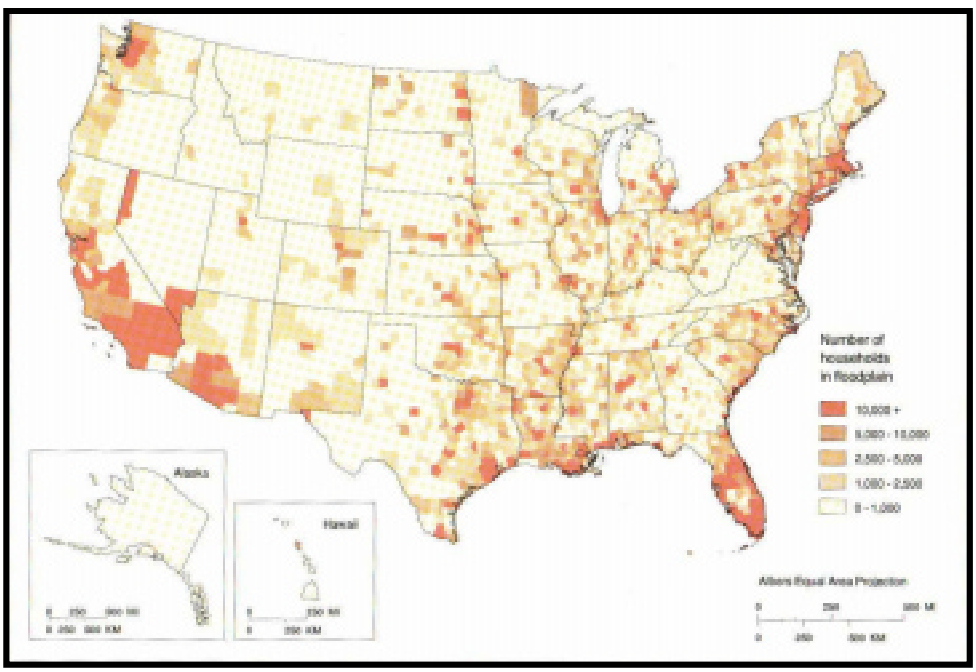

Figure 7 - Geographic Distribution by county of households in the US in the 1% pa floodplain
(data from Donnellay and FEMA, 1987; after FEMA, 1997)

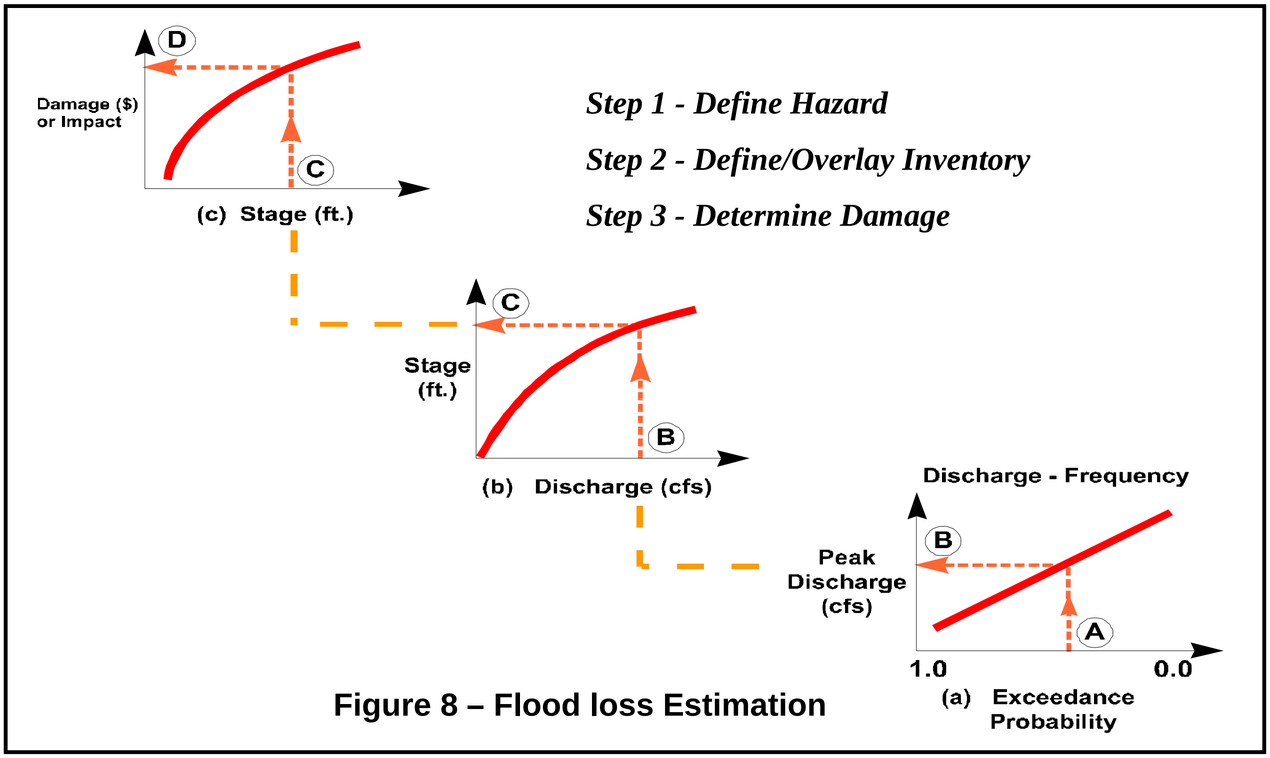

Figure 8 – Flood loss Estimation

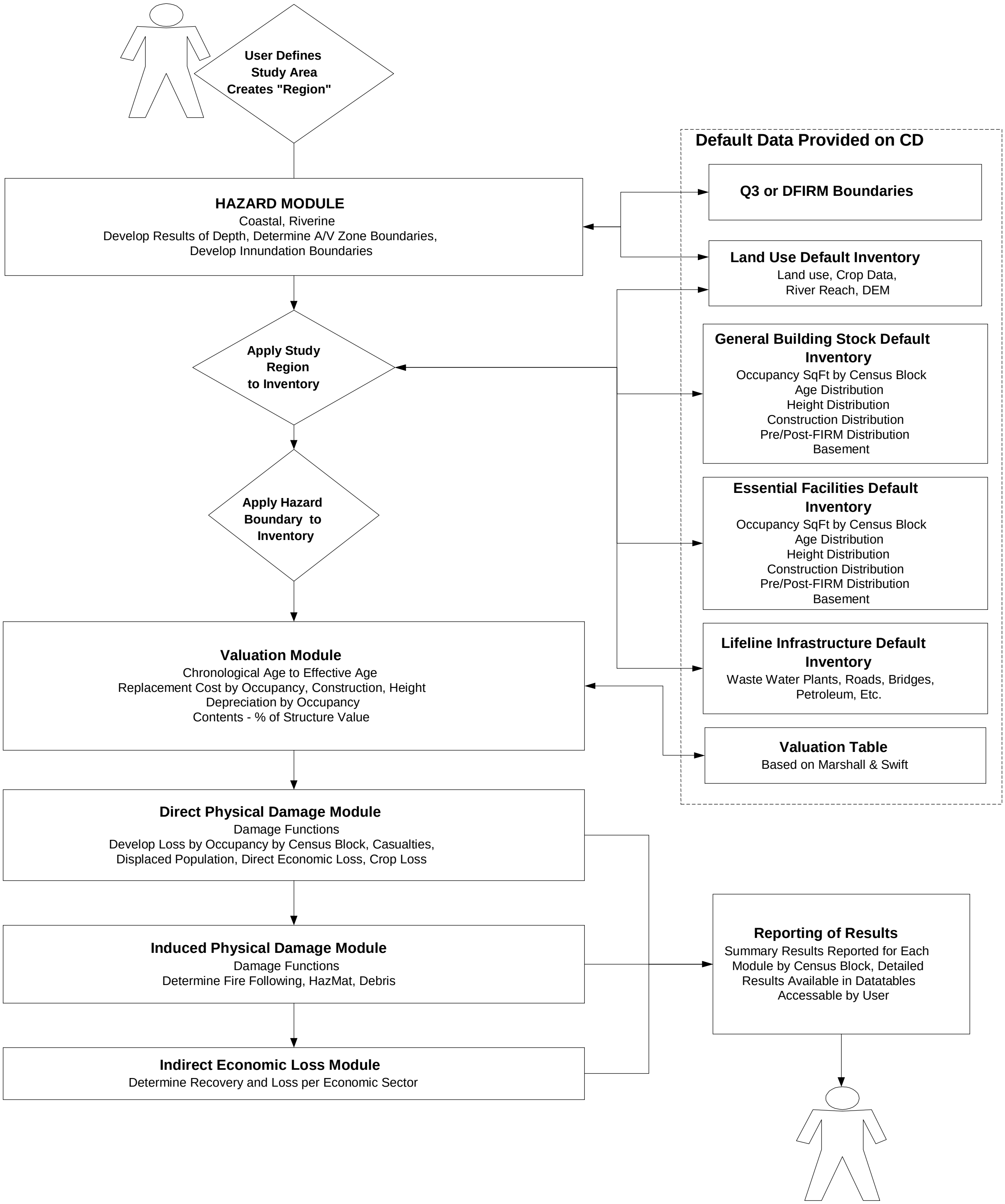
User Defines
Study Area
Creates "Region"
HAZARD MODULE
Coastal, Riverine
Develop Results of Depth, Determine A/V Zone Boundaries,
Develop Innundation Boundaries
Default Data Provided on CD
Q3 or DFIRM Boundaries
Land Use Default Inventory
Land use, Crop Data,
River Reach, DEM
Apply Study
Region
to Inventory
General Building Stock Default
Inventory
Occupancy SqFt by Census Block
Age Distribution
Height Distribution
Construction Distribution
Pre/Post-FIRM Distribution
Basement
Apply Hazard
Boundary to
Inventory
Essential Facilities Default
Inventory
Occupancy SqFt by Census Block
Age Distribution
Height Distribution
Construction Distribution
Pre/Post-FIRM Distribution
Basement
Lifeline Infrastructure Default
Inventory
Waste Water Plants, Roads, Bridges,
Petroleum, Etc.
Valuation Module
Chronological Age to Effective Age
Replacement Cost by Occupancy, Construction, Height
Depreciation by Occupancy
Contents - % of Structure Value
Valuation Table
Based on Marshall & Swift
Direct Physical Damage Module
Damage Functions
Develop Loss by Occupancy by Census Block, Casualties,
Displaced Population, Direct Economic Loss, Crop Loss
Induced Physical Damage Module
Damage Functions
Determine Fire Following, HazMat, Debris
Reporting of Results
Summary Results Reported for Each
Module by Census Block, Detailed
Results Available in Datatables
Accessable by User
Indirect Economic Loss Module
Determine Recovery and Loss per Economic Sector

Table 1A - National Flood Insurance Program
as of Sept. 30, 1998

Policies in-force	Insurance in-force	Written premiums in-force	Contracts in place per 1000 persons
4,117,936	$ 483 billion	$ 1.6 billion	12.47

Table 1B - National Flood Insurance Program Loss Statistics
January 1, 1978 through Sept. 30, 1998

Total losses	929,903
Closed losses	703,527
Open losses	17,458
Crop losses	208,918
Total payments	$ 8.4 billion
Average Payments per year	$ 420 million
Policies In-Force	4,117,936
Policy loss pymts per yr per policy	$ 102.