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The Generation of Flood Damage Time Sequences

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John P. Breaden
University of Kentucky

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THE GENERATION OF FLOOD DAMAGE TIME SEQUENCES

John P. Breaden

University of Kentucky Water Resources Institute
Lexington, Kentucky

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Dr. L. Douglas James, Principal Investigator

ABSTRACT

There is a need in water resources planning to develop a procedure for determining the time pattern in which flood damages occur as a function of the rise and fall of the flood hydrograph. The widely-used approach for estimation of flood damages does not take into account the fact that the frequency of the annual flood peak may not be the same as the frequency of the total annual flood damages. As examples, several small storms during the year may do more damage than a single larger storm, or flood damages may be reduced by a reduction in flood duration rather than the flood peaks.

This report presents a digital computer subroutine DAMAGE which can be used to estimate the direct and indirect damages to property in the four basic categories of crop, field, urban, and public facilities as functions of the depth and duration of flooding, seasons, and the time laps between flood events. DAMAGE may be called with recorded or simulated annual hydrographs and used to analyze the time pattern of damages in the flood plain for optimizing the policies for operating reservoir flood control storage or for estimating the average annual damages for use in formulation of alternative flood control schemes.

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CHAPTER I

THE NATURE OF FLOOD DAMAGE

INTRODUCTION

Natural processes require space. During the runoff phase of the hydrologic cycle, excess precipitation first collects in small feeder channels. As the water flows downstream, these combine to form progressively larger streams and rivers. Human activity also requires space. Some activities serve needs, which range from obtaining food and maintaining adequate shelter to achieving satisfying cultural and aesthetic experiences. Other activities are deliberate sacrifices of present well being so that more time and effort can be devoted to saving for long-run needs. Men accumulate capital so future needs can be more easily satisfied.

Most of the time, no conflict exists between the space requirements of natural runoff and human capital accumulation. Streams flow quietly within their banks while men go about their business in the surrounding countryside. Occasionally, during short periods, nature requires much more than its normal amount of space to accommodate runoff. Flood water overflows the river banks and interferes with men engaged in activities to meet immediate needs, and furthermore, accumulated capital may be damaged or destroyed.

Flood damages are as diverse as the variety of human activity which can be interrupted and the variety of property people acquire (8, pp. 77). They can be directly caused by contact with flood waters or indirectly accrue through a chain of cause-and-effect linkages felt at a distant location. Both direct and indirect effects may be difficult to express in terms of the magnitude of loss, and even known losses may be difficult to translate into economic units or dollars. Sometimes, it may be appropriate to restore damaged

property. Other times, the damage may be such that restoration is not worthwhile or even impossible. The bricks around the base of a house may be discolored; a family heirloom may be ruined; a life may be lost.

Wise ordering of human activity requires objective analysis of the effects of flooding by type of activity. Estimates are needed of the flood damages which would result to a variety of real (existing) or hypothetical (potential future) combinations of human activity (transportation, commerce, farming operations) and property (buildings, roads, planted crops). Estimates are needed of how damages vary with differences in a variety of flood characteristics (depth, duration, velocity). Only from such information is it possible to rationally compare alternative adjustments to flood hazard and select an optimum flood control plan. The problem at hand is how to estimate (quantify) flood damages from relevant information on the extent and severity of flooding and on activities underway and the property located in areas subject to flooding. It is not to recommend a plan of action or to judge the wisdom of past policy. It is not to predict the frequency or time pattern of future flood events.

CATEGORIES OF FLOOD DAMAGE

Flood damages are so diverse that orderly evaluation requires the damages to be classified before estimation. While the distinctions among categories are complicated by inconsistencies and continuing evolution in benefit-cost terminology (11, pp. 161-193) and by the recent introduction of multiple accounts into project evaluation (26), five empirical categories are useful. These are direct damages, indirect damages, secondary damages, intangible damages, and uncertainty damages.

Direct Damages: Property (the capital men have accumulated to achieve greater value from their use of land) is harmed when inundated by floodwater.

National income suffers as resources which otherwise would be devoted to advance the general welfare must now be diverted to rehabilitation of previously accumulated capital. Direct damage may be defined as the magnitude of this diversion. For comparison with other social values, the results are expressed in monetary units, a task more straightforward for direct damages than for effects in the other categories.

The damage or loss may be taken as the least of three amounts (the least amount may or may not be associated with the course of action followed by the property owner). If the property fulfilled a function worth restoring, the damage may be taken as the cost of restoring the property to a state adequately performing its pre-flood function. If restoration cannot be justified, (or is physically impossible) the damage may be taken as the present worth of the expected future productivity if the flood had not occurred. The loss in income from crops destroyed in the field is a special case of this. If some other kind of property can be used to fulfill the same function at less cost, the damage may be taken as the cost of the substitute measure.

Direct or water contact damages may be classified according to the nature of the property or restoration process. Damages accrue to structures as buildings are reduced in structural soundness, functional performance, or aesthetic quality; to other possessions people have in buildings or elsewhere in the hazard area; and to vegetation from urban landscaping to agricultural crops. Cleaning soiled property after a flood is a difficult and costly job. The property owners and their families, neighbors, and friends invest long, hard hours in drying damp belongings and in removing the sediment and debris deposited by the flood. Hired labor is more often used for public facilities and commercial establishments. The sacrifice represented by these efforts may be a major damage item and can be estimated by man-hours of work at an appropriate wage.

For shallow flooding, direct damage increases approximately linearly with depth (11, pp. 250-252). If the depth exceeds four or five feet, the incremental flood damage per foot of additional depth drops and eventually approaches zero as the property approaches total destruction. A convenient equation for estimating direct damage is of the form

$$D = M f(d) \quad (1)$$

The direct flood damage in dollars (D) is proportional to the market value of the inundated property (M) and a function of the depth of flooding f(d) which is nearly linear at shallow depths and eventually approaches an upper limit of near unity for very great depths. For shallow depths, f(d) may be taken as Kd where K is a proportionality factor determined by examining historical flood damage information for relevant kinds of property. The value of K may be adjusted upward to reflect damages added by higher sediment content and higher velocities. The total damage to the variety of property types located in a given floodplain can be obtained by summing the damages to individual properties.

This process suggests the practical necessity of grouping estimates to like properties in estimating total flood damages over a large flood plain. It is not computationally feasible to apply equation 1 to every piece of property for measuring flood damage for use in planning when a large area is inundated. With the availability of high speed digital computers, the problem is not so much in multiple application of the equation as in multiple determination of parameter values.

Each individual property has at the time of any given flood its own values of K and M, both of which are subject to change by the time of the next flood. K depends on the dimensions, elevations, building materials, contents, and occupant flood fighting activities that relate to the structure as well as on the depth, duration, velocity, sediment content, and other characteristics of

the flood. The relationship is extremely complicated and very poorly researched. Even if planners had good information on how all these factors affect K, it would not be practical to expect estimates for each variable for each parcel at the time of each flood for a typical planning study. The practical solution is to use a typical value pertaining to a typical structure with the idea that positive and negative departures will average out over the many buildings in the flood plain. Correct estimates by individual structures are not so important for planning as a correct estimate of overall damage.

Indirect Damages: Human activities are made more difficult or prevented when floodwater obstructs activity paths. National income suffers as additional resources must be used to complete the activity or the activity goes undone. Indirect damages represent the magnitude of this loss in economic efficiency. It includes the value of lost business and services and the costs of alleviating hardship, safeguarding health, constructing temporary barriers, removing goods from the flood area, rerouting highway and railroad traffic, and delay of delivering goods and services. Because the variety of ways an individual flood will disrupt human activity is so great, the number of individual interruptions is so many, and each is of itself relatively small and time-consuming to evaluate, indirect damages as a group are usually taken as a fixed percentage of the direct damages, and an appropriate percentage is determined from pilot studies. The percentages adopted by the Corps of Engineers (13, pp. 17), based on studies for a 1955 flood, of business loss and cost of emergency measures are residential 15%, commercial 35%, industrial 45%, utilities 10%, public facilities 34%, agriculture 10%, highway 25%, and railroads 23%.

Secondary Damages: The economic loss caused by flooding may extend further than the losses to those whose property is damaged or whose activities are

hindered. Other people depending on output produced by damaged property or on hindered services may feel adverse effects. Adverse effects also accrue to those who supply goods and services to the flooded area. Secondary damages include such losses. On the other hand, resources that could otherwise be devoted to other purposes because of the flood must be shifted to repairing damage. Pecuniary gains are shifted from users of output from the flood plain and suppliers of input to the flood plain to suppliers of materials and labor for rehabilitation and to suppliers of goods and services from areas not hit by the flood. Secondary effects thus tend to be offsetting, and hence are under normal economic conditions considered to be zero from the national viewpoint. Only where substantial unemployment means that new jobs are created rather than diverted from other beneficial activity is a secondary benefit considered appropriate from an efficiency viewpoint (21).

Intangible Damages: Recent thinking in water resources planning by Government policy makers has favored more explicit analysis of project consequences with respect to objectives other than economic efficiency. Environmental quality, social well-being, and regional development are the three additional accounts within which benefits and costs are to be reckoned (22, 26). The idea is that through this broader analysis such effects as grief and hardship, loss of life and health, sense of insecurity for living under perpetual flood threat, and temporary loss of essential public service will be presented in a way wherein they can become a more explicit influence on decision making in project planning. Today, much emphasis is put on the environmental and social consequences caused as a direct or indirect result of flood damage or the threat of future floods. The economic and aesthetic value of property in urban flood plains tends to be depressed by flood events. This has a definite impact on the social well-being of the affected community. Concentrated efforts are underway to evaluate more precisely these social and environmental damages which, until now, have been enumerated only in narrative and descriptive form.

Urban and suburban flood plains receive much of the spotlight because of the concentration of life and property in such areas. However, the damage and threat of damage to rural areas also have a definite impact on the local or regional economy. Even where residences are built on high ground and human life is free from danger, the loss of farm products, equipment, soil, property, and farm to market roads can cripple a local economy. Economic well-being is redistributed as the reduction in farm output causes a scarcity of certain products and a rise in prices. The farmer may find it necessary to borrow operating capital because of the loss of his crops.

Uncertainty Damages: Years may pass without a flood, and then, suddenly, a major flood may bring financial ruin. The ever present uncertainty with respect to when the next flood will occur and the magnitude of the losses it will bring imparts a burden of insecurity which may be considered as a damage in its own right. The uncertainty damage cost is the amount in excess of the expected value of the damages that individuals are willing to pay to avoid a flood loss pattern. The concept is empirically supported by the fact that people are willing to pay annual insurance premiums exceeding expected annual losses (11, pp. 254-255) to avoid financial disaster or even the financial inconvenience of irregular budgeting. The willingness to pay for greater financial security or convenience is what makes the insurance business profitable. Studies of practices in buying insurance are in fact one source for estimating uncertainty damage (27, pp. 15-36).

SEQUENCE OF FLOOD CAUSED EVENTS

The pattern of human activity in the flood plain begins to change with the first warning of impending danger. Some people will begin to install barriers to hold back rising water or to relocate movable property at higher elevations while others will gather key possessions and flee the area.

Communication and transportation networks may become congested until they no longer operate efficiently. As the flood rises onto the flood plain, water and sediment come in contact with a wide variety of property. Some items become almost worthless upon wetting. Others are crushed or battered by hydrostatic pressure or carried away by moving water. Vegetation may be washed away, killed as saturation means the depletion of soil oxygen, or buried under deposited sediment. Some kinds of deterioration are almost instantaneous while others continue long after the floodwaters recede unless remedial steps are taken to dry areas subject to rust or rot. Users of transportation and communication facilities find themselves blocked by floodwaters or non-functioning facilities. Factories and businesses are closed until key components are restored, and farm operations must be postponed until equipment can again be brought into the fields. Business losses may change cash flow patterns through a trade area for many months.

The ideal data base for flood damage estimation would be on-the-spot records of how each property item and each human activity was affected by a series of flood events representing a range of conditions with respect to such parameters as time of year, duration since last flood, hydrograph shape, warning, etc. The ideal analysis would then assign each effect a fair economic value and sum the values to estimate total damage. Compilation of such a broad data base, however, is manifestly impractical as a routine step in planning. Such detailed information might possibly be collected in a research case study of a limited area, but even information of this type is unavailable. Even if it were, the problem remains as to how the results should be adjusted before application to other areas. Consequently, the sequence of events hypothesized for the study to follow must be regarded as a suggestive model to encourage future data collection rather than as an empirically substantiated pattern. The sequence is designed to yield flood damage estimates based on known effects of flooding on people and their property.

ESTIMATION OF FLOOD DAMAGES

The flood damage estimates used for water resources planning are generally collected by survey teams who rely heavily on the memory of local residents with respect to what happened during major historical flood events. If the team can get into the field soon enough after a flood, high water marks and observed unrepaired damages also provide important information. Interviews and residual water marks are fairly good sources for providing an understanding of what went on in terms of areas and depths of inundation and kinds of damages inflicted, but interview responses can seldom be used directly to estimate the economic loss from flooding. People vary drastically in the viewpoint they take of damage, the effects they overlook, and the kinds of things they unintentionally or purposefully exaggerate. Standardized estimating procedures must be used to translate physical events into economic loss. Urban damages are estimated from standardized house types. Standardized curves and percentages are originally developed from thorough reviews of a few specific flood events where trained professionals were able to make field checks of reported damages.

These standardized estimating procedures are applied to a given flood plain by first categorizing the kinds of property subject to flooding. The number of units or market value of property of each kind is tabulated by flood depth. The depth, property amount, and standardized procedures are used to estimate the damage to each kind of property. The results are then summed over the applicable property categories to obtain a total damage. This total damage may then be plotted against the flood stage which produced it, and the process can be repeated for a sequence of stages to develop a stage-damage curve. Once such a curve is developed for a given reach and if it is kept updated to reflect changing flood plain conditions, it can be used to estimate the damage from the peak stage reached by any flood.

Average annual damages are often estimated from peak stages recorded over a sequence of years and stage-damage curves reflecting the desired flood plain land use (11, pp. 250-256). When all flood events are separated by at least a year and are relatively uniform with respect to duration and hydrograph shape, the method gives as good an answer as is usually needed for general water resources planning purposes. However, it is inadequate in a number of important situations. These include:

1. It will give the same estimate for two years having the same peak stage even though the flood one year will be associated with a single-sharp crest while the second year may have had a second crest nearly as large as the first six months later. In this latter case, one may want to sum the damages associated with the stages of the two floods, but this procedure will inflate the estimate to the degree that the flood plain has not yet had time to recover from the first flood.

2. When storage reservoirs are used for flood control, stage-damage curves are not sufficient for establishing reservoir operation policy. They give the same damage estimate for a flood that recedes rapidly to below flood stage as for one where flooding is prolonged over a long period as the reservoirs are emptied.

3. They do not provide an adequate basis for studying the effectiveness of floodproofing and emergency flood-fighting measures in reducing flood damage. The effectiveness of these measures depends particularly on excluded timing variables.

When an existing procedure is inadequate, the best way to derive a better method is to begin by returning to basic principles. In this case, that means to review the sequence of events during a flood to develop a new approach that overcomes the observed deficiencies. This study attempts to use known event patterns to simulate the time pattern of damages as they occur during a flood and the time pattern of recovery or restoration of the flood

plain to "normal" conditions. The goal is to use the simulation to estimate damages through a period of back-to-back flood hydrographs or to estimate damage changes wrought by changes in the flood hydrograph, other than those in flood peak, associated with different reservoir operation schemes. The first step in this process is to review the major characteristics which determine the damage a flood event causes.

FLOOD CHARACTERISTICS AFFECTING DAMAGE

Flood damage relates to a combination of factors including depth of water and also velocity, duration of inundation, the lapse of time since the last flood, rate of rise of the flood hydrograph, season, and climate.

The velocity of flow determines the amount of sediment carried onto the flood plain and deposited in the relatively still water there. The removal of mud from buildings and contents creates a major cost in cleanup operations. Sediment can penetrate and thereby destroy the usefulness of such materials as a mattress or sofa. On the other hand, deposited sediment can replenish the topsoil and thereby make fields more fertile. High velocity flows may erode highway fills, scour gullies in fields, or push buildings off their foundations. The scarcity of data makes it difficult to isolate the increase in damage caused by increased velocity. Fortunately, for a given spot on the flood plain and for a given stage, velocity seldom varies significantly from one flood to another. Consequently, difference in damages associated with differences in velocity can best be handled by using a stage-damage curve commensurate with local velocity conditions.

The degree to which property is damaged may increase the longer the property is underwater. Most organic matter becomes water logged, and metals rust with periodic wetting and drying. Maximum damage to capital goods is reached at some point in time when the value of the property is reduced to minimal salvage value so that there can be no further damage.

However, the length of time a transportation facility, water treatment plant, or industrial or commercial enterprise is underwater can increase losses relating to the value of employment, services, or profit (indirect or activity related damage). Long spring floods can also delay access to fields until planting is no longer worthwhile.

The period of time that lapses between two consecutive flood events is another major factor affecting damages. If two floods of equal depth occur in rapid succession, the second flood will not add a great deal to the damages which occurred from the first flood. Alternatively, if the second flood occurred after the damages caused by the first flood had been repaired, the second flood may double the damage total. In order to deal with this effect, an accounting can be made of the time rates of repair of different kinds of property (residences, stores, cropland) and used to estimate the damageable value at any point in time.

The time it takes for a flood wave to travel from the source area of runoff to the location where damage occurs on the flood plain affects the damages caused by a flood. The period of time the flood stage takes to reach an elevation which causes the initial damage after a flood-producing precipitation event is the warning period. The longer the warning period, the more time people have to evacuate or employ flood-proofing measures. Historically, people have not been found to be very responsive to the danger until the initial damage has occurred (13, pp. 99). If warnings were followed by planned programs of flood fighting and evacuation, there would be less of the panic and confusion that frequently increases damages. The rate the water rises after initial damage occurs also has a direct bearing on the time available to employ preventative measures and evacuate personal property.

Agricultural land use and certain industrial and commercial enterprises are more susceptible to damage in some seasons than in others. The extent of damage to crops in the early spring is much less than the damage

caused just before harvest in the fall. If the flood occurs early enough in the growing season, the crop can be replanted with a minor loss of income; the later the flood occurs in the growing season, the greater the damage. Winter floods cause more damage to stored crops than do floods in the summer season when feed stored in the fields is used up to be replenished at harvest time. Climates with well defined four seasons have more variation in potential damages whereas climates that are more uniform all year long have less damage variation by season.

LAND USES SUFFERING DAMAGE

The magnitude of flood damage is determined by the current land use on the flood plain. The reasons used to explain why human activity gravitates to the flood plain vary from ignorance to informed risk taking, but the fact remains that some people inevitably occupy flood plains. Land use can be subdivided into three basic kinds of property subject to flood damage; urban, public facilities, and agriculture. Each land use involves a distinct set of damage processes which need to be considered separately.

Land use for urban development denotes all kinds of buildings and contents. The major classes of buildings are residential, industrial, commercial, and public buildings housing churches, schools, fraternal organizations, etc. Farm buildings may be included in the residential category because of the similarity in damages suffered by rural and urban residences. Public facilities include municipal water and sewage systems, railroads, highways, and all types of utility lines and powerplants. Agricultural property includes crops and pasture, stored crops, fields, fences and equipment. The task ahead is to simulate the flood damage process relating to each of these land uses.

CHAPTER II

PRINCIPLES USED TO SIMULATE DAMAGES AS THEY OCCUR DURING A FLOOD HYDROGRAPH

INTRODUCTION

The best way to improve flood damage estimation is to develop theoretically reasonable and then empirically substantiate models which relate flood losses to property and flood characteristics (30). For many estimating purposes, it is only necessary to relate losses to a few major flood characteristics. Often, depth has been used alone except for seasonal adjustments in estimating agricultural damages. This chapter develops the simulation concept of this thesis and then expands the basic depth-damage relationship (equation 1) to include additional flood characteristics.

The flood characteristics used in this analysis are depth of flooding, duration of flooding, season, and the sequential timing of flood flows. Also discussed will be the system used to estimate damage variation with elevation differences on the flood plain and with time increments over a flood hydrograph. Finally, simulation of the process through which flood damages are repaired will be presented.

NEED FOR DAMAGE SIMULATION

Flood damage inventories taken shortly after historical floods provide the raw data for comparing the economic consequences of implementing alternative flood control measures. After an inventory is completed, the total damages may be plotted against the peak water surface elevation or stage recorded during the flood. A stage-damage curve for a defined segment of the flood plain is developed either as data from additional floods becomes available

or as typical stage-damage curves representing land use categories can be aggregated in accord with observed flood plain land use. The second procedure must be used where inventoried damages from historical floods are not available or where land use changes with time invalidate historical damage estimates.

Once a reliable stage-damage curve has been developed, the flood damage caused by a flood of given stage can be read directly. The estimate is valid to the degree flood damage can be assumed to be determined by depth alone. Such an assumption cannot be used to estimate crop damages because season of the year is of primary importance, but resulting estimates of urban damages have been reasonable enough for the method to have received widespread use. This is not to say that factors other than depth have little influence on urban damage. The more likely explanation is that the stage-damage curve is based on historical damage inventories, and the floods experienced at a given location often do not vary much with respect to other factors. A given watershed customarily exhibits much more variation among its floods with respect to peak stage than with respect to duration, warning time, sediment content or most other flood characteristics. In fact, a uniform time factor is a basic assumption used by hydrologists in the unit-hydrograph method for estimating flood peaks.

Average annual flood damage is estimated by going into the stage-damage curve with the sequence of historical annual flood peak stages, estimating each corresponding damage, and averaging the results. Alternatively, damages at regular stage intervals may be read and multiplied by the hydrologically determined flood frequency range each stage represents (for example, .05 for a flood having a probability of .125 of occurring in any given year and being used to represent floods of probabilities from .10 to .15). The sum of the damage-frequency range products then provides an estimate of average annual damage.

The procedure has built in two assumptions. It assumes that damage can be estimated from stage alone. It also assumes that total annual damages can be estimated from the magnitude of the year's largest flood, an assumption which is invalid for flood plains where significant damages are caused by the second and third largest floods during some years.

If one has need to estimate average annual flood damages at a location regularly subjected to two or more floods in a given year and for which a stage-damage curve has been derived, the obvious method is to enter the curve with each flood stage and sum the damages for an estimate of total damage during the year. The method is reasonably valid as long as multiple floods do not occur too close to each other in time. When only short time intervals occur between floods, the damage from the second flood is reduced because some property damaged by the first event will not yet be restored. For floods that occur close together, the second flood does little more than extend the duration of the first event.

If the hypothesis that flood damage is affected by duration, time since the last flood, and other factors besides stage is correct and if the reason that damage estimates based on stage-damage curves minimize the effects of these factors is indeed because the factors do not vary too much from flood to flood of a given stage in a given watershed, then the validity of using stage-damage curves in comparing the economic merit of alternative flood control measures depends on whether a measure alters the relative magnitude of these other factors which also affect damage. Such alteration is in fact the case for a measure which reduces peak stage while prolonging flood duration.

Both principal structural measures for flood control change hydro-graph shape. Channelization makes peaks sharper. Reservoir storage makes peaks flatter. The effect of reservoir storage on the pattern of flood damages over the course of the year is particularly pronounced. Where runoff from a large share of the tributary watershed is controlled by flood control reservoir

storage, the pattern of streamflow is changed from one of relatively sharp flood crests rising and causing damage and then soon receding to flows too low to damage anyone to one where stream levels are kept just below bank full stage for long periods of time while the reservoir drains. Flood volumes stored in the reservoir need to be emptied as quickly as possible in order to minimize the possibility that a second flood peak will occur when the reservoir has too little storage to contain it.

While reservoirs greatly reduce major flood peaks, the subsequent periods of prolonged high flows create a new flood damage pattern. If any storm occurs when the stream is almost bankfull, minor flood damage can be caused by runoff which would otherwise be easily contained within the channel. Several storms may be large enough to cause damage during a long drawdown period as it is very difficult to adjust reservoir releases to accommodate runoff events from a downstream uncontrolled watershed whose time of rise is generally less than the stream travel time from the reservoir.

One can reduce the frequency and the severity of these damages by reducing releases to allow slack capacity between the release rate and bankfull flow to absorb some uncontrolled runoff events. The price is a longer period of reservoir drawdown and a greater probability of a really large event causing catastrophic losses. Economic criteria specify the optimum release rate as the one minimizing the sum of the expected values of the two types of damage. However, the optimum economic tradeoff cannot be determined without some means for estimating damage during the drawdown period. If damage is estimated from peak stage alone, the same figure will be obtained no matter what release schedule is used as long as the original peak is not exceeded. Such a procedure is of absolutely no help in choosing among many possible patterns of releasing stored flood flows.

If damage were solely determined by peak, the optimum release rate would equal downstream channel capacity less an allowance for local

inflow. Once the channel capacity is exceeded by a large event, the peak flow rate should be maintained until flood storage is emptied. Maintaining peak flood flows for a longer duration would not add to the damage and would reduce the possibility of added damage from a still larger stage.

Such an operating policy is not acceptable. Prolonged periods of flood flows following major flood peaks do add to total damage. Farmers are delayed in planting and rehabilitating their fields, buildings deteriorate and prolonged road closures upset community commerce. Duration must be reckoned as a significant factor in determining flood damage. One objective of this study is to be able to estimate damage differences with reservoir operating policy differences through continuous simulation of damages as they occur hour by hour through the total flood event.

THE DEPTH-DAMAGE-DURATION RELATIONSHIP

For shallow depth flooding, the incremental flood damage per incremental foot of flood depth is relatively constant. In the terminology of equation 1, D/M may be replaced by D_m or the amount of damage as a fraction of market value, $f(d)$ may be taken as Kd , and K may be represented as D_f to denote a factor for estimating the incremental increase in damage with depth. Through these substitutions, equation 1 becomes

$$D_m = D_f d \quad (2)$$

Application of equation 2 requires use of empirical data collected from past flood events to estimate D_f and then use of the estimated D_f to estimate D_m for the values of d given for a particular flood situation. The empirical data will consist of sets of D_f and d and will plot as a straight line of slope D_m going through the origin if equation 2 applies (See lines in 8). For certain types of property, such as crops, however, the line intercepts the

vertical axis above the origin. This happens if a large increment of damage is associated with the very fact of flooding. If the damage represented by this intercept (D_{mn}) were introduced directly into equation 2, we would obtain

$$D_m = D_{mn} + D_f d \quad (3)$$

however, for computational ease it is advantageous to redefine D'_f as the increase in D_m per unit increase in d expressed as a fraction of D_{mn} . Thus D'_f equals D_f/D_{mn} or

$$D_m = D_{mn} (1 + D'_f d) \quad (4)$$

The assumption of constant incremental increase in damage with depth as built into equation 4 is only good for relatively shallow flood depths. At greater depths, damages increase with depth at a lower incremental rate. At still greater depths, damages reach a maximum and no longer increase. A reasonable computational approach is to use the full value of D_f for shallow depths, a fraction of the full value for intermediate depths, and limit the value of D_m to a maximum ($D_{mx} \leq 1$) for very deep floods. For some kinds of damage, for example crop damage, the empirical data does not justify use of a fractional D_m for intermediate depths but rather a constant D_m for all depths until D_{mx} is reached. However, D_{mx} will vary with crop and, for each crop, with month of the growing season.

Damages also increase with flood duration. T_f may be defined as a time factor representing the incremental fractional increase, per unit increase in duration, in damage at the given depth. When introduced in equation 2

$$D_m = D_f d (1 + T_f t) \quad (5)$$

where t is the flood duration. However, equation 5 needs to be modified to incorporate the interaction effect through which depth and duration in combination will influence damage. At large depths, damage will be so great that

additional duration can add little. After very long durations the same situation will prevail with respect to additional depth. The interaction effect is greatest when the depth is shallow and the duration is short, and it becomes dominated when either variable is large enough to signify nearly complete loss. For example, a corn crop is ruined after it has been underwater for a month whether the depth is one foot or two feet. It is ruined after it has been ten feet underwater whether the duration is a day or a week. The interaction effect is brought into equation 5 by introducing I_f as an interaction factor to obtain

$$D_m = D_f d (1 + t (T_f + I_f d)) \quad (6)$$

where I_f represents the incremental fractional change in damage per unit increase in the product of depth times duration not otherwise represented in the equation. Ordinarily, one would expect I_f to have a negative value because an increase in either factor reduces the ability of an increase in the other to cause additional damage.

If the empirical data indicates a discontinuity in the form of significant damage being caused by a flood of minimal depth and minimal duration, the concept of equation 4 needs to be introduced into equation 6. The result is

$$D_m = D_{mn} (1 + D'_f d (1 + t (T_f + I_f d))) \quad (7)$$

In order to apply equation 7 to data on the depth and duration of a given flood to estimate damages, numerical values must be estimated for D'_f , D_{mn} , T_f , and I_f from empirical measurements of flood damages ($D_m = D/M$) of specific type for known combinations of d and t . At least four sets of data are required to apply equation 7 four times and solve for the four unknowns. Because of measurement or estimating difficulties, a much larger set of data and a least squares approach provide much more reliable estimates. Separate sets of values need to be estimated for the four parameters (D'_f , D_{mn} , T_f , and I_f) for each major damage category (corn, houses, roads, etc.). For some categories, one would anticipate that one or more of the parameters (other than

D_f) might be zero, and that equation 7 would thus revert to the form of one of the earlier equations. In other cases, limits to the availability of appropriate data may preclude estimation of all four parameters and force use of one of the more simplified equations.

Equation 7 provides the power to estimate the flood damages which occur during any finite interval of time. The equation can be applied once for conditions applicable at the beginning of the period and a second time for conditions applicable at the end. The difference between the two estimates is an estimate of the damages inflicted during the period.

In going from the beginning to the end of the time period, the duration increases by the length of the period. For a flood stage rising to a new peak, depth will increase from a beginning-of-the-period to an end-of-the-period value. For a falling flood stage, the assumption is that no additional damage occurs to property emerging from the inundated area. The additional damage to property remaining inundated can be estimated by using the end-of-the-period depth for the estimates at both ends of the interval. For a stage rising but still less than an immediately preceding peak, damage is also largely increased by extending the duration unless the water dropped low enough in between for some repair to occur.

Obviously some of the complexities in applying equation 7 must be more fully described, but the basic principle should now be manifest. The traditional approach is to estimate flood damage from properties of the flood peak alone through use of a stage-discharge curve. The simulation approach developed in this study is to estimate flood damage from conditions as they exist on the flood plain at regular time intervals during the flood and sum time increment damages for an overall total.

SEASONAL ADJUSTMENT

With the details dependent on the climate, geographical location and local practice, the season of the year is often a major factor affecting flood damages. Crops, for example, are damaged more severely in the late summer and fall just before harvest than in the spring. Seasonal values of the four basic parameters in equation 7 must be estimated and used for each kind of damage that varies with season. These parameters can be estimated for most widely grown crops from data published by the USDA (23, Table X). The estimation procedure is discussed in Chapter IV.

ZONE DIFFERENCES

The potential for damage to property in the flood plain varies from reach to reach along a river. Such variation can be handled in simulation by using reaches as short as is necessary to reflect differences in land use. At any given location, however, the potential for damage also varies over the cross section of the flood plain. The most obvious cause is differences in hazard associated with differences in elevation, but differences in soil and topographic conditions may also be important, as both of these factors influence land use.

For these reasons, it is essential to build into a flood damage simulation procedure the power to deal with differences in land use by degree of hazard. A typical flood plain has three hazard zones. The low lands immediately adjacent to the stream (zone 1), the terrace land or main flat portion of the flood plain (zone 2), and the upper slopes as the land rises from the flood plain (zone 3). Land use varies among the zones, and boundaries between prevailing land use types provide a convenient basis for separating zones.

The land in zone 1 is most susceptible to flooding and to streambank erosion. Urban use is normally least extensive, and agricultural use depends

largely on physical and environmental factors. Along small tributaries, this strip is often so narrow and the threat is so small that this land is farmed like other land. Along larger streams, this area is often left to permanent pasture, idleland, or woodland. In urban areas river oriented human activity has historically occupied streambanks, and consequently lead to urban damages in zone 1.

Above this zone is the terrace land (zone 2) where most of the agricultural and urban activities take place and where the bulk of the damages occur. Soils tend to be the most fertile and flat areas make construction of urban development and transportation facilities less costly. Zone 3 may be either urban or agricultural. Gently sloping land tends to have more damages because as it attracts more intense land use. Steep canyon-like slopes prevent cropping and restrict urban development. These three zones are described here only in the most general way, and more precise definitions are needed in adapting the simulation procedure to a given flood hazard situation.

Zone boundary elevations on both sides of a stream must be identical so that a specific elevation will be in the same zone on either side of the stream. The flow at which water enters a zone is estimated by the rating (stage-discharge) curve (Chapter IV) referenced to the control section in the reach. Lesser floods may only reach into zone 1, and damage estimates will only be needed for that zone. Larger floods may reach into zones 1 and 2. For the largest floods, damage will occur in all three zones.

The land use must be delineated for each zone in order to locate the property subject to damage. If the land is used for agriculture, the acreage of specific crops in each zone must be quantified. Damages depend on crop yields as largely determined by the type of soil and soil productivity. A correlation can be made between the expected yield for a given crop and soil type. By identifying flood plain soil types and the acreage of specific crops grown on each soil in each zone, the value of the crops can be estimated.

If the land use is urban, the value of urban property in each zone must be determined. Similar estimates are needed for public facilities and stored crops.

EFFECT OF REPAIRS BETWEEN FLOODS

Another important concept is the effect on flood damage by the time that has lapsed since the last flood. If consecutive flood events occur with very little time lapse between them, the damages caused by the second event would be reduced to the duration effect on the deterioration of inundated property plus the losses from the extended interruption of human activity. However, to the degree lapsed time permits restoration of damaged property, additional damage occurs. The additional amount can be estimated by keeping an account of the last time a property was damaged and how badly it was damaged and applying a reasonable estimate of the repair rate.

To illustrate this process, figure 1 shows a double-peaked hydrograph followed by another storm about two months later. The flow rises past Q_f at which the stream overflows its banks and flood damages begin and then past Q_p at which property P begins to be damaged. For each increment of time the property P is flooded, equation 7 will give an added increment of damage. After the floodflows reach the peak (b) and start to recede, damage continues with duration until the property is out of the flood water (c).

The second flood peak (d) comes so soon that no repair is possible and thus only adds damage through the duration effect to what has already occurred from the first flood peak. However, a flood having the same peak that occurs in May (g) causes more damage. Enough time has lapsed to allow repairs to at least partially restore the property. The minimum time lapse between (e) and (f) for restoration to commence and to be completed varies for different kinds of property and different property owners. For this simulation, average repair periods were assumed for the various categories of property.

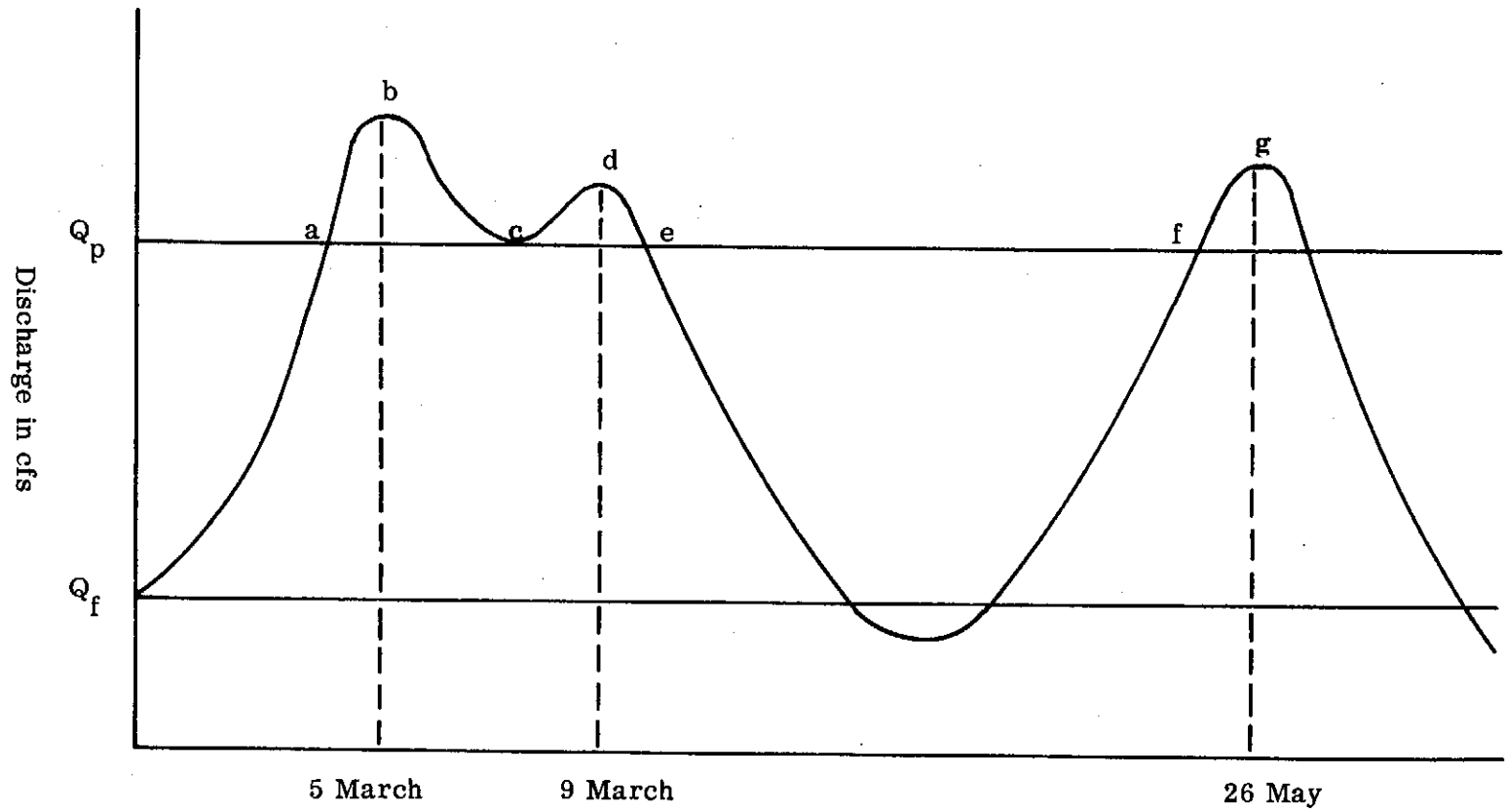


FIGURE 1 CONTINUOUS FLOOD HYDROGRAPH

The estimation of the rate of rehabilitation for damaged property was derived from historical data supplied by the Huntington District of the Corps of Engineers and assumptions based on judgment. On the average, buildings were assumed to be 99 percent repaired after 100 days, and this is equivalent to a uniform percentage rate per 6-hour period of 1.15 percent. The recovery factor per 6-hour period (ratio of unrepaired property at the end to that at the beginning of the period) would be 0.9885. Public facilities are assumed to be repaired more rapidly because of the urgency placed on their use and the greater financial resources of government. The property was assumed 95 percent restored within 23 days. This yields a uniform percentage rate of 5 percent per 6-hours or a recovery factor per 6-hour period of 0.95. The values of 0.9885 and 0.95 are built into the simulation program, but individual users can easily change them to whatever numbers they feel to be appropriate for their situation.

Recovery of crops in the field is complicated because farmers respond differently to flood damage with time in the growing season. It takes about 15 days, depending on the soil, for a field to dry sufficiently to support farm equipment and for the soil to become properly conditioned to cultivate and plant. Crop land flooded in the early spring may result in late planting. Slightly later flooding will result in replanting with only limited loss in production. Still later flooding will cause a serious loss in production should the crop be replanted. If the flood occurs too late for replanting the original crop, a quicker growing substitute crop can sometimes be substituted, normally with some loss in income. Should the field be damaged too late for replanting any kind of substitute crop, the farmer must choose between abandoning the field until the next growing season and keeping the existing crop in the field and salvaging what is left at harvest.

Other agriculture property damaged by a flood event (such as fences, sheds, gullies, waterways, and terraces) are assumed to be repaired at a

constant rate after a 15-day drying out period. Stored crops cannot be repaired once they are washed away, but they can be replenished after the next harvest.

SUMMATION OF DAMAGE TOTALS

The damages are first estimated for zone 1 closest to the stream, then for the middle zone (zone 2), and finally for the slopes or upper zone (zone 3). Within each zone, the aggregate damages are estimated by averaging damage rates at the low, middle, and high points in the zone. Separate average rates are used for each kind of property located in the reach during a 6-hour period. The damages to each kind of property are then added to estimate the total damage for a 6-hour period.

Through the use of a high speed digital computer, the damages that occur each 6-hour period can be estimated, and totals can be accumulated very rapidly for many reaches. The flow records for many years can be used to estimate average annual damages that are more reliable at a lower cost than that for the long-hand method.

CHAPTER III

PROGRAM DEVELOPMENT

INTRODUCTION

The new emphasis on environmental quality and the increased difficulty in justifying water resource projects because of rising costs of construction and interest rates have made the job of the water resources planner more complex and time consuming. The planner must be more careful to investigate every possible alternative and to have a thorough knowledge of all the factors that might effect project performance. The computer can be an invaluable planning tool. The computer not only accelerates conventional computational work, but it permits the use of many numerical methods which once could not be used because of the required computational time. When properly used, the computer increases time for investigation of more alternative schemes, collection of better information, and for interpretation of the numerical results. It also permits computational procedures that better represent what actually occurs in nature. Simulation of flood damages is but one example.

DAMAGE is a Fortran subroutine designed to simulate flood damages during the time period in which they occur from information on the flood hydrograph and on flood plain land use. A time sequence of flows, such as that provided by a hydrologic program for continuous flow simulation, is translated into a time sequence of damages. This chapter presents the operations that are important to understanding the subroutine. A complete listing of the Program is in Appendix A. Each listed line of the program is assigned a number for easy reference in the text as the program is explained. A listing of typical data used by the program is in Appendix B. A dictionary defining all

variables appearing in the program is in Appendix C. The reader should refer to this last appendix for definitions of the program variables subsequently used in the text.

DAMAGE AS A SUBROUTINE

The simulation approach to flood damage estimation described on the following pages is programmed in DAMAGE, a Fortran Subroutine. The subroutine is designed to receive a recorded or simulated flow in the hydrograph sequence from the calling (main) program and return to the main program an estimate of the damages caused. The necessary information is brought into the subroutine through seven calling arguments (Appendix A, DMGE0001) and through data cards read directly from the subroutine (listed in Appendix B).

The subroutine receives through the calling argument a flow (Q6HR) representing a six-hour period in a specified month of the year (MONTH) and day of the month (DAY) and for a specified channel reach (KREACH). Months are numbered from January as 1, and reaches are numbered from 1 to a maximum of 25 as assigned for the study. The damage estimated as accruing during the six hours is returned to the main program as FDM6HR. While the subroutine is only provided one flow per time it is called, the flows used in a sequence of callings should be provided in the proper order to define the entire flood hydrograph by six-hour time increments beginning just before the first damage occurs and with no low flows between peaks omitted.

The flows used to represent the hydrograph for a reach should be associated with a control point at which the flood stage is known to increase monotonically with the area flooded within the reach. Stream gaging stations make the best control points. If a gaging station is not available, some representative point on the stream may be substituted; but it is necessary to develop a depth-discharge relationship to use in place of the rating curve available for gaging stations.

The data cards describe properties of the flood plain that the subroutine needs in order to estimate damages. Once this information has been read, there is no need to read it again as long as damages are still to be estimated for the same flood plain. The subroutine reads a new set of data if called with RDT as TRUE and does not read data if RDT is FALSE. Sometimes a very long interval will occur between damage causing flood events. In this case the intervening flows can be omitted and the first flow of the next flood event can be provided for DAMAGE with RIN as TRUE. The estimation procedure will assume that all property has been fully repaired since the last flood and continue to estimate damages. If Q6HR immediately follows the flow used in the preceding call, RIN should be FALSE. This device for omitting calling DAMAGE low flows should not be used to separate floods less than 100 days apart or occurring in the same growing season. DAMAGE may be called with LWRITE as TRUE if one wants detailed output on the kind and location of the property damaged and as FALSE if only a total dollar value is desired.

PROGRAMMING TO ESTIMATE AREA AND DEPTH OF FLOODING

The simulation requires a functional relationship to estimate areas flooded and depths of flooding from flows. A derivation based on Mannings's equation for open channel flow (10, pp. 83-85) shows the area inundated (A) to relate to the flood producing flow (Q equals the total flow less the channel capacity) as

$$A = K Q^a \quad (8)$$

where K and a are parameters of the flood plain. The same derivation relates the average depth of flooding to flow as

$$d = C Q^b \quad (9)$$

where C and b are also flood plain parameters.

For a wide flood plain that can be represented by two banks sloping gently toward the stream and extending past the limits of flooding, a and b both equal 0.375. When estimating damages for a flood plain where a reliable stage-discharge curve has been established, the curve can be used to estimate b and thereby improve the results. Provision is made in the program to read values for b for each of the three zones for each channel reach.

In order to estimate a value of b for a given zone from the rating curve, one reads from the curve sets of values d_1, Q_1 at some point near the bottom of the zone and d_2, Q_2 at some point near the top as shown on figure 2. Thus

$$d_1 = C Q_1^b \quad (10)$$

$$d_2 = C Q_2^b \quad (11)$$

Solving equations 10 and 11 for b gives

$$b = \log \frac{d_1 Q_2}{d_2 Q_1} \quad (12)$$

the program estimates values of K as defined by equation 8 (RKA in Fortran, DMGE0092-4) and of C as defined by equation 9 (RKD, DMGE0086-91) for each zone and each reach from the input data (Q, A, d, b , and a assumed equal to b). With values for K, a, C , and b stored in memory based on the particular Q, A , and d in the input data, the program can estimate depths and areas for any other incoming Q .

The depth constant (RKD1-3) is defined as the maximum flood depth (DZD) within the zone divided by $QZD^{**}EXP$ (DMGE0083). The flow in each zone (QZD) is raised to an exponent (EXP) that defines the rate of increase of depth with flow (equation 12). The area constant (RKA1-3) is the area

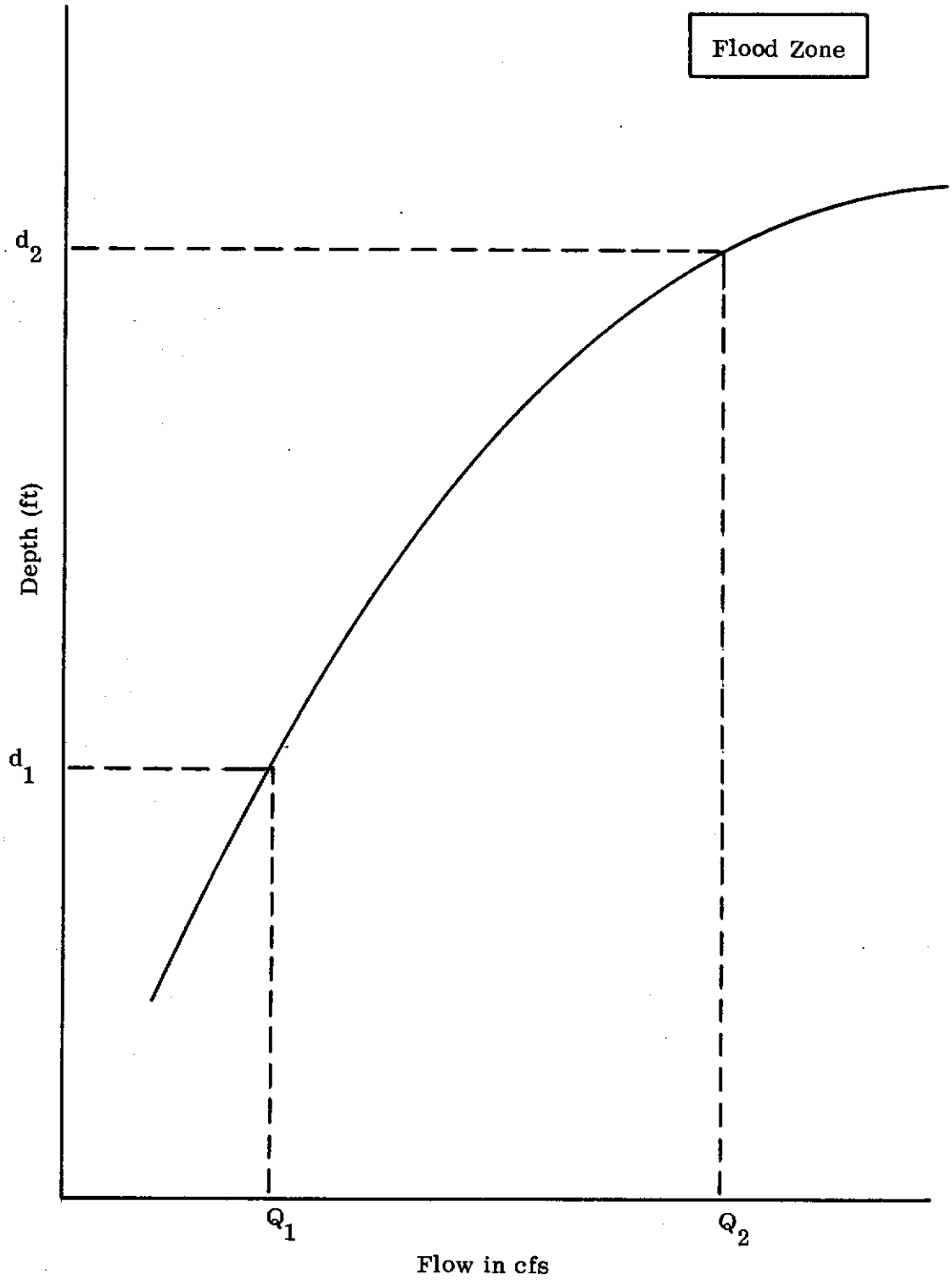


FIGURE 2 FLOOD REACH RATING CURVE

flooded (AZD) divided by the maximum depth (DZD) within the zone (DMGE0084). For zones two and three, the program deducts the flow at which flood water first enters the zone from Q6HR to estimate Q in equations 8 and 9 and thence the depth and area that applies to that zone.

The depth of flooding in each zone is the product of the depth constant and the flood flow raised to the exponent that best represents the rating curve in that zone. The area flooded is the product of the area constant and the depth of flooding. If flood flows completely submerge a lower zone and start flooding in the next higher zone, then the area of flooding is equal to the total area of the zone and the depth equals the depth in the higher zone plus the depth in the lower zone when water first enters the higher zone.

PROGRAMMING TO ESTIMATE THE EFFECTS OF PREVIOUS FLOODING

As a hydrograph may rise and fall several times during a flood, the highest flood crest yet reached during the sequence is stored; and each current flood stage is checked for its relationship to the previous peak. If property was damaged by a previous flood peak and there has not been sufficient time for restoration, the current flood can only cause damage limited to the amount of repair performed since that flood plus the value of the property that was not lost in the first flood. Restoration begins when flood waters recede from around the property. The rate of restoration is determined by a repair factor appropriate to each kind of property. The property is gradually repaired until it is fully restored. Further flooding would cause damage to the full value of the property.

ESTIMATING CROP DAMAGES

Crops and farming methods vary widely by climate and latitude. Cotton is grown in Georgia, potatoes in Maine, corn in Ohio, wheat in Iowa, and

cabbage in California. Often, the best yields are from crops grown in a river valley, very often a flood plain, where the soil is rich. The economic incentive is to grow the most valuable crops on the richest soil to obtain the greatest yield for the most income.

Farmers can be expected to plant higher valued crops on their better soils, but they also tend to avoid planting the crops on which they are most financially dependent in high flood hazard areas. For damage simulation, the program provides for classifying flood plain soils into three groups by productivity (high, medium, and low) and for classifying flood hazard by dividing the flood plain into three zones. Three data arrays are thus required as input data for the program to estimate the yield per acre and the income the farmer realizes from that yield for a given crop grown in a given reach and zone. YIELD is the yield per acre that can be expected for each crop in each of the soil types; CSTFZ is the portion of the crop land planted to each crop as a function of soil type and hazard zone; and STZD is the portion of flood plain land in each soil type indexed by zone and reach. The crop yield for a given reach and zone (ZYLD) is estimated by summing over the soil types as shown in equation 13 (DMGE0355); and the income to the farmer from that yield (CCD) is estimated by equation 14 (DMGE0357). CCD is the product of the unit price (CPICE) of the crop, yield per acre (ZYLD) and the portion of the land in the reach in crops (FLF).

$$ZYLD = \sum_{\text{Soil} = 1}^{\text{NSTP}} \text{YIELD (crop, soil)} * \text{CSTFZ (crop, zone, soil)} \quad (13)$$

$$\text{CCD} = \text{CPICE} * \text{ZYLD} * \text{FLF} \quad (14)$$

Crop damage not only varies with the kind of crop, geographical location, and soil type but also varies with growth of the crop over the year (23, Table N1). The simulated crop damage should be sensitive to these conditions. Most crops in the corn belt area of the United States are planted in the spring and harvested in the fall. Winter wheat is planted in the fall and harvested in the spring in time for the summer crops to be cultivated and planted. Seasonal changes make it necessary to incorporate within the program a way to keep a record of the state of each crop by time of year.

Should a flood occur late in the planting season, a crop may be replanted, but yield is often reduced. When flooding occurs after the last date for replanting, the farmer may choose to plant a substitute crop. For example, soybeans can substitute for corn at a location where corn cannot be replanted profitably after May 31 and soybeans can be planted with some success until June 15. Finally, a date passes when it is not profitable to plant any crop.

These alternatives are reflected in the damage simulation in an array of maximum damage factors (CMDf) developed for each month and read as input data. CMDf is the ratio of the maximum damage that can accrue to the crop in the subscribed month to the gross sale price of the crop at harvest time. In preparing data for flood damage simulation, CMDf may be adjusted for the value of substitute crops. CMDf can also reflect the reduction in damage to the crop as portions are harvested.

Another factor to consider is the time it takes to get back in the field after a flood. The program assumes that it takes 15 days (360 hours) after a flood for a field to dry out sufficiently so that the ground can be prepared and crops can be replanted (DMGE0233). A check is made to determine if this 15 day period has passed before additional damage from more flooding is simulated for any crops other than those left in the field after the first flood.

Studies show that the damage to crops depends on both depth and duration of the flood. Other things being equal, as the depth of flooding increases, crop damage increases. Also, the longer the water inundates the crop, the greater the damage. No data could be found that breaks this relationship into a graduated scale of depth or duration verses damage. The best information that could be found was that developed by USDA which distinguishes floods less than two-feet deep from those over two feet deep and durations less than 24 hours from those greater than 24 hours. The data exhibited a definite interaction effect between depth and duration as defined by equation 7.

The data obtained from the USDA were used to estimate the four parameters in equation 7 for each month of the year. In the notation used in the program, D_f' is CDPF, D_{mn} is CBDM, T_f is CDRF, and I_f is CDDI. The monthly values estimated for each of these parameters from the USDA data for Ohio for corn, winter wheat, oats, soybeans, hay and pasture are tabulated in Appendix B.

Substitution of these parameters in equation 7 provides for estimating the damage (CDF) per acre in a given crop the expression (DMGE0387)

$$CDF = CBDM * (1.0 + CDPF * DEPTH) * (1 + (CDRF + CDDI * CPKDP) * DRTN) \quad (15)$$

where CPKDP is the maximum flood depth yet encountered in the current event, DEPTH is the current flood depth, and DRTN is the duration since farmers were last able to enter their fields. The term $CDRF + CDDI * CPKDP$ is held to a minimum of 0.1 (DMGE0386) to prevent the program from ever estimating a flood damage reduction with increased duration. If the estimated damage (CDF) exceeds the maximum possible value for that month (CMDF), the maximum value is used as an upper limit (DMGE0388). The maximum depth (CPKDP) gives numerically more consistent results when used with an

interaction factor, and its use seems logical in that the duration effect continues until the farmer can get back into the field to perform normal cultivation.

CDF, as estimated by equation 15, represents the amount of flood damage expressed as a fraction of that which would occur were a flood to completely destroy a crop just before harvest. It is estimated from mean monthly values of the four damage parameters. Actually, values of these parameters vary over a month. The mean values are assumed to be those for the 15th of the month. The program estimates CDF1 for the 15th preceding the date of the flood and CDF2 for the 15th following the date of the flood. It then interpolates between the two according to the date (DMGE0399).

The damage is computed at the beginning of the current six-hour period using the previous depth and duration and at the end of the current period using the new depth and duration. The difference between the current and the previous damages is the resulting damage for the current period (DMGE0442).

The program keeps track of the crop damage during past periods of flooding in the current growing season by a factor CDD (DMGE0332). CPDM (DMGE0437) is the fraction of the crop value that remains after this flood history and is estimated as one minus CDD over the maximum possible damage factor (CMDF). If a previous flood has occurred during the same growing season, the damage per acre (CDF) is reduced by multiplying by the fraction CPDM (DMGE0440).

A flood that occurs just before planting causes damage by delaying the time of planting and thereby reducing crop yield even though no physical damage may occur to a crop in the field. The period between normal planting time and the latest possible planting time is particularly critical. The simulation subroutine reads data on the latest possible date for planting each crop (LFY) and still obtaining full crop yield. A fractional loss of 0.003 times the harvest value of the crop is added to CDF for each six hours planting is delayed past that date (DMGE0452).

The total damage to a given crop equals the product of the income the farmer would receive were no flooding to occur (CCD from equation 14), the fraction of that income lost because of flood damage (CDF), and an indirect damage factor (CIDF) to account for losses to farm workers, food processors, and others besides the farmers (DMGE0454). The total damage to all crops is the sum of the individual crop totals.

ESTIMATING FIELD DAMAGES

Not all the damage that occurs when farmland is inundated is to crops. Field damages are defined for this simulation to include damage to fences, farm roads, the fields themselves through erosion or deposition of soil or trash, or any property other than growing or stored crops or buildings. Such damages are normally a small portion of the total agricultural damage, and the information base for making quantitative estimates is much more limited.

In the initial attempt to estimate field damage by using equation 7, D'_f was called FDPF, D_{mn} was FBDM, T_f was FDRF, and I_f was FDDI. Substitution of these terms in equation 7 gives a result analagous to equation 15 with the difference being that CFD (field damage in dollars per acre) is estimated from the above four parameters beginning with F rather than those beginning with C. By defining $FDRF + FDDI * CPKDP$ as DRTM, the result is

$$CFD = FBDM + (1 + FDPF * DEPTH * (1 + DRTM * DRTN)) \quad (16)$$

Since FDDI is a negative number, the relationship between DRTM and DEPTH plots as shown in Figure 3. This type of relationship which worked well for crops where total destruction occurs once the depth passes D_t did not work well for field damage which can continue to increase almost indefinitely as greater depth causes more harm to fields that are never completely destroyed. Thus DRTM was redefined as the exponential decay function shown in Figure 3.

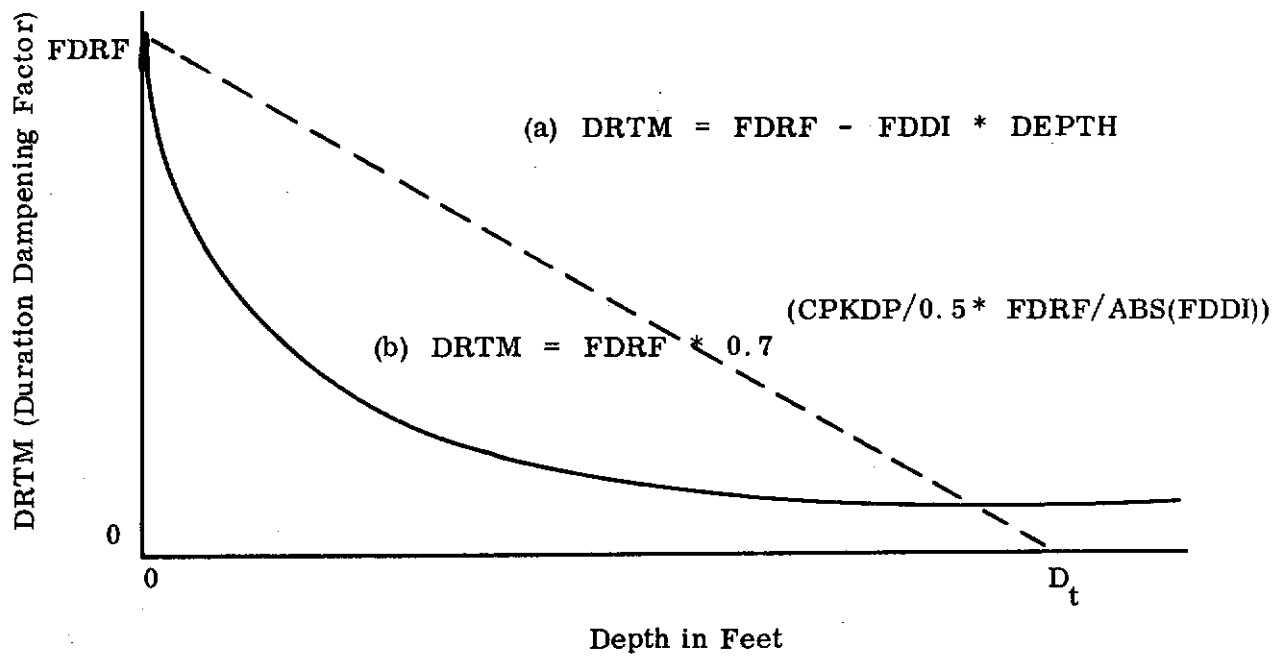


FIGURE 3 FIELD DAMAGE DEPTH - DURATION INTERACTION CURVE

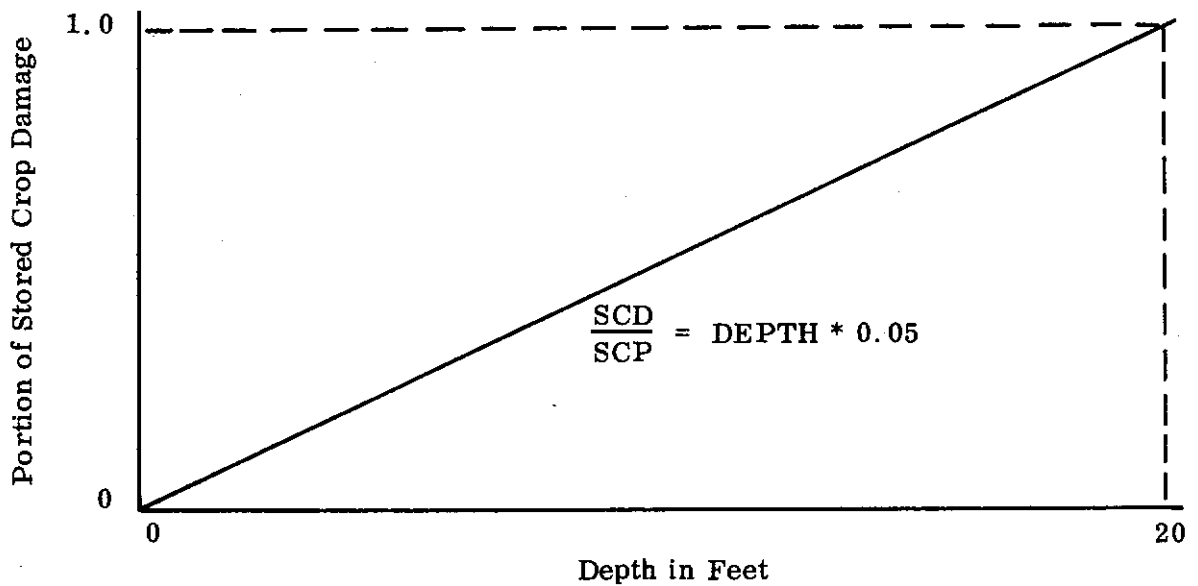


FIGURE 4 STORED CROP DAMAGE CURVE

Thus

$$\text{DRTM} = \text{FDRF} * 0.7^{**}(\text{CPKDP}/\text{FDDF}) \quad (17)$$

(DMGE0462) where FDDF is defined as $0.5 * \text{FDRF}/\text{ABS}(\text{FDDI})$ and held to a maximum value of 40 (DMGE0061-2). At this maximum value, the duration factor would by a depth of 40 feet have decayed to 0.7 of its value for shallow flooding. The data used in the simulation runs imply a smaller value of 33.5 feet. Simulation based on figure 3 estimates minimal values of additional damage from extended deep flooding; however, an absolute upper limit of \$100/acre is used (DMGE0464).

Field damages accruing during a period are estimated as the total accumulated damage at the end of the period less the accumulated total at the beginning of the period (DMGE0472). This difference was adjusted by a factor to include indirect damages and a factor (FRTO) to adjust for field damages caused by previous flooding but not repaired before the current flood began. Field damages are assumed to be repaired at an average rate of 80 cents per acre per day (DMGE0247-53) beginning 15 days after the flood water leaves the hazard zone.

ESTIMATING STORED CROP DAMAGES

Crops for feed such as silage and hay are often stored in fields or barns after harvest in the fall for feeding livestock from November through May. Flooding of the storage areas can ruin the feed if not wash it away. Either way, once a stored crop is inundated, it is assumed to be economically worthless. Therefore, if crop storage areas have been flooded to a greater depth since the last harvest (DMGE0478), the program assumes no further damage to the stored crops. Duration does not seem to have much effect on the magnitude of damage. Depth of flooding is considered the flood characteristic that causes the damage, and the damage estimating function has the simple form of equation 2. The damage per unit depth (D_f) equals the value of stored crops per foot of elevation.

Crops are assumed to be stored on the flood plain during the 151-day period from December 1 through April 30. The value of the stored crops is a maximum on December 1, and it is reduced as the feed is consumed by livestock until none is left by April 30. Thus the program reduces the value of the stored crops by 1/151 of the initial value for each day during this period (DMGE0150). Initial (December 1) values by reach and by hazard zone are supplied the program in the input data. The crops are assumed to be stored in 20-foot high stacks.

Damages to stored crops are assumed to occur only during this 5-month period and only then during 6-hour periods when floods reach depths they have not previously reached since December 1. The program estimates the damage to stored crops (SCD) by multiplying the value of the stored crops (SCP) by the amount the current flood depth exceeds the previous maximum (PKDP - PPKDP) times 0.05, the fraction of the 20-foot stacks per foot of depth (DMGE0480). Figure 4 illustrates the straight line relationship between depth and stored crop damage. The damaged value is then increased by the crop indirect damage factor (CIDF). If the flood depth reaches 20 feet, the entire crop is destroyed (DMGE0479). After the program computes the stored crop damage, it combines the field and the stored crop in the same damage total in the tabulated results when a more detailed printout is requested (LWRITE is TRUE).

ESTIMATED BUILDING DAMAGES

Building damages are defined for the simulation as including all damages to buildings including the structures themselves, their contents, and associated outside improvements and landscaping. Buildings include such public or private structures as residences, commercial and industrial establishments, churches, government buildings, etc. Farm buildings are also included.

The typical situation is for most flood damages to be building damages, but the relationship between buildings and the damages they suffer when flooded is very complex. Each variation in use, layout, and building material affects the degree of damage. Only part of the variation, however, is caused by differences among buildings; much of the variation is caused by differences in the way those occupying the buildings react to flood hazard and respond to flood warnings. For flood damage simulation, it is not practical to collect full descriptions of all buildings in the flood plain and it is impossible to forecast how particular persons will respond at the time of any given flood. Total flood damages are estimated by summing the damages a given flood would cause to typical buildings and recognizing that while the results may be quite wrong for any particular building the overall estimate can be used for planning.

The damage data that was obtained (8, 19) indicated that building damages can best be estimated by an expression having the form of equation 6. Unlike for crop damage, the depth-damage relationship plots through the origin. The parameter D_{mn} is zero. For the other three parameters, D_f is called UDPF, T_f is called UDRF, and I_f is called UDDI. Substitution in equation 6 gives an estimating function for CUD, the fraction of the market value of buildings and contents lost through flood damage, as

$$CUD = UDPF * DEPTH * (1.0 + DRTM * CDRTN) \quad (18)$$

where

$$DRTM = UDRF + UDDI + DEPTH \quad (19)$$

CDRTN is the duration flood water has been around the base of the building. Repair is assumed to begin immediately after the flood waters recede as opposed to after the 15-day drying period used for crop and field damages

Two modifications to equation 18 were found to be necessary before it would give damage estimates compatible with available data on damage

experiences. One was to set an upper limit to the fraction CUD. Obviously, a value exceeding unity would be unacceptable. The data suggested that floods are unlikely to completely destroy buildings (11, pp. 251-253) and a maximum damage fraction of 0.63 was finally selected (DMGE0275-7, 487). Secondly, the depth factor UDPF is not really independent of depth below this upper limit. The damage to a building of increasing the flood depth from seven to eight feet is less than that from the first foot of flood depth. A relationship of the form of figure 5 was adopted.

In the simulation, equations 18 and 19 are used to estimate flood damage (DMGE0488-90) after a control to prevent the duration effect from being negative. If the depth is great enough to cause the fraction of damage to exceed 0.25, the depth factor is taken as $UDPF/4$ for the additional depth (DMGE0492). For the data derived for the case study, the break points come at depths of 5.0 and 35.4 feet.

The equations are used to estimate damages to the end and then to the beginning of the six-hour period and then take the difference adjusted for indirect damages and for unrepaired damage from previous floods. The damage is then estimated as this fraction multiplied by the value of property (UDV) read for the particular reach and hazard zone (DMGE0504). The current depth is used to estimate damage to the end of the period. The maximum depth previously flooded (BDEPTH) is used to estimate damage to the beginning of the period. Therefore, if a flood rises to a new peak, the damage during the period is caused by both additional depth and additional duration. Otherwise, the additional damage is caused by additional duration.

The flood damage associated with people being unable to occupy buildings while they are flooded is normally included as part of the indirect damage and estimated as a percentage of direct damage. Such an estimation procedure, however, is not appropriate for a continuous damage simulation routine as the hourly loss from lost occupancy is roughly constant over the

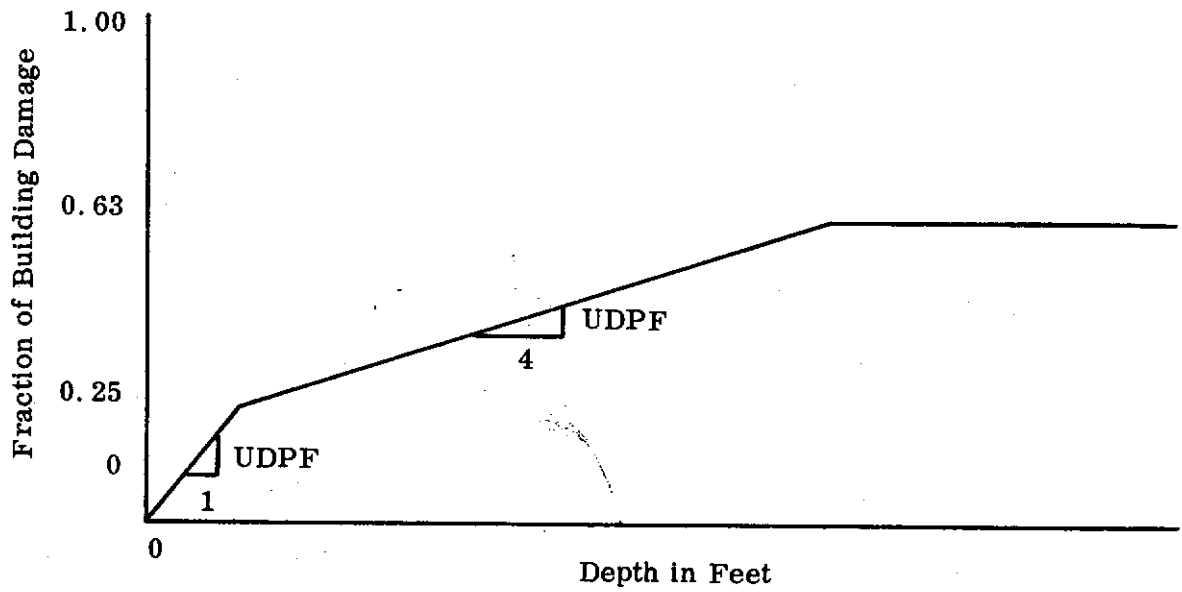


FIGURE 5 BUILDING DAMAGE CURVE

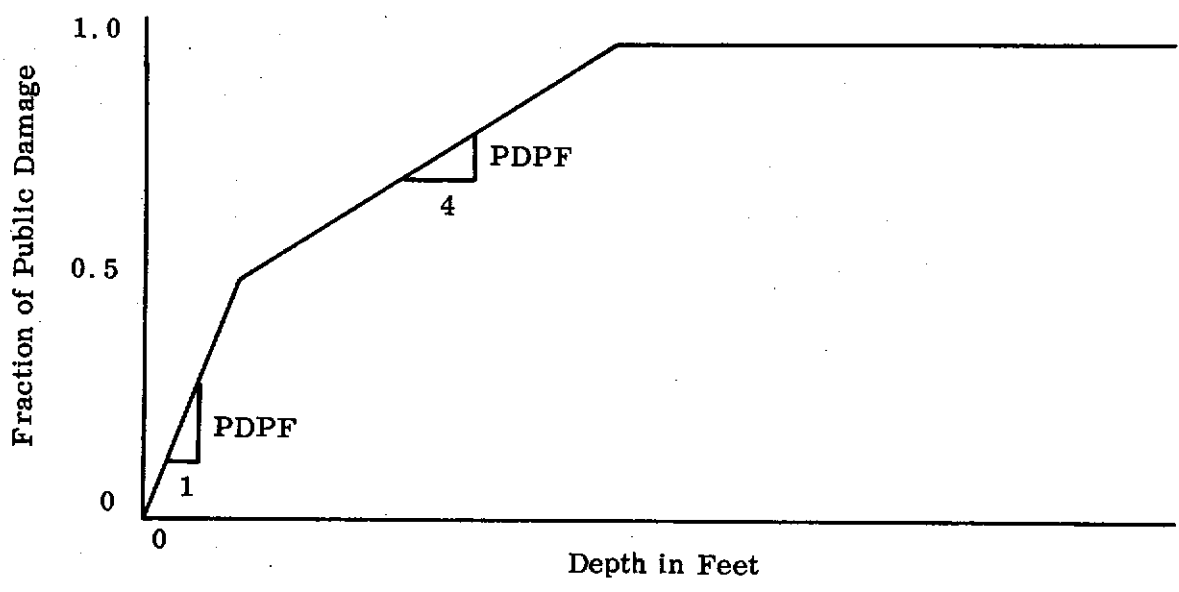


FIGURE 6 PUBLIC FACILITIES DAMAGE CURVE

duration of the flood while direct damages are concentrated during the period a building is first inundated. Thus damages from lost occupancy should not be included in UIDF but rather in a separate parameter UPDD.

The damage from lost building occupancy is estimated in the simulation from UPDD, the value of buildings in the area, and the fraction of them being flooded (DMGE0506). While UPDD also includes the extra cost of conducting business from temporary quarters, the procedure used to estimate a value for the parameter is based on the cost per day to a family of extra expenses for food and temporary lodging. It is divided by 4 to convert from a daily to a six-hour basis and by 20,000 as the average value of a home and contents.

ESTIMATING PUBLIC DAMAGES

An important component of the total damage caused by an flood is that to facilities providing transportation and community functions. These include streets and roads, highways, railroads, parks and playgrounds, sewage systems, electric and phone lines, etc. Such public facilities tend to have similar physical characteristics. They are usually built close to the ground or underground and made of durable material (concrete, steel, creosoted wood, etc.) to last against exposure to the natural elements without excessive maintenance costs.

Damage to such public facilities has two major components. One is harm to the physical facility. The other is harm done to those who depend on service from the facility and have that service interrupted. What minimal data can be found suggests that damage to the physical facilities is relatively independent of flood duration, probably because of the durable type of construction used for such facilities. Physical damage is thus simulated by an expression of the form of equation 2 where D_f is called PDPF. The damage from loss of service relates primarily to the duration of the interruption. The amount of damage is simulated by multiplying another factor (PPDD) times the length of the interruption in days.

The data supplied the program includes information on the maximum flood damage public facilities can be expected to sustain by reach and by hazard zone (PZD). The concept is to identify those public facilities in the designated area and estimate the maximum amount of damage flooding of the characteristics (primarily depth and velocity) common to that flood plain could do to them. Normally, this will be a repair and restoration cost far less than complete replacement cost. The information array is read by the program (DMGE0079), the appropriate element (PDV) is selected for the reach and zone being analyzed (DMGE0364), and damages during any six hours are taken as a fraction of PDV (DMGE0523).

The increase in the fractional damage to public facilities (CPD1) is taken as linearly proportional to the depth of the water (DMGE0512). If CPD1 exceeds 50 percent of the total damageable value of the facility, the rate of additional damage (PDPF) is decreased to 25 percent of the depth-damage factor (DMGE0513) until the depth causing maximum damage is reached.

$$CPD1 = PDPF * DEPTH \quad (20)$$

or
$$CPD1 = 0.5 + * PDPF (DEPTH - 0.5/PDPF) \quad (21)$$

For the data of the case study, the depth-damage curve shown in Figure 6 resulted.

Damage to public facilities during a given six-hour period is simulated (DMGE0520) as the difference between the damage through the end of the period (CPD1) and that at the beginning of the period (PCPD) reduced if necessary by a factor (PRTO) to account for damage unrepaired from previous floods. Thus, PCPD accounts for flood damage since the current flood began, and PRTO relates to floods recent enough for the damage to have been partially but not completely repaired. It applies when the waters recede to the point where repair crews can enter to begin their work, but a second flood occurs before they can finish. PRTO denotes the fractional state of

repair when the second flood begins. The repair rate used within the program assumes repair of five percent of the outstanding damage per six-hour period or complete restoration within 23 days after the flood water recedes.

The damage is translated from a fractional to a dollar amount by multiplying by the maximum damage potential PZD and a factor to incorporate indirect damages (PIDF). This factor includes that portion of the indirect damages associated with physical harm to the facilities as opposed to that portion associated with loss of use. The damage through loss of use is simulated as proportional to the amount of physical harm done to the facilities to the point in time (DMGE0523). The daily loss factor (PPDD) expresses a fraction of that physical harm as a loss.

SUMMING DAMAGE ESTIMATES BY REACH

The basic loop for damage estimation (DMGE0333-527) produces values for the designated six-hour period for crop damages, field damages, stored crop damages, building damages, and public damages. Each estimate is based on a fractional damage rate and on read data providing the value of the exposed property. Both the fractional rate and the property value vary with elevation on the flood plain. Furthermore, repairs can begin sooner at higher elevations where drying occurs first.

The damages estimated in the basic loop are in dollar-per-acre rates. Rates are estimated for the deepest flooded areas in zone 1, for flooding of the average depth found in that zone, and for the areas in zone 1 with the shallowest flooding. If the flooding enters zone 2, the same three rates are estimated for that area too. If the flooding enters zone 3, the cycle is repeated one more time except that the shallowest flooding in zone 3 is by definition of zero depth and doing no damage. Because of the same depth and flood history, fractional damage rates are the same just above as just below a hazard zone boundary; but dollar-per-acre rates differ with the land use change the boundary implies. Flood history (duration) factors and repair

rates are determined at each zone boundary, and their values are averaged for zone midpoint conditions.

In situations when the flood is expanding out over a hazard zone and then starts to recede, the physical location of the middle of the flooded area within the zone will change with time. For damage estimation, it is allowed to move outwards as long as the flood is rising but not to recede when the flood recedes (DMGE0567, 662, 764); otherwise, simulated damages are too large as lower more heavily damaged locations are used as midpoints during the recession.

Total flood damages by category within a zone are estimated by applying the prismoidal formula utilizing the sum of the per-acre rate at the deepest point, the per-acre rate at the shallowest point, and four times the per-acre rate at the midpoint (DMGE0615-0618). The sum is divided by six and multiplied by the total acreage flooded in the zone. Crop, field (including stored crop), building, and public damages are then summed to obtain a total for the hazard zone in the given reach and six-hour period (DMGE0619, 716, 778).

The total damage for the reach (TT) is obtained by accumulating each kind of damage for each zone. TC, TF, TU and TP are the total damages for crop, field, urban and public facilities respectively for each reach (DMGE0800-804).

SYNOPSIS

The purpose of the written discussion in this chapter has been to present the basic principles used in the flood damage simulation procedure. A thorough statement by statement exposition was not attempted because it was felt unnecessary with the listing of the program in Appendix A and the dictionary of variable definitions in Appendix C. With these principles at hand, the interested reader has the tools for following programming details.

CHAPTER IV

COLLECTING DATA FOR FLOOD DAMAGE SIMULATION

INTRODUCTION

The function of flood control storage is to hold peak flows for gradual release during later periods of lower flow. Effective operation of flood control reservoirs to minimize downstream flood stages requires definite rules that can be used by those charged with opening and closing gates at the dam to decide when flows should be held and when they should be released. Rule formulation becomes increasingly complicated with (a) larger numbers of flood storage reservoirs (b) more reaches with flood damage problems (c) longer time lags for flow from control points to damage points, and (d) more uncontrolled tributaries large enough to produce damaging floods.

As more storage is used to reduce high flood stages, one factor likely to be overlooked in developing operating policy is that prolonged releases extend the duration of flooding in low-lying areas. Farmers and other users of such areas may experience duration damages unknown without the project. For example, delays to spring planting because of prolonged wet conditions is a significant problem along some regulated rivers. This duration damage needs to be balanced against stage damage in seeking the minimum total for optimum operation of the system. The differences in environmental effects and the social consequences (differences in characteristics of the sufferers) of these two types of flooding should also be considered.

Operation procedures have traditionally been derived from historical flow sequences (11, pp. 470-471) as the basic data and then been expressed as a policy that would have minimized the adverse effects had they been used during these historical events. The operator is required to watch key

parameters such as streamflow at various points within the basin, current and predicted weather conditions over the basin, snowpack conditions, channel capacities, and flood plain use by season. He is provided rules for observing these parameters and determining how much and when to open or close gates according to his observations. One major problem with such rules is that future floods do not follow historical time and areal patterns. "Fifty-year floods" can vary tremendously in the primary source area for runoff, the timing of storm conditions leading to the peak, and outbursts of rainfall during the recession period; and all of these factors should be incorporated into decisions on how to operate a reservoir system. One approach to designing for the wide variety of flow sequences that may potentially occur in the future has been to apply rules of probability to simulate long traces of flow sequence so that reservoir operation can be studied under many more event sequences than could possibly have occurred during the historical record (11, pp. 481-485).

It is evident that if the operation of complex system of reservoirs and channels and the consequent damage patterns can be simulated for a wide variety of flood events, more effective operating procedures can be derived. Flood damage simulation can translate either historical or simulated flow traces into flood damage. The approach to damage pattern simulation is presented in two reports. This one describes the simulation procedure. A companion report by Harman (7) describes its application to a complex multiple reservoir flood control system.

Four assumptions made for Harman's initial application of DAMAGE were dictated by the desired scope of his study, are not inherent in the program, and thus need not be followed by subsequent users. His analysis is based on reservoir operation for single purpose flood control in that other project purposes such as recreation and water supply are not considered. Secondly, the economic effects of the flood damages are considered; but the effects on environmental quality, regional development, and social welfare are

neglected. Thirdly, his analysis is confined to effects within the basin under study. Relatively minor effects on downstream rivers are neglected. Lastly, his application takes existing reservoir and channel conditions and land use as given. Other users can just as well project future conditions and introduce them into the program through the input data. In reality, the simulation of areas flooded by depth and duration that DAMAGE provides is a powerful tool for pinning down the social and environmental as well as the economic consequences of flooding.

DAMAGE can be used as a subroutine to any program that can provide a continuous hydrograph or simultaneous hydrographs at up to 25 damage points. For each hydrograph (specified by 6-hour time increments), DAMAGE will simulate the damages in each reach. The topic at hand is collection of the data required to perform such a simulation.

THE CASE STUDY BASIN

The basin selected for the collection of data to be used in program development was the Muskingum River Basin in southeastern Ohio (Figure 7). This basin contains 15 flood control reservoirs built to protect productive agricultural land and many thriving communities. The history of the basin (17) is typical of the course of development that results in flood damage when rivers overflow their banks.

Marietta, the first permanent settlement in Ohio Territory, was founded at the confluence of the Muskingum and Ohio Rivers by the Ohio Company in 1788. In the decade that followed, access northward into the Muskingum River Basin was opened by roads, and in 1799 the town of Zanesville was founded. Rapid economic development followed in the early 1800's. Large stands of hardwood timber, abundant game, and large streams for transportation routes caused the growth of lumbering, trapping, and trading; and trade centers were largely located along the rivers. Early

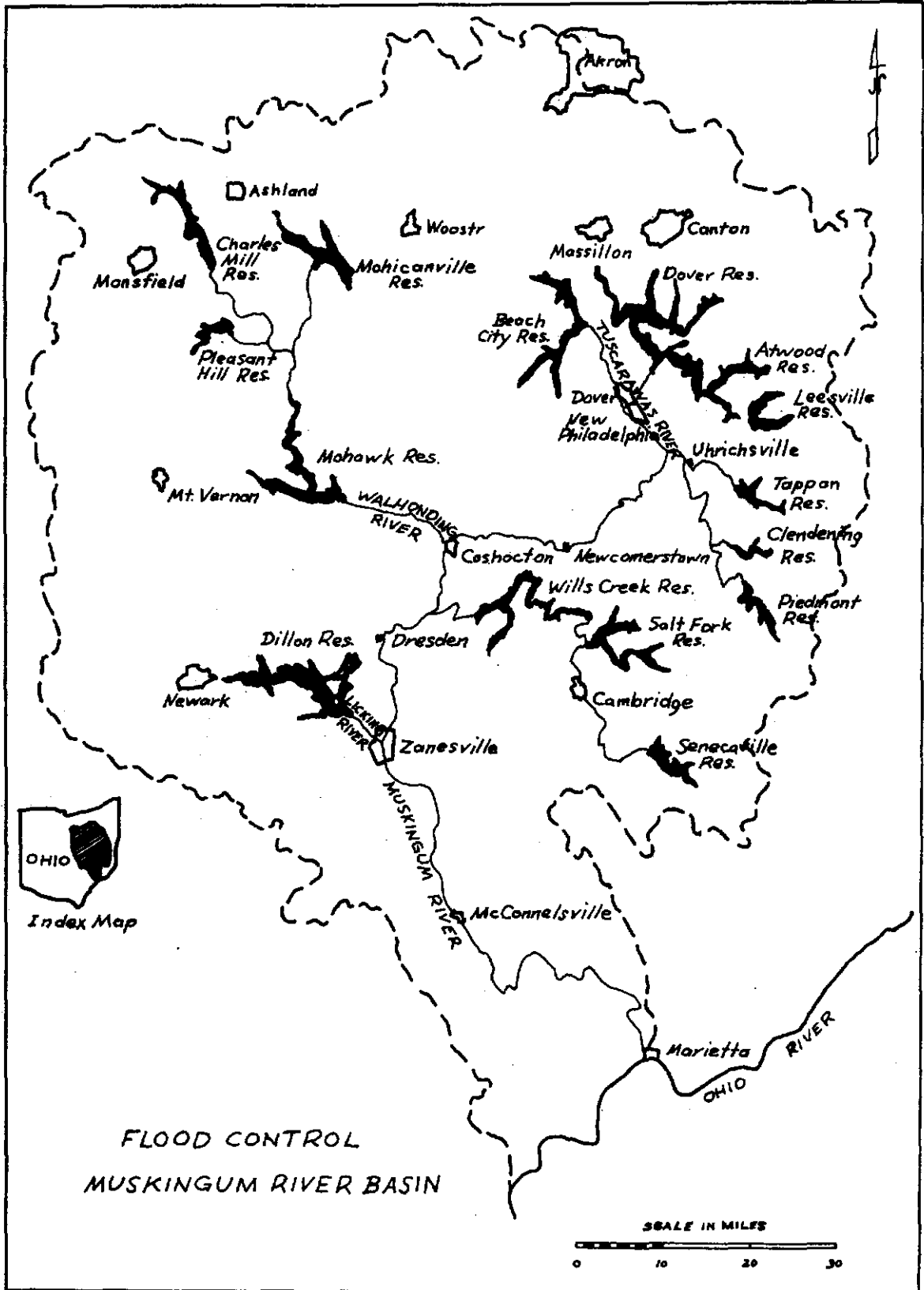


FIGURE 7

agriculture was also confined to the fertile bottom lands, but as the flood plains became crowded, the new farmers began to settle in the uplands. Over time, poor soil conservation practices led to erosion, caused upland agriculture to become unprofitable, and accelerated the movement of population to urban areas along the streams. New industry and substantial urban growth occurred in such centers as Akron, Newark, Zanesville, and Coshocton.

Urban development in the flood plain also increased as the development of water transportation in the basin stimulated manufacturing activities in the urban centers and the development of the mineral resources of the area. The Ohio Canal, completed in 1832, connected Cleveland on Lake Erie with Portsmouth on the Ohio River by passing through the Muskingum basin. The Muskingum River was also opened to navigation between Dresden and Marietta in 1841.

As the towns and communities grew along the watercourses, more and more development became subject to flood damage. A major flood catastrophe in 1913 caused \$14 million in damages; however, it was not until the Muskingum Watershed Conservancy District was established by court decree on June 3, 1933, that a program for flood control got under way. The District was given broad authority to engage in all the water control functions stated in the Ohio Conservancy District Act plus such other functions as water conservation, forestation and the building of check dams and other control works to prevent soil erosion and avoid clogging of stream channels. Negotiations between the Muskingum Conservancy District and the Ohio Department of Public Works led to construction of 15 dams administered by the U. S. Army Corps of Engineers, an important example of cooperation among various levels of government.

Water is stored in these 15 reservoirs for flood control, water supply, and recreation. The storage allocated for flood control is 1,589,900 acre-feet, and the storage allocated for conservation is 223,100 acre-feet. The State

owns nearly 55,000 acres of park, forest and wildlife areas for hunting, fishing, and picnicking by the public, and maintains over 8,600 acres of water surface for water sports.

The Muskingum River basin lies wholly within the State of Ohio and covers 8,038 square miles, one-fifth of the total area of the State. The basin is about 100 miles wide from east to west, about 125 miles from north to south, and extends to within 25 miles of Lake Erie. Two main tributaries, the Mohican and Tuscarawas Rivers, flow southward from Mansfield in the northwest and Akron in the northeast part of the basin. The Kokosing River joins the Mohican River near Walhonding, forming the Walhonding River which flows eastward to Coshocton. The Tuscarawas River to the east turns westward at Uhrichsville, meeting the Walhonding River at Coshocton. This confluence forms the Muskingum River which flows generally southward, emptying into the Ohio River at Marietta.

Although flood severity has been reduced tremendously by the reservoirs, flood damages still occur. In January 1959, a flood produced damages amounting to about \$23 million in the Muskingum River basin, the greatest of any flood of record. Higher property values and increased development in the flood plain areas account for this apparent anomaly (17, p. 133). The hypothesis of Harman's report is that more efficient operation of these 15 reservoirs could have reduced these damages.

SOURCES OF DATA

The primary sources of input data on the Muskingum Basin flood plain were the Huntington District office (15) of the Corps of Engineers and the offices of the Soil Conservation Service, U.S. Department of Agriculture in Lexington, Kentucky (12), and Coshocton, Ohio (14). The Huntington District had previously contracted with Burgess and Niple, Limited, Consulting Engineers, Columbus, Ohio, for a flood damage survey of the Muskingum

River basin (2). The report completed in 1966 was an excellent source for the economic data necessary to develop and test DAMAGE. The Soil Conservation Service supplied the expertise on crop and field damages and supplied the crop damage tables used in developing the crop damage factors and other pertinent information on agricultural damages. They also provided soil mapping information and information on the crops grown in the flood plain.

PREPARATION OF INPUT DATA

The input data falls into two broad categories: that used to establish the flooded area and that used to estimate damages within that area. The reach data defines by river reach such characteristics for a given flow (c. f. s.) as the depth of flooding, the area flooded, and the soil characteristics in the flood plain. Data on economic activity by flood plain location and other parameters are used to estimate damage to four major kinds of property: crops, fields, buildings, and public facilities. The input data will be discussed in the order it is read by the program (listed in Appendix B) except that the crop damage data is read before the reach data in the program but is discussed after the reach data in the text for continuity.

The data presented in Appendix B is read by an unformatted READ Subroutine (24, pp. 79-80, 219-223). It would be a relatively simple matter for a prospective user to modify the read statements in DAMAGE to match the input capabilities of the computer available to him.

REACH DATA

The first data item is the number of stream reaches (NRCH) to be used to represent the flood plain under investigation. If reaches have been delineated in previous studies, it is advantageous to review them for appropriateness and minimize changes to them in order to simplify data preparation. Whether reviewing old or establishing new reach divisions, in

order to minimize flow differences within a reach, reaches should be divided at junctions where a marked increase of flow occurs. The extra-long reaches that division by this rule alone will cause on the lower main stems of larger rivers should be divided into smaller segments. In the headwaters, the upstream end of the analysis should be terminated at reservoir sites or where flood damages are no longer considered significant. DAMAGE can handle no more than 25 reaches in a single analysis; however, a larger basin can be subdivided into two or more subdivisions for separate analysis.

Most of the data required to specify flood hazard by reach can be taken from sets of stage area curves (Figure 8) and rating curves (Figure 9), one curve of each type drawn for each reach. The stage, the flow and the total area flooded within the reach must be referenced to a control section. The maximum of three zones used to describe variation of topography and land use with elevation in the reach's flood plain may be plotted on each stage-area curve and each rating curve. Zone 1 normally extends from the water surface elevation, at the control section, at which flooding within the reach first begins to cause damage to a point where most intensive land use cause major damages to begin. Zone 2 includes the part of the flood plain where the bulk of the damages occur, and Zone 3 is higher ground damaged only very infrequently. Appropriate elevations to use in separating the zones may be evident from breaks in the slope of stage-property market value curves as shown in Figure 10. Arbitrary break points may be used to separate the zone if land use patterns or benched topography do not provide clear boundaries. The hazard zones as plotted on the stage-area curve, Figure 8, and the rating curve, Figure 9, can then be used in obtaining numerical input data.

FLF (KRCH)*: The fraction of the land farmed is the ratio of the cropland area to the total flood plain area for each reach. Cropland excludes

* KRCH is a counter designating the number of the particular reach. Elements in the array go from one to NRCH. The other counters specify hazard zone (KFZ) and soil type (KSTP).

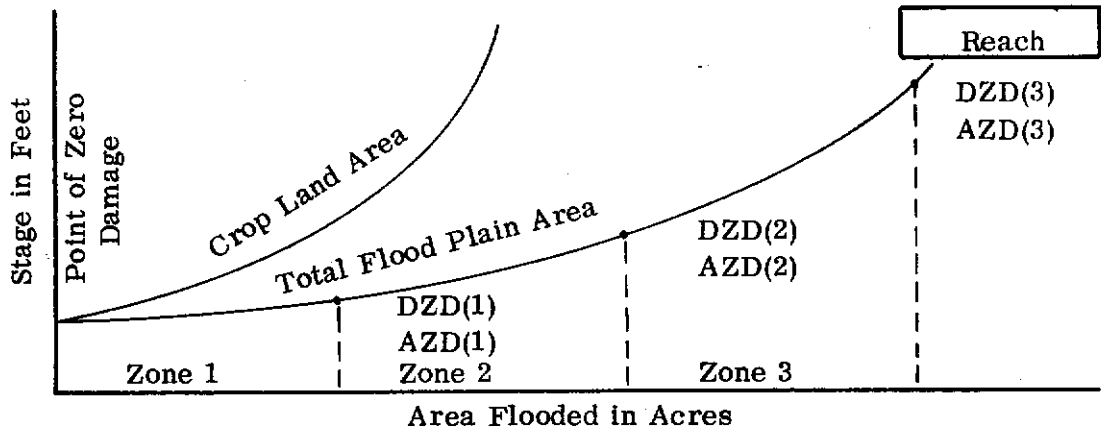


FIGURE 8 STAGE AREA CURVE

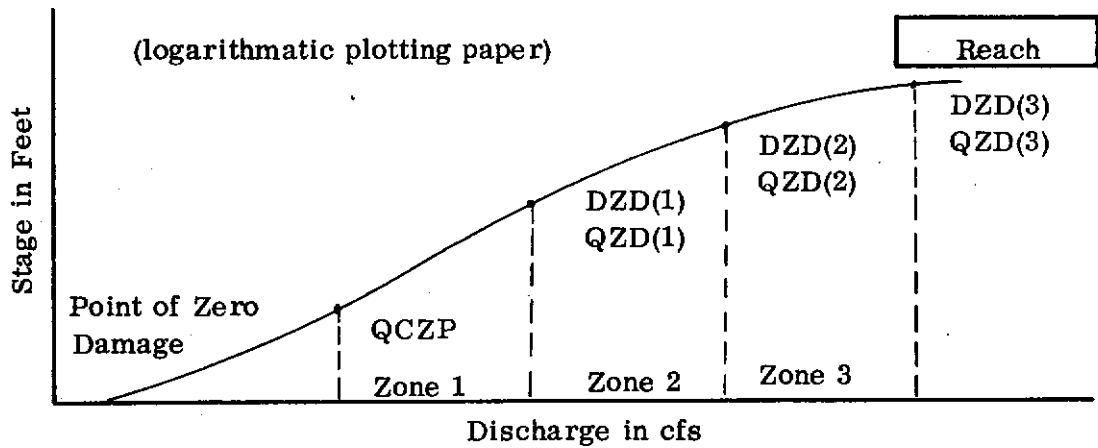


FIGURE 9 RATING CURVE

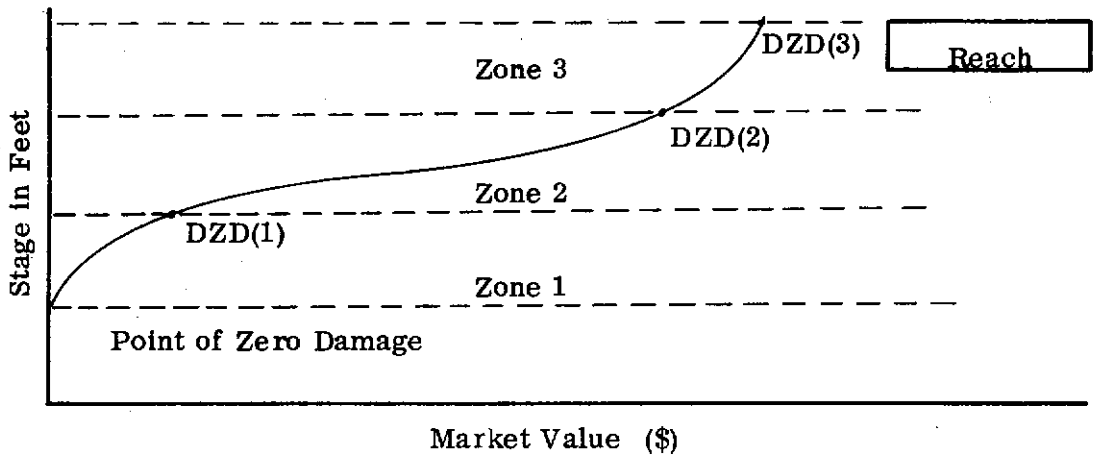


FIGURE 10 STAGE DAMAGE CURVE BY LAND USE

areas occupied by building sites, roads, utilities, and idle lands from which little or no income is derived.

QCAP (KRCH): The channel capacity is the maximum flow through the reach that will not result in flood damage. In Figure 9, QCAP is the discharge at zero damage. Channel capacities may have to be established by field surveys, and hypothetical rating curves may have to be developed from reach hydraulics if better information is not available.

QZD (KRCH, KFZ): QZD is the stream flow at the stage that defines the boundaries between Zone 1 and 2 (KFZ = 1), Zone 2 and 3 (KFZ = 2), and an arbitrary upper limit to Zone 3 (KFZ = 3) of approximately the maximum probable flood depth. This data may be taken from Figure 9 for each reach (KRCH).

DZD (KRCH, KFZ): DZD is the difference between the stage at which the hazard zone is completely inundated and the stage at the lower edge of Zone 1. Estimates can be read from Figure 9.

AZD (KRCH, KFZ): AZD is the area of land within the zone boundaries. Estimates can be read from Figure 8.

STZD (KRCH, KSTP, KFZ): Flood plain soils can be classified into as many as three type groups to reflect differences in agricultural productivity: soils with a high potential crop yield (soil type 1), soils with medium potential crop yield (soil type 2), and soils with low potential crop yield (soil type 3). Sometimes, crop damages can be adequately estimated from a two-way classification. In this case, NSTP may be taken as 2, and only two soil cards are needed per reach. If all flood plain soils are of approximately equal productivity, NSTP may be taken as 1, and the data for STZD consists of one card with a value of 1.0 for each hazard zone.

The necessary information for classifying soils by productivity can be obtained from soil scientists familiar with the flood plain and with the distribution of soils in the particular zones. STZD is the decimal fraction of

the soil found in the flood zone (KFZ) and in the reach (KRCH) that is of each type (KSTP). The columns as shown in Appendix B must total to unity.

EXP1 (KRCH), EXP2 (KRCH), EXP3 (KRCH): A rating curve (Figure 9) may be approximated by the relationship of equation 9. Based on the segment of the rating curve which applied to the particular zone, EXP may be estimated as b in equation 12, and the process may be repeated for each of the three zones. The values of Q and d for substitution in the equation may be taken from Figure 9.

CROP DAMAGE DATA

CIDF: The crop indirect damage factor represents the indirect damages resulting from crop losses. A factor of 1.10, indirect damages at 10 percent of the direct damages, has been suggested (13, p. 17). More precise analysis is seldom warranted because of the complexity involved in gathering the information (11, p. 171).

NSTP: The program can use from one to three soil types to distinguish the soils in the flood plain according to productivity. NSTP is the number of soil types selected.

NCRP: NCRP is the number of kinds of crops to be used to estimate crop damage. As the program is limited to a maximum of ten crops, acreages for crops not grown in sufficient quantities to be in the top ten in economic importance should be included with some similar crop.

In order to estimate crop damages, the program requires values for each of the four parameters in equation 7 for each month of the year. Values were estimated from data published by the USDA on crop and pasture flood-water damages as fractions of flood-free gross returns by month, yield, flood depth (separate tables for 0 to 2 feet and for over 2 feet), and flood duration (separate tables for less than 24 hours and for over 24 hours). Gross returns as used in developing the tables are based on adjusted normalized

prices (11, p. 209). The USDA has compiled such information for major crops in each portion of the country. The following example shows how the tables were used to estimate parameter values for the simulation program.

EXAMPLE

The USDA Tables show corn yielding 75 bushels per acre and grown in the southern portion of the northeast area of the United States to be damaged by flooding in the amounts shown in Table 1. The simulation requires values for five parameters (CBDM, CDPF, CDRF, CDDI, and CMDF) each subscripted by crop (KCRP) and month (KMO). As each estimation sequence follows the same procedure, the example will be limited to corn in June. In the nomenclature of equation 7, CBDM is D_{mn} , CDPF is D'_f , CDRF is T_f , and CDDI is I_f . If depths less than two feet are taken as averaging one foot, depths over two feet are taken as averaging three feet, durations less than 24 hours are taken as averaging 12 hours, and durations over 24 hours are taken as averaging 36 hours, substitution in equation 7 yields

$$\begin{array}{ll}
 \text{Eq. 7} & D_m = D_{mn} (1 + D'_f d (1 + t (T_f + I_f d))) \\
 d = 1, t = 12 & 0.29 = D_{mn} (1 + D'_f (1 + 12 (T_f + I_f))) \\
 d = 3, t = 12 & 0.42 = D_{mn} (1 + 3D'_f (1 + 12 (T_f + 3 I_f))) \\
 d = 1, t = 36 & 0.40 = D_{mn} (1 + D'_f (1 + 36 (T_f + I_f))) \\
 d = 3, t = 36 & 0.51 = D_{mn} (1 + 3D'_f (1 + 36 (T_f + 3 I_f))).
 \end{array}$$

Simultaneous solution of these four equations for the four unknowns gives

$$D_{mn} = 0.165, D'_f = 0.424, T_f = 0.0893, \text{ and } I_f = -0.0238.$$

Simultaneous solution, however, is a very time consuming process that may not be commensurate with the precision of the data and the assumptions for averaging depths and durations. Therefore, the approximate procedure described below was substituted. The results give less severe increases in

TABLE 1

FLOOD WATER DAMAGE FACTORS FOR CORN AS A PERCENT FLOOD FREE GROSS RETURN

Yield: 75 bushels per acre

Source: USDA

Location: Southern portion of northeast United States

Row Designation	Depth	Duration	Growing Season for Corn							
			April	May	June	July	Aug.	Sept.	Oct.	Nov.
P ₁	< 2'	< 24 hr.	1	8	29	21	8	3	2	1
P ₂	> 2'	< 24 hr.	1	10	42	54	25	17	14	3
P ₃	< 2'	> 24 hr.	2	11	40	29	15	7	4	1
P ₄	> 2'	> 24 hr.	2	13	51	64	35	26	20	4

marginal flood damage with depth and duration than does the exact solution, but the values of 3 feet and 36 hours are probably on the low side, and higher values reduce D'_f and T_f . The ideal procedure for estimating the four parameters is to obtain the raw data used by the USDA in compiling its Tables and to use that data for least square estimation based on equation 7, but that was beyond the scope of this study. The values estimated for the parameters are data read by the program; program users are encouraged to estimated parameter values by the best method commensurate with their data base.

CDPF (corn, June): The depth factor (D'_p) is the fraction of the crop value lost per unit increase in depth of flooding, expressed as a fraction of the loss at minimum depth. Approximate values were estimated from the short duration percentages on Table 1. Based on a two-foot depth difference between the first two rows on the tables,

$$D'_f = \frac{1}{2} \frac{(P_2 - P_1)}{P_1} \quad (22)$$

Substitution for the month of June gives

$$D'_f = \frac{1}{2} \left(\frac{42 - 29}{29} \right) = 0.22 = \text{CDPF}$$

CDRF (corn, June): The duration factor (T_p) is the fraction of the crop value lost per unit increase in duration of flooding expressed as a fraction of the loss at minimum duration. Based on a 24-hour difference between the second and fourth rows on the table,

$$T_f = \frac{1}{24} \frac{P_4 - P_2}{P_2} \quad (23)$$

An example substitution for June gives

$$T_f = \frac{1}{24} \frac{51-42}{42} = 0.009 = \text{CDRF}$$

CDDI (corn, June): The depth-duration interaction factor (I_f) reflects the difference in effect of increased duration as one goes from one depth to another. The estimate of CDRF showed a factor of 0.009 at a depth of 3 feet. At the one foot depth, the results are

$$I_f = \frac{1}{24} \frac{40-29}{29} = 0.016$$

The difference in values per foot difference in depth is

$$I_f = (0.009 - 0.016) / 2 = -0.0035 = \text{CDDI}$$

CBDM (corn, June): The fraction of the crop value lost by flooding of minimum depth and short duration can be estimated from equation 7 with t taken as 12 hours, and d as 1 foot, D_m as 0.29 from Table 1, and the three other parameters as the values estimated above. Thus

$$D_{mn} = \frac{D_m}{1 + d D_f (1 + t (T_f + I_f d))} \quad (24)$$

$$D_{mn} = \frac{0.29}{1 + 0.22 (1 + 12 (0.009 - 0.0035))}$$

$$= 0.235 = \text{CBDM}$$

CMDF (corn, June): The maximum damage factor for a crop in any given month of the growing season may be derived from other data supplied by the USDA (Potential Crop Damage Value per Acre of Unharvested Crop by Yield and Half-month Intervals). The factor is defined as the ratio of the loss to the farmer if the crop is completely destroyed in the month to the market

value of the crop at harvest time. The data in Table 2 is used to estimate a value of the factor for June for corn yielding 75 bushels per acre. Assuming floods are equally likely in either the first or in the last half of June, the average flood loss is \$56.15 from June floods that completely destroy the crop. Division by the value of the crop at harvest time (\$97.50) gives $CMDF = 0.576$.

CPRICE (KCRP): The market price used per unit of production should be normalized to average out the year-to-year effects of weather conditions and other market abnormalities (11, p. 209). USDA sources can provide reasonable estimates for most crops. The value used for corn was \$1.01 per bushel.

LFY (KCRP, KFY): The last possible month (counted from January as 1) a crop can be planted to produce full yield is read as LFY (KCRP, 1) and the last day of that month is read as LFY (KCRP, 2). For the Muskingum valley, local farm advisers indicated production would suffer if corn were planted after May 15.

YIELD (KCRP, KSTP): YIELD is the number of units of production per acre indexed by crop and soil type. Local agricultural statistics showed the best Muskingum soil, to yield 110 bushels of corn per acre, medium soils to yield 80 bushels per acre, and the worst soils to yield 60 bushels per acre.

CSTFZ (KCRP, KSTP, KFZ): The information provided in this array is the fraction of the crop land in each combination of hazard zone (KFZ) and soil type (KSTP) planted to each crop (KCRP). A detailed survey showing the crop planted in each field in the flood plain could be combined with a detailed map of soil types and with hazard zones plotted on a topographic map to estimate each element of the array. Cropping patterns, however, change from year to year, and a number of uncertainties complicate projection of future crop patterns. Also, data for any given year will show crop patterns to vary with reach as well as with the three subscripted items shown; but if the entire basin is in the same agricultural region, reach variations may not

TABLE 2

CROP BUDGET DATA FOR ESTIMATING DAMAGE
TO CORN FROM JUNE FLOODS

Yield: 75 bushels per acre Source: USDA

Location: Southern portion of northeast United States

Floods between June 1-15

Corn replanted to soybeans - yield for soybeans in bushels per acre	18
Value of original corn crop @ \$1.30	\$ 97.50
Less cultivating, picking, processing, and marketing costs of corn	<u>36.27</u>
Net value of corn loss	\$ 61.23
Less gross value @ \$2.42 per bushel replacement soybean crop	\$ 43.56
Plus production costs of soybeans	<u>28.91</u>
Total Flood Loss	\$ 46.58

Floods between June 16-30

Too late to replant any crop - value of crop (corn) @ \$1.30 per bushel	\$ 97.50
Less cost of one cultivation	2.30
Less picking cost	6.22
Less processing and marketing cost	<u>23.25</u>
Total Flood Loss	\$ 65.73

persist in the long run. The most refined procedure for filling this array would be to map for every field the distribution of the fraction of years over a long period that the field is expected to be planted to each crop. In most cases, an approximate method based on qualitative information is satisfactory and much quicker. The following example illustrates such a method.

EXAMPLE

For an example reach of the Muskingum River near McConnelsville, Ohio, the distribution by hazard zone of soil types was estimated as tabulated below. The productivity group for each soil is shown in parenthesis.

The distribution of soil by hazard zone

<u>Zone 1</u>	<u>Zone 2</u>	<u>Zone 3</u>
70% Charin silt loam and loam (high)	30% Chili loam (medium)	40% Allegheny silt loam (medium)
15% Orville silt loam (medium)	20% Wheeling silt loam (high)	30% Monongahela silt loam (medium)
15% Lobdell silt loam (high)	30% Monongahela silt loam (medium)	30% Chili loam (medium)
	20% Tyler silt loam (medium)	

Fractions of zone areas by soil productivity group (STZD)

Soil type 1 (high) = 0.85	(high) = 0.20	
Soil type 2 (med.) = 0.15	(med.) = 0.80	(med.) = 1.00

Total flood plain area (T_L) in reach from Figure 8 in acres

1220	1040	1280
Total area 3540		

Total crop land area in reach from Figure 8 in acres

380	500	607
Total area 1487		

FLF $FLF = \frac{1487}{3540} = 0.4201$

Estimated reach acreages of crop land by soil type

$(C_L = STZD \times T_L \times FLF)$

<u>Zone 1</u>	<u>Zone 2</u>	<u>Zone 3</u>
Soil type 1		
$C_{L11} = 436$	$C_{L21} = 55$	$C_{L31} = 0$
Soil type 2		
$C_{L12} = 77$	$C_{L22} = 222$	$C_{L32} = 697$
Soil type 3		
$C_{L13} = 0$	$C_{L23} = 0$	$C_{L33} = 0$

Summation over all reaches in the flood plain of values for C_L estimated in the above manner.

Soil type 1		
$\Sigma C_{L11} = 7838$	$\Sigma C_{L21} = 3355$	$\Sigma C_{L31} = 492$
Soil type 2		
$\Sigma C_{L12} = 5614$	$\Sigma C_{L22} = 10255$	$\Sigma C_{L32} = 10916$
Soil type 3		
$\Sigma C_{L13} = 0$	$\Sigma C_{L23} = 839$	$\Sigma C_{L33} = 0$

The portion of the above total acreages in corn is estimated by distributing the corn acreage by zone and by soil type according to available information on local farming practice. The soil-type weightings are based on division of the total flood plain area by soil type, and the hazard-zone weightings are based on an observed tendency to plant more corn on higher ground. Each weighting factor is expressed as a multiple of the fraction of medium productivity land in Zone 2, planted to corn. The factors are tabulated as follows.

Weighting factors for intensity of corn cropping by soil type and hazard zone.

	Weighted by Soil Type <u>1/</u>	<u>Zone 1</u>	<u>Weighted by Zone</u>	
			<u>Zone 2</u>	<u>Zone 3</u>
Soil type 1 (high)	58/32	$W_{C11} = 1.63$	$W_{C21} = 1.81$	$W_{C31} = 1.99$
Soil type 2 (med.)	<u>1.00</u>	$W_{C12} = 0.90$	$W_{C22} = \underline{1.00}$	$W_{C32} = 1.10$
Soil type 3 (low)	10/32	$W_{C13} = 0.28$	$W_{C23} = 0.31$	$W_{C33} = 0.34$

1/ The percentages of the soil planted to corn are 58% (high), 32% (med.), and 10% (low).

If these weighting factors were fractions of the total area planted to corn, the total acreage of corn in the entire flood plain would be

$$W_{C11} \times \Sigma C_{L11} = 12776$$

$$W_{C12} \times \Sigma C_{L12} = 5035$$

$$W_{C13} \times \Sigma C_{L13} = 0$$

$$W_{C21} \times \Sigma C_{L21} = 6073$$

$$W_{C22} \times \sum C_{L22} = 10255$$

$$W_{C23} \times \sum C_{L23} = 260$$

$$W_{C31} \times \sum C_{L31} = 979$$

$$W_{C32} \times \sum C_{L32} = 12008$$

$$W_{C33} \times \sum C_{L33} = 0$$

$$\text{Total acres} = 47404$$

The total corn land in the flood plain is 20,042 acres. Thus, to convert to fractions, each weighting factors should be multiplied by

$$C = \frac{20042}{47404} = 0.4230$$

The resulting estimates of CSTFZ are

	<u>Zone 1</u>	<u>Zone 2</u>	<u>Zone 3</u>
Soil type 1 (high)	$W_{C11} \times C = 0.6894$	$W_{C21} \times C = 0.7656$	$W_{C31} \times C = 0.8417$
Soil type 2 (med.)	$W_{C12} \times C = 0.3807$	$W_{C22} \times C = 0.4230$	$W_{C32} \times C = 0.4653$
Soil type 3 (low)	$W_{C13} \times C = 0.1184$	$W_{C23} \times C = 0.1311$	$W_{C33} \times C = 0.1438$

If the fractions estimated in the above manner for a given soil in a given hazard zone are summed over the various crops, the total may exceed unity (especially for the better soils in the higher zones). The physical interpretation is that the fraction of the available land of this type that is planted to crops is greater than the fraction for flood plain land as a whole. In terms of the example, more than 42 percent of the best soil in the highest zone is planted to crops.

FIELD DAMAGE DATA

The four parameters used in equation 7 to simulate field damages are estimated by using the same procedure derived for the crop factors. The USDA has estimated values for field damages to fences, farm roads, equipment, waterways, and terraces, etc. The values given in Table 3 are for the corn belt area of the U. S. in dollars per acre.

TABLE 3
UNIT FIELD DAMAGES

<u>Row Designation</u>	<u>Depth</u>	<u>Duration</u>	<u>\$/Ac.</u>
P ₁	< 2'	< 24 hrs.	0.46
P ₂	> 2'	< 24 hrs.	0.88
P ₃	< 2'	> 24 hrs.	0.90
P ₄	> 2'	> 24 hrs.	1.58

Substitution of the dollar per acre figures in Table 3 into the basic simulation model in the manner shown in equation 22 and simultaneous solution of the four equations for the four unknowns gives $D_{mn} = 0.095$, $D'_f = 1.526$, $T_f = 0.156$, and $I_f = -0.0297$. The approximate procedure described in equations 23 to 25 yields values of $D_{mn} = 0.24$, $D'_f = 0.456$, $T_f = 0.033$, and $I_f = -0.007$; and these values are listed for FBDM, FDRF, FDPF, and FDDI in Appendix B. In areas of high bank erosion, the dollar per acre values obtained from the USDA should be adjusted to reflect erosion damage.

STORED CROP DAMAGE DATA

SCDA (KRCH, KFZ): The required stored crop data are the market values in dollars per acre of the crops stored at the end of the harvest season

for later livestock feeding within each area designated by reach (KRCH) and hazard zone (KFZ). Estimates are made from field information on the average annual values of stored crops by storage location.

URBAN DAMAGE DATA

UZF (KRCH, KFZ): UZF is the market value of urban structures in each reach and flood hazard zone. Information on the location and value of buildings is obtained from field surveys, published topographic maps, and county tax records. Property value can be plotted against stage for each reach, and the property value for each flood zone can then be read as shown on Figure 10.

UDPF: The urban damage depth factor reflects the damage caused per unit increase in depth of water inundating urban structures and their contents. The factor is defined by equation 6 and was estimated by trying to duplicate flood damage estimates made by Burgess & Niple for historical floods. The resulting value was found to be 0.10 in the Muskingum River Basin (8, 19).

UDRF: The urban damage duration factor reflects the damage caused per unit increase in the duration of water on urban structures and their contents. The factor as defined by equation 6 was adjusted by trial and error and estimated to be 0.001 in the Muskingum River Basin.

UDDI: The depth-duration-interaction factor relates the combined effect of depth and duration to urban property damage. The factor as defined by equation 6 was also adjusted by trial and error and estimated to be -0.00008 in the Muskingum River Basin.

UPDD: As people are evacuated from their homes, they must find shelter. The added expense was estimated to be \$50.00 per day for each family occupying a \$20,000 home.

UIDF: The indirect damage factor was estimated by averaging published percentages of direct damages to residential, commercial and

and industrial property (Chapter I). This average value was then adjusted to best fit the Muskingham River Basin data. The factor was estimated to be 1.331.

PUBLIC FACILITIES DAMAGE DATA

PZD (KRCH, KFZ): PZD is the maximum damage floods characteristic of the flood plain under study can do to public facilities such as roads, sewers, railroads, water mains, and other miscellaneous items that cannot be classified as buildings. In order to estimate appropriate values, all such facilities within each reach and hazard zone need to be identified. The maximum amount of damage each identified facility can suffer then needs to be estimated. The best data base is records of major historical floods in the area. Historical damages can be expressed on a unit basis (per mile of road, sewer, etc.). PZD can then be summed from the products of unit values and measures of the extent of identified facilities. For the Muskingum Basin flood plain, stage-facility value curves were drawn, the hazard zones were identified, and estimates of PZD were read from the curves.

PDPF: The public facility damage depth factor is the damage per foot of flood depth to public facilities as defined by equation 20. A value of 0.25 was estimated for Muskingham River Basin Study by trial-and-error matching of damages noted from historical floods.

PIDF: Public indirect damage factor reflects the indirect damage caused by flood damage to public facilities (Chapter I). The value was estimated to be 1.208 for this study by adjusting the factor to best fit the data.

PPDD: The variable reflects the daily loss to the public from inability to use the facilities and is estimated to be 0.03 per day for this study. The estimate was derived by assuming 40 percent loss of public services for an average of 14 days.

SUMMARY

The data described in this chapter are listed in Appendix B. Much further study is needed to establish better estimates for a number of the items. These can then be used in the flood damage simulation to achieve improved results.

CHAPTER V
OVERVIEW OF RESULTS

INTRODUCTION

A planner's confidence in a simulation program depends on his agreement with the cause-and-effect relationships used as a basis for simulation, his understanding of how to assemble the necessary input information and execute the program, and his skill at interpreting the output and applying it to planning decisions. The first three chapters developed the relationships used for simulation in DAMAGE. Chapter IV dealt with data assembly. This chapter illustrates program output and interpretation through an example application to a hypothetical flood on a reach of the Muskingum River near McConnellsville Ohio (Appendix B, Reach MR-2).

An application to another flood plain will naturally require development of an appropriate set of input data to reflect local conditions. It may also require some adjustments to the Fortran programming in order to generalize the simulation to handle conditions not encountered in the Muskingum Basin. As a simple example, other areas of the country may have field conditions that permit replanting crops less than 15 days after flood waters recede. Greater changes will be needed as additional empirical studies provide better information on the rates of repair of flood damage to buildings and public facilities and on factors affecting repair rates. Other important contributions may come from more definitive studies on how depth and duration interact to cause flood damage and on how flood events change day-to-day activities in the lives of people.

Much raw data that could contribute to better flood damage simulation is no doubt stored in various offices across the country in the form of records

as the consequences of historical flood events. Flood damage estimation could be greatly improved if the relevant information could be compiled from such records and evaluated. One purpose of DAMAGE is to stimulate such studies by putting research needs into better perspective.

TYPICAL RESULTS

In order to illustrate the flood damage patterns simulated by DAMAGE, a hypothetical flood hydrograph is used. The hypothetical flood is designed to cover a range of event sequences that did not occur during any historical flood and thus make it unnecessary to use a large number of historical floods to display the same variety of situations. The hypothetical hydrograph is plotted on Figure 11. A very large flood occurs March 9, and several smaller floods occur later the same month. A second major flood, identical to the first, then peaks on May 10.

The hypothetical hydrograph illustrates the damages caused when a major flood is followed by later flood peaks. The flood in late March does little additional damage after a short flood free period. During such periods, some repairs may be made to buildings and public facilities, but there is insufficient time to prepare the fields for replanting. The May flood illustrates the magnitude of the damages after sufficient time has elapsed for repairing property and replanting crops. The lower portion of zone one, next to the stream banks, is used in this chapter to illustrate crop and field damages. The lower portion of zone two is used to illustrate building and public damages. These improvements do not exist in zone one at McConnellsville.

Crop Damages

When the initial flood occurs in March, the only crop that is in the field is winter wheat. Other crops such as corn, oats, and soybeans are planted in April. As the flood overflows the stream banks and inundates

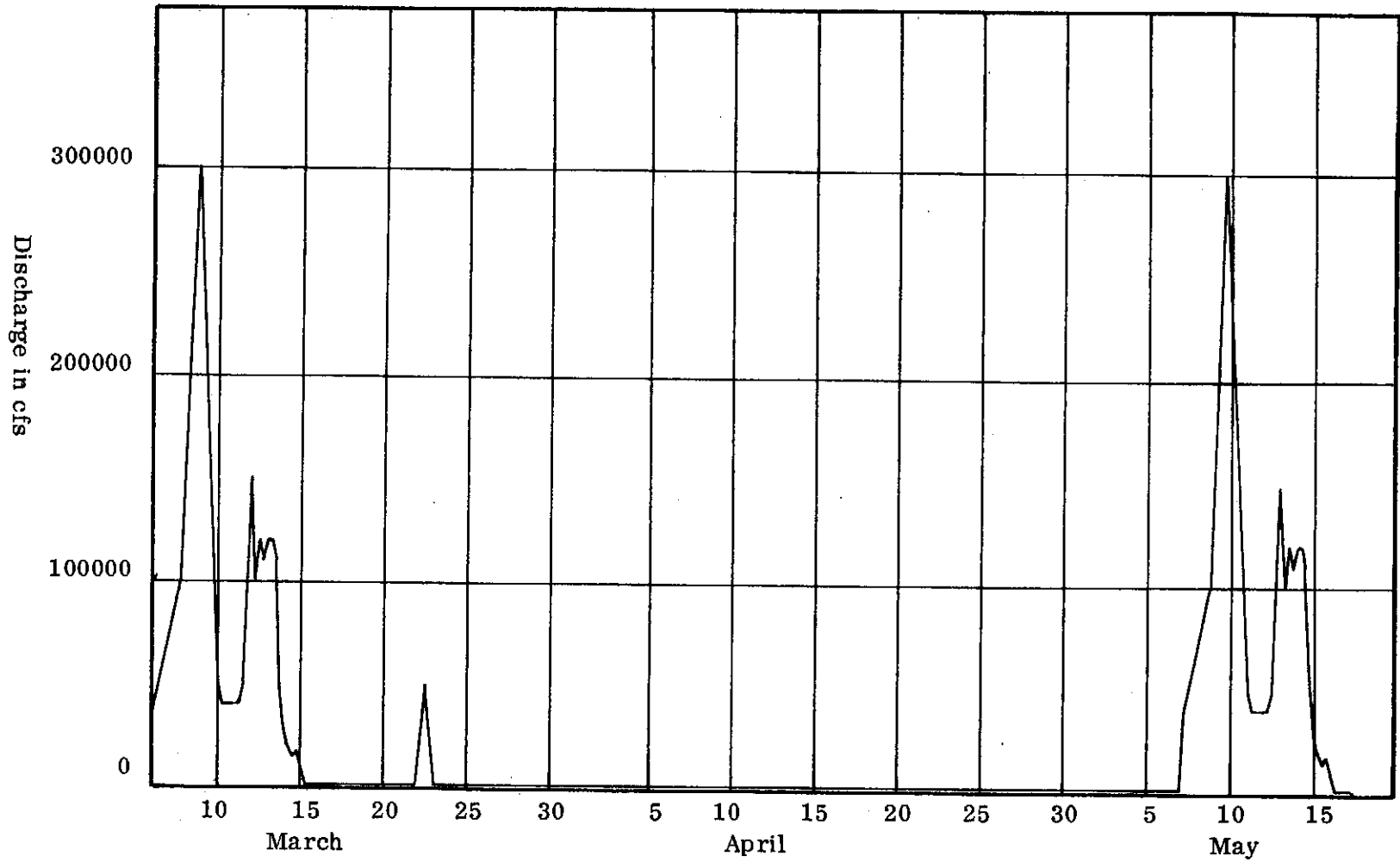


FIGURE 11 FLOOD HYDROGRAPH

adjacent fields of winter wheat, the most rapid rate of damage occurs when the crop is first inundated (Figure 12). In the example, that rate is relatively low (CDF = \$0.165 per acre) because of an immature crop. The time rate of inflicted damage gradually decreases as the flood flows continue to rise until the crop is largely destroyed. The damage rate next to the bank has decreased to less than one third its peak value by the time the flood crests. The total damage rate over the flood plain, however, is a maximum closer to the time of the peak because more total area is under water and crops on the fringes of the flooded area are suffering damage at their maximum rate. When the flows recede and then rise again, it has little effect on the already destroyed wheat crop. Even after the flows are within the stream banks for a period of seven days, not enough time for the fields to dry out and a new crop to be replanted, the very small added increment of damage to the crop from new flooding amounts largely to extending the delay before replanting. When the flood recedes, and the sun comes out for a period of 45 days, the farmer replants his winter wheat as it is still too early to plant small grain (23, Table VII). On May 7th, the second storm inundates the fields of winter wheat. This time the crop is well grown (CDF = 0.872), and the major damage occurs during the first 12 hours of the storm. As the duration of the storm continues and the flood depth fluctuates, the damage factor for each increment of time decreases as before and CDF is equal to 0.025 by the end of the flood.

In late April and early May, the corn crop was planted, and the May storm wipes out the young corn in the same way as the winter wheat crop was wiped out in March. It is still early enough in the season to replant corn (23, Table VII). Should the storm have occurred between June 1 - 15, a substitute crop of soybeans could be planted. By the end of June, it is too late to plant any crop; and the corn would be left in the field to be salvaged at harvest time. If the storm occurred during September, just before harvest, the entire crop would be lost. The program handles these varying conditions.

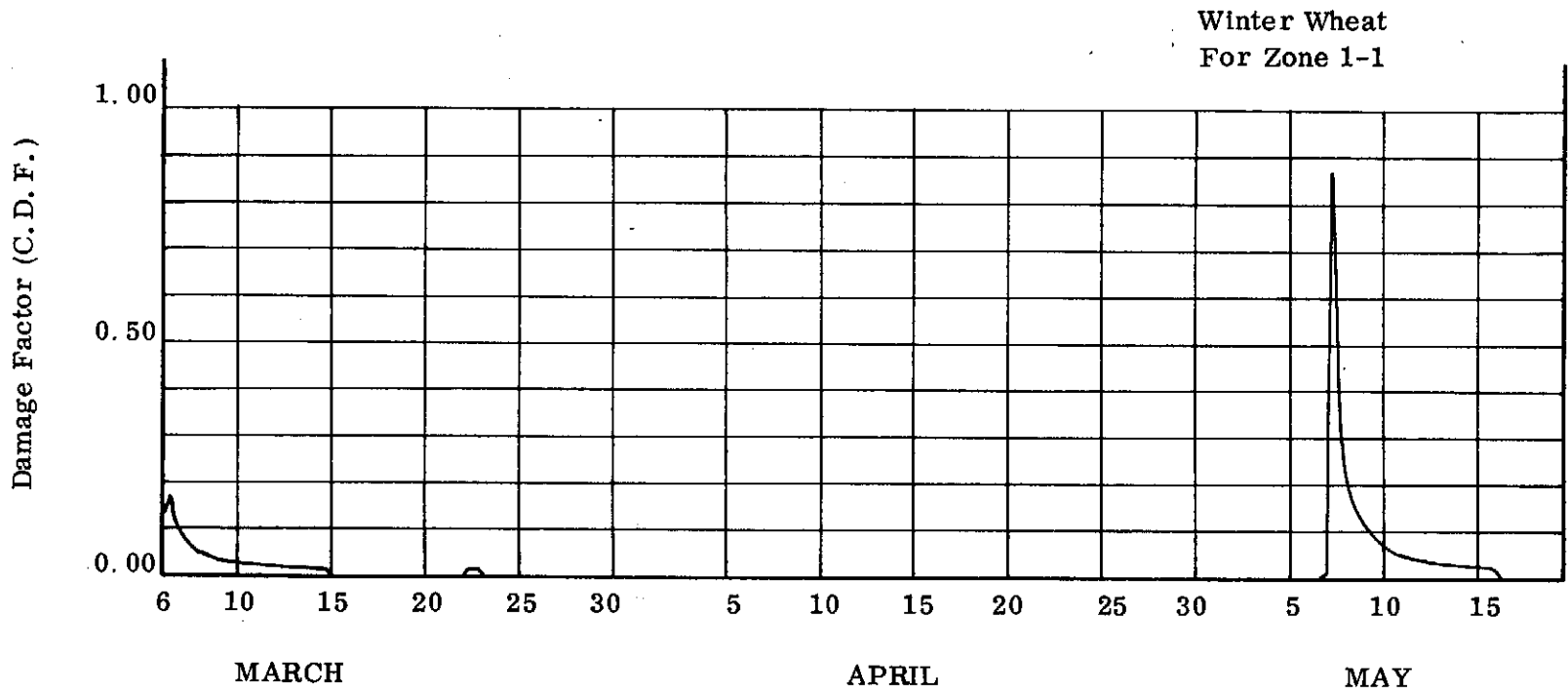


FIGURE 12 CROP DAMAGE CURVE

Field Damages

Field damages tabulated in the output data include damages to both the stored crops and to the fields (erosion, lost fence, debris, etc.). Figure 13 shows that the damage to stored crops increases as the flood depths increase until the depth of 20 feet is reached. Flooding deeper than 20 feet causes no further damage as the stored crops are gone until the next harvest. By the May flood, all stored crops have been fed to livestock and none are left to be damaged.

The damage to fields follows a similar pattern except that after a period of time for repairing fences, removing debris, and filling eroded gullies, the fields can be damaged again. Field damage is not concentrated toward the earlier part of the flooding to the degree that crop damage is. A small increment of damage continues to be added until the flood recedes.

Building Damages

As there are no buildings along the river banks in the McConnelsville reach, the flood water must reach into zone 2, 9.0 feet above flood stage, before damage to buildings begins. The rapid rate of rise of flood water into zone 2 produces the fastest time rate at which damage occurs. Building damage is, however, not concentrated in the early part of the flood to the degree that agricultural damages are because, in terms of equation 7, D_{mn} is zero. The time rate at which damage is inflicted declines as the hydrograph begins to rise more slowly toward the end of March 6. At the end of March 7, another period of intense rain causes the hydrograph to begin again to rise more rapidly, and the rate of damage again increases. This second peak in the damage rate is less than the first because after longer durations added depths do not add so much damage.

At a depth of 35.4 feet (Figure 5), building damage reaches the maximum of 0.63 times the market value. AUD12, as plotted on Figure 14, denotes the fraction of building value associated with unrepaired damage at any

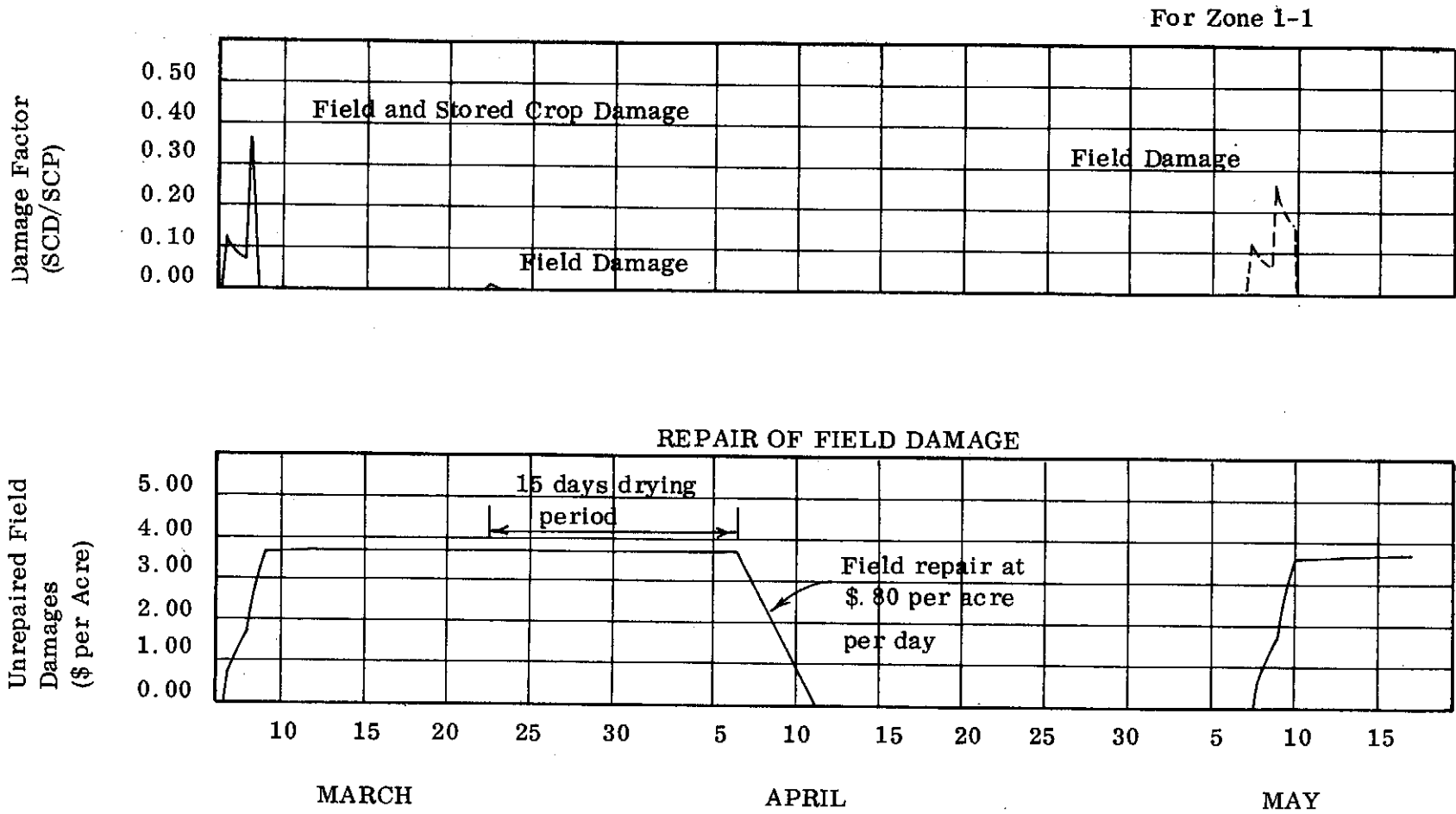


FIGURE 13 FIELD AND STORED CROP DAMAGE CURVE

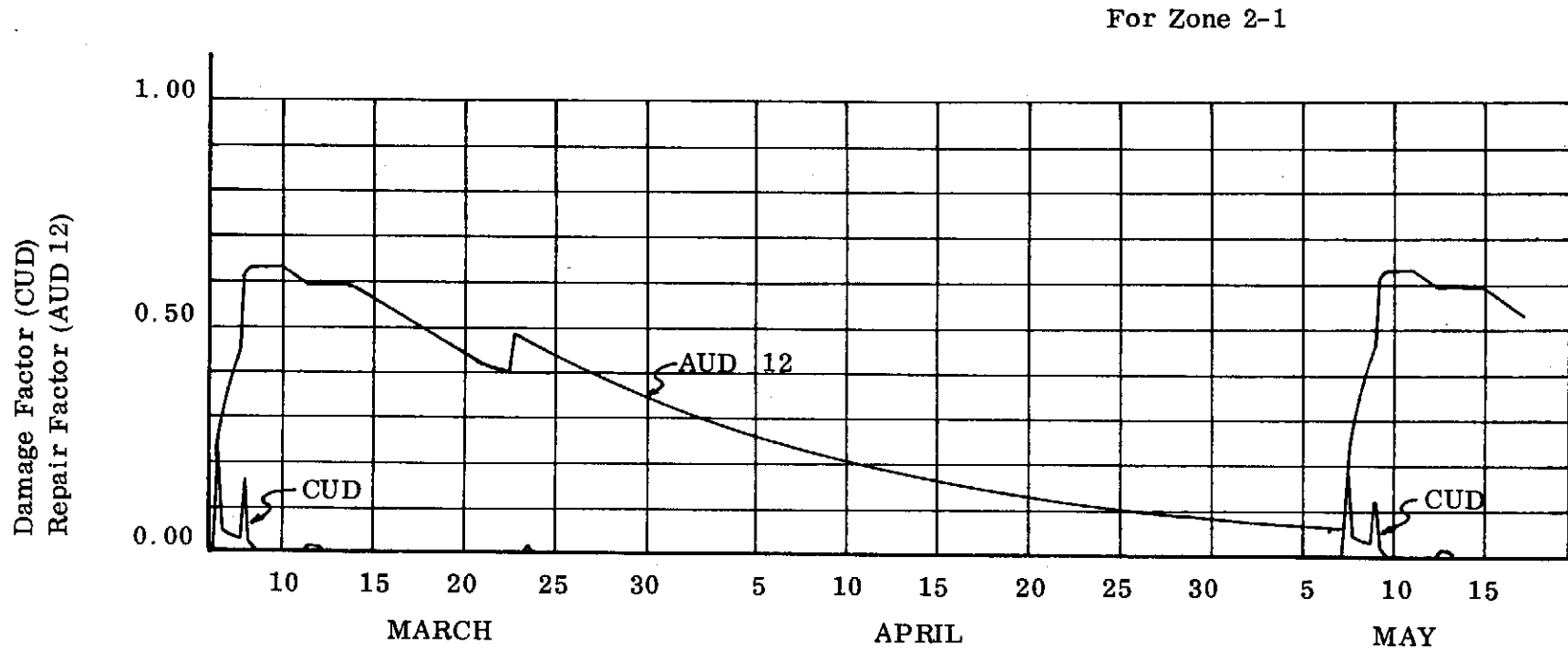


FIGURE 14 BUILDING DAMAGE CURVE

point in time. When the flood water recedes from the zone on March 10, the program begins to simulate building repair. Very little additional damage results from the reoccurring flood on March 11. The portion of the property that has been repaired during the one-day flood free period is not very much and is all that is lost. The damage from not having use of the property during the duration of the flood also resumes. The smaller flood on March 22nd causes more damage because more repair work has been accomplished in the seven preceding days. The flood that occurs in May does less damage than that in March because the property has not been restored to it's original value prior to the first flood event.

Public Facility Damages

Public facilities have a different damage pattern than the other kinds of property. The only duration effect is the one from lack of use of the facilities as estimated through PPDD. The damage to the physical facilities is assumed only sensitive to the depth of flooding. After the flood recedes, the rate of repair of the facilities is much faster than for other kinds of property (99% restored within 23 days). The second peak of March 11th causes major damages because of repair since the first flood peak. The repair factor (APD12) reduces at a rapid rate as shown in Figure 15. By March 22nd the facilities are almost totally repaired. By the time the May flood occurs, the facilities are in good repair, and the magnitude of the damages are the same as the March flood.

Aggregation of Damages Over the Flood Plain

Damages to property located in the flood plain at different depth zones are summed from spot patterns similar to those just illustrated. The irregularity in the damage patterns summed for the flood plain as a whole (Figure 16) is because of the various states of flooding at different elevations above the river bank. The aggregated damage curves rise and fall faster than the spot

For Zone 2-1

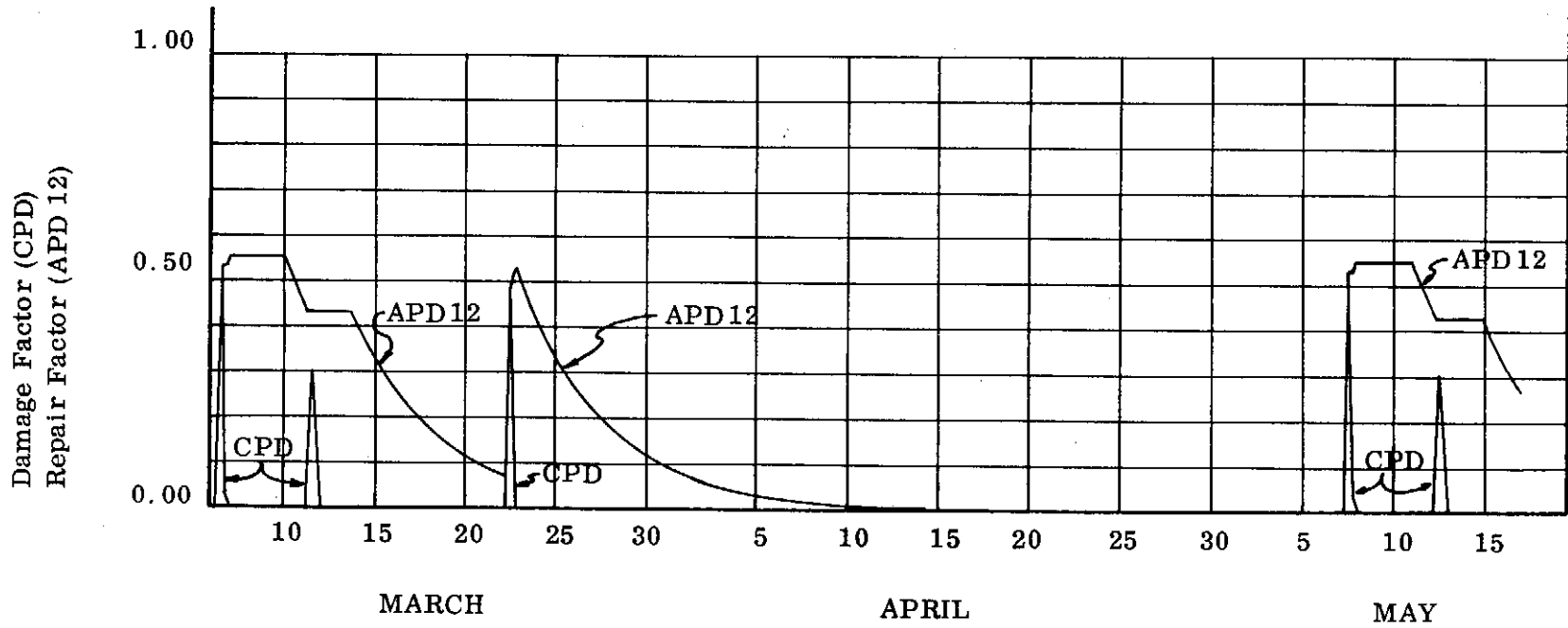


FIGURE 15 PUBLIC FACILITIES DAMAGE CURVE

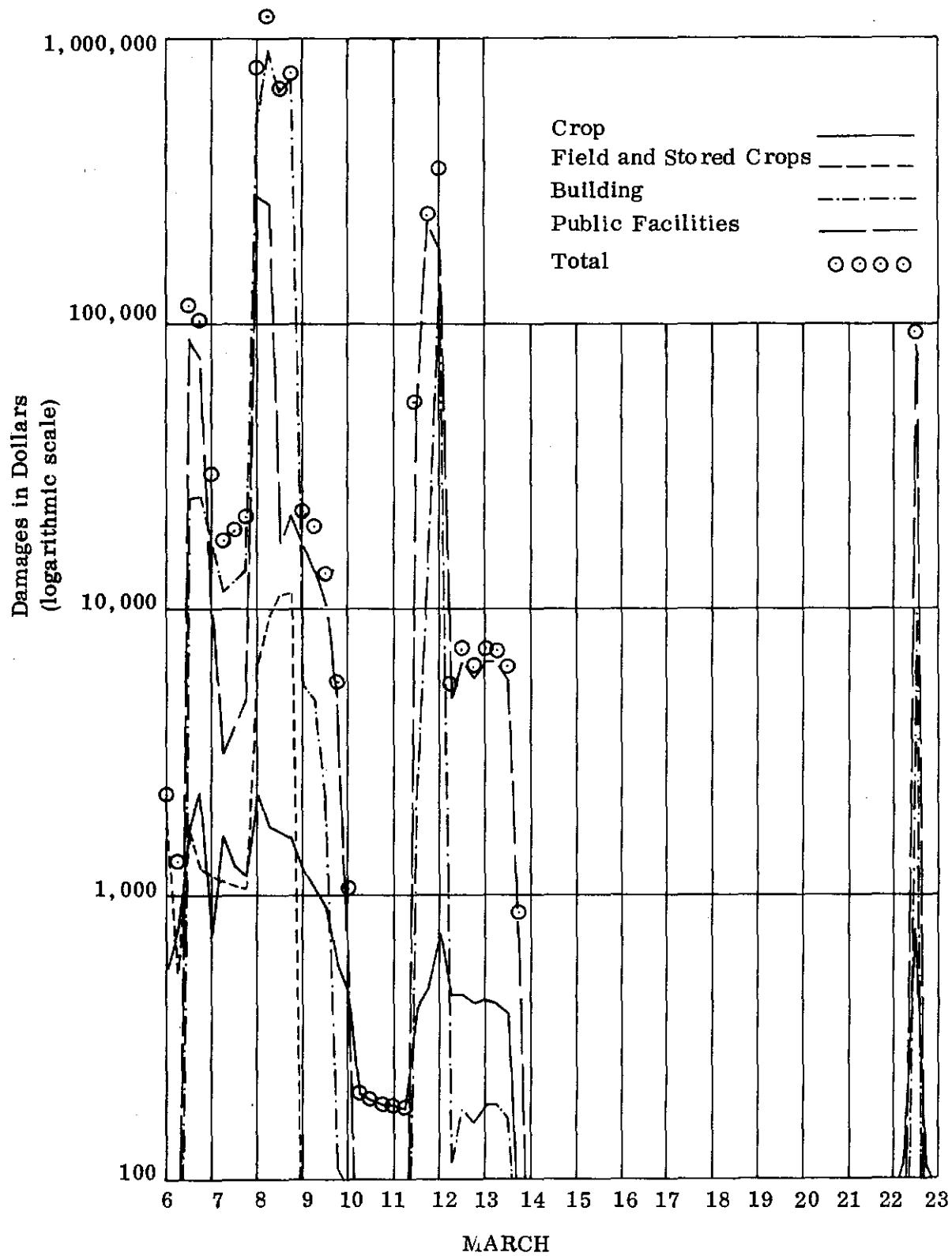


FIGURE 16 a AGGREGATION OF DAMAGES

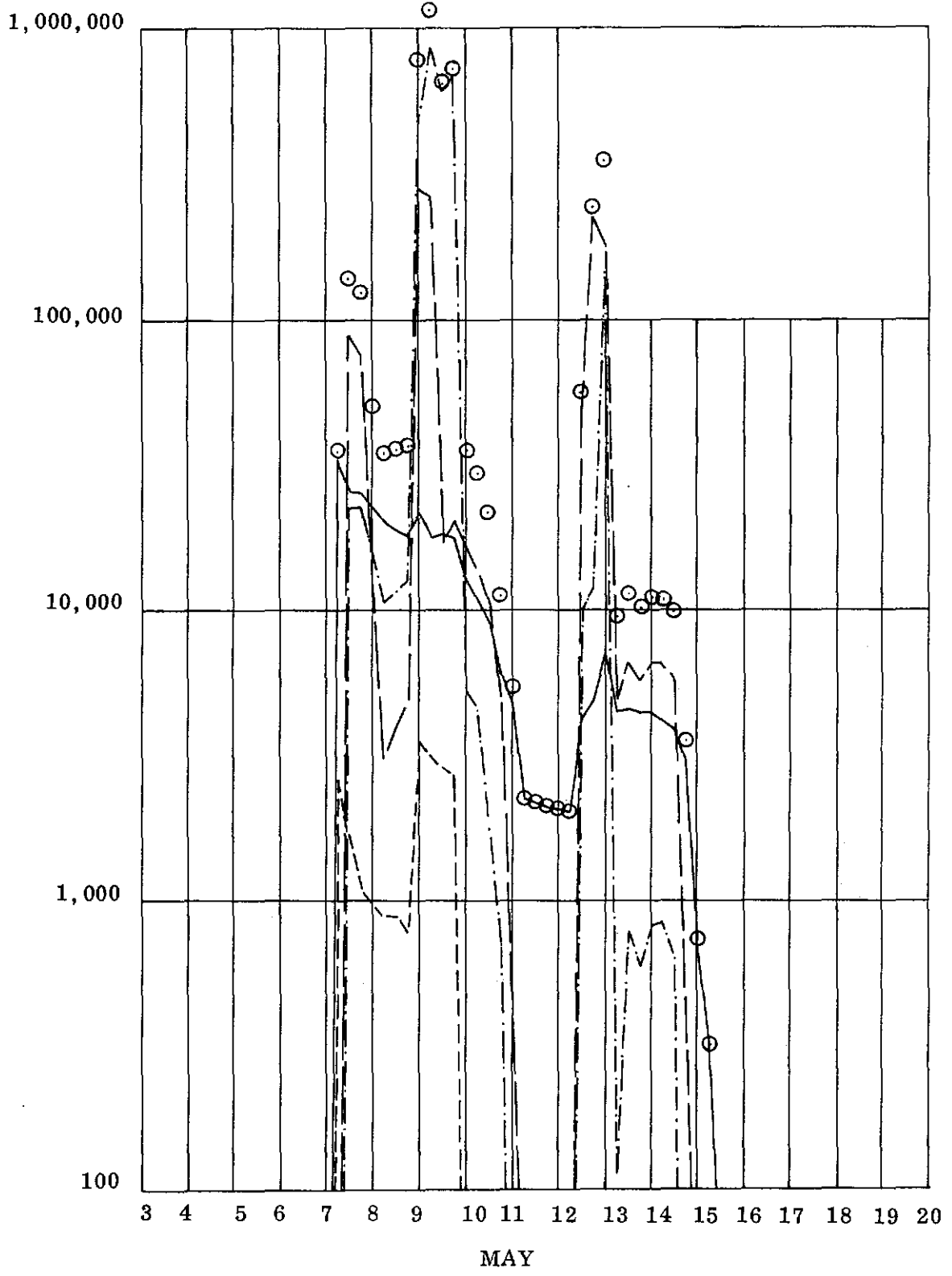


FIGURE 16 b AGGREGATION OF DAMAGES

curves because new areas are inundated and formerly flooded areas emerge from the water.

One important aspect of the program is shown clearly by comparing the results of the aggregate curves for the March and May floods. Both floods produced identical hydrographs, yet, the resulting damages are different.

Crop damage patterns differ from other damage patterns because of the growth of the crops. The March flood caught a young crop that was just planted and produced relatively little damage. Whereas the May storm caught the crops later in the growing season, produced much more damaged and delayed replanting at a time of the year when it is much more critical.

The field and stored crop damages follow a different pattern. The stored crops are wiped out during the first flood, and the second flood damages fields that are in the process of being repaired. The second flood produced much less damage than the first event.

Building damage patterns are very similar for both storms, but the magnitude of the damages differ. The buildings are not totally repaired by the time the second flood event occurs and consequently they suffer less damage.

Public damages are identical for the March and May floods because of more rapid repair. Public facilities repair was simulated over a total period of 23 days, and there were 45 flood-free days between storms.

THE ART OF FLOOD DAMAGE SIMULATION

There are many ways that flood damage simulation can be useful to the planner. The procedure used in applying DAMAGE to flood control reservoir operation is just one example. The application (7) varies operation policies for 15 reservoirs in the Muskingham River Basin to find the one minimizing damage. While flood flows stored in the reservoir reduce flood damage, the stored water must later be released to provide storage space for the next flood. This release can cause channels to flow bank-full for long periods of time. This long duration of bank-full flows has caused, in some

locations, agricultural land adjacent to the streams to be too wet to cultivate during critical spring planting seasons. If a storm occurs while the streams are flowing full, the added discharge from uncontrolled drainage areas cause additional flood damage. On the other side, slow releases may not empty the reservoir quickly enough to allow sufficient space for another major storm. Because damages are increased if release rates are either too large or too small, it is necessary to determine the marginal tradeoff of estimated damages. The best possible tool for doing this is the ability to estimate flood damages as they occur during a flood hydrograph produced by the reservoir releases and runoff from uncontrolled drainage areas.

Common practice in estimating average annual damages is to compute the frequency of the peak flows, then relate the flows to water depths and the depths to damage. It is apparent that frequency of flood damage does not necessarily correspond to frequency of flood peaks. Damages can occur more than once a year and the largest peak does not necessarily cause the greatest damage. It is more realistic to compute the damages directly as they occur in a given year and then compute the frequency of the damages rather than going through intermediate steps of computing the frequency of the flood peaks. In this manner the estimation of annual average flood damages for economic analysis can be obtained by running the entire period of hydrologic record. This is a very practical application of DAMAGE, and alternate schemes for flood control planning can be compared and analyzed. Hydrographs which may differ radically in shape as well as in peak can be developed for alternative flood control schemes and the scheme that produces the maximum damage reduction, net of the cost, can be selected.

The program can also be used to predict the damage as a flood occurs, or soon after it occurs, in the field. The flood plain data can be obtained and stored. As the storm develops in the upper portions of the watershed, flows can be routed downstream, and the damages can be predicted in the flood plain. This could be a useful tool for flood warning systems.

The damage estimates obtained from the program are only as good as the degree to which the input data represent field conditions. Judgment must be made as to the accuracy desired, and the accuracy obtainable is determined in part by the funds available for the study.

An important step in obtaining data is to delineate carefully land uses by reaches and zones. The value of the property within each zone can then be estimated. Expected future changes can be introduced by changing the input values to reflect projected conditions. Land use zoning policy can be taken into consideration by adjusting the input data accordingly. Data may need to be updated periodically to reflect changes in flood plain conditions or new information of a more general nature.

As a planning tool, DAMAGE needs to be adjusted and upgraded as new information is uncovered. The program can be adjusted externally or internally. The external method is to make trial runs trying to match a given set of recorded damages for historical floods in the flood plain under investigation. Adjustment of input data by trial and error may be achieved by changing the damage factors (UDPF, UDRF, UDDI, etc.), damage multipliers (UPDD, UIDF), etc.), or the property values. This last adjustment is accomplished by multiplying the initial market values (MV) by the ratio of the known flood plain damages (FD) to the damages computed by a trial run of the program (CD), $(MV * FD/CD)$.

Changes may be necessary to internal parameters (these incorporated in the Fortran programming) to reflect conditions that are unique to the area. One example may be in the rate of repair (DMGE0265 or DMGE0278). Heavy industrial or commercial areas may have a different rate of repair than a flood plain that is predominantly residential.

RESEARCH NEEDS

Much of the input data is derived from direct observation of physical conditions in the flood plain being studied. The primary research need with

respect to these items is to devise more efficient procedures for assembling current information on land use, cropping patterns, soil characteristics, building construction, etc. All such information has a wide range of applications other than flood damage simulation. Centralized collection procedures would greatly reduce the duplication of effort among various users and make for better planning as fewer decisions would have to be made without such information being available.

Many of the remaining input parameters are factors expressing the degree to which specific property types are damaged by floods. These are based on the hypothesized model of equation 7 and listed in Table 4. More research is needed here to test, verify, or refine the hypothesized model and to gather better information on parameter values.

The crop damage parameters were derived from information obtained from the U.S. Department of Agriculture for widely grown crops. More research is needed to test the validity of equation 7 for estimating crop damage, to obtain better estimates of parameter values for widely grown crops, and to gather information on more kinds of crops. Field damage factors were also derived from USDA data. However, more research is necessary on the damage caused by stream bank erosion. Until this is done, the field damage factors for areas of extensive erosion must be estimated by trial-and-error matching of known experiences. The urban and public damage factors need to be thoroughly examined over a wide range of property characteristics under controlled conditions. They are the most critical factors because they have the greatest influence on the magnitude of the damages. The estimates used for the indirect damage factors and loss-of-use factors were developed from past studies (13, p. 17). However, more research along these lines is also needed.

The depth-damage-duration relationship (equation 7) was derived to fit depth-damage curves available from the Corps of Engineers (19) and

TABLE 4

DAMAGE PARAMETERS

	<u>Crop</u>	<u>Field</u>	<u>Urban</u>	<u>Public</u>
Indirect Damage Factor	CIDF	CIDF	UIDF	PIDF
Minimum Damage Factor	CBDM	FBDM	b	b
Depth Damage Factor	CDPF	FDPF	UDPF	PDPF
Duration Damage Factor	CDRF	FDRF	UDRF	b
Depth-Duration Damage Factor	CDDI	FDDI	UDDI	b
Maximum Damage Factor	CMDF	100.0	0.63	1.00
Loss of Use Factor	a	b	UPDD	PPDD

a- small amount added at DMGE0452. b- assumed to be negligible.

USDA (23) with assumptions as to the effect of duration (Crop-DMGE0385, 0387; Field-DMGE0462, 0463; Stored Crop-DMGE0480; Building - DMGE0489, 0491, 0492, 0493). A great deal of data is available on the relationship of depth to damage but not much is known about the effects of flood duration on property. The depth-damage relationship in the public facilities damage equation (DMGE0512, 0513) may need to be varied by specific kinds of facilities. Special flood damage estimation models may be required for facilities such as highway bridges and electric power relay stations.

Another area for research would be repair rates for specific kinds of property. The assumption was made that over a wide area the repair period would average out over similar kinds of property (Field rate - DMGE0248, 0249; Building rate - DMGE0267; Public rate - DMGE0280). This assumption would need to be verified.

The degree of accuracy provided by DAMAGE depends on the values used for the damage parameters (Table 4) and the thoroughness of gathering the field data. The degree of accuracy desired depends on the purpose for which the results are to be used. For studies comparing alternative schemes for flood control or for regulation of reservoir operations, the type of accuracy required relates to the ability to estimate damage differences from hydrograph shape differences. However, to use the program to determine average annual damages for project formulation and justification, the total magnitude of the damage is more important. The reliability of the data on flood plain conditions is very important to any method of determining damages but good flood plain survey techniques are available. The greater problem is in determining appropriate damage factors (what will happen to a given property when inundated); and DAMAGE, as does other methods for determining damage presently used in practice, suffers from a poor information base. It does, however, provide help in showing the factors for which further study is most needed.

SUMMARY

DAMAGE is a first attempt to simulate damage patterns with time during a flood or a series of floods. The program attempts to relate direct damage to harm caused to capital improvements and indirect damage to activities that occur during and after a flood. The high speed computer makes it possible to simulate the harm and the activities in the order in which they occur.

The program DAMAGE is not the last word in estimating flood damage, but perhaps it will stimulate an approach that is more sensitive to what actually happens during floods. Much can be done to improve damage simulation through refinement of concepts presented in this report. Further research is needed to understand what really happens during flood events. In the time being, DAMAGE can provide a quick and efficient method to estimate damage for comparing schemes of flood control measures and regulations.

APPENDIX A

APPENDIX A

LISTING OF SUBROUTINE DAMAGE

	SUBROUTINE DAMAGE(RDT,RIN,Q6HR,MONTH,DAY,KREACH,FDM6HR,LWRITE)	DMGE0001
C	TAKES A REPRESENTATIVE FLOW FOR A SIX-HOUR PERIOD ON SPECIFIED	DMGE0002
C	MONTH AND DAY OF THE YEAR IN A SPECIFIED CHANNEL REACH	DMGE0003
C	AND ESTIMATES THE DAMAGE CAUSED.	DMGE0004
C	RDT ENTERS TRUE WHEN DATA IS TO BE READ (THE FLOOD DAMAGE	DMGE0005
C	ESTIMATING FACTORS FOR THE REACH HAVE NOT YET BEEN ENTERED INTO	DMGE0006
C	THE PROGRAM).	DMGE0007
C	RIN ENTERS TRUE WHEN BEGINNING A NEW SEQUENCE (ALL FLOOD PLAIN	DMGE0008
C	PROPERTY HAS BEEN REPAIRED SINCE THE LAST FLOOD).	DMGE0009
C	LWRITE ENTERS TRUE WHEN DETAILED OUTPUT IS REQUESTED	DMGE0010
	LOGICAL RDT,RIN,LKFZ,LPK,LAPK,LBPK,LWRITE	DMGE0011
	INTEGER DAY	DMGE0012
	DIMENSION CBDM(10,12),CDPF(10,12),CDRF(12,12),CDDI(10,12),	DMGE0013
	1 CMDF(10,12),CPRICE(10),YIELD(10,3),CSTFZ(10,3,3),FLF(25),	DMGE0014
	2 QCAP(25),QZD(25,3),DZD(25,3),AZD(25,3),STZD(25,3,3),RKD1(25),	DMGE0015
	3 RKD2(25),RKD3(25),RKA1(25),RKA2(25),RKA3(25),FZA(3),FZD(3),	DMGE0016
	4 FZCD(3),FZFD(3),FZUD(3),FZPD(3),FZTD(3),DRHR(3),FFHR(3),	DMGE0017
	5 LMONTH(3),LFY(10,2),CDRHR(3),CCD(10),CDM(10),CD1(10),CD12(10),	DMGE0018
	6 CD2(10),CD23(10),CD3(10),CD3M(10),PFZD(3),PDRHR(3),PCDRHR(3),	DMGE0019
	7 CPDM(10,3),CDD(10),SCDA(25,3),SCDC(25,3),UZD(25,3),PZD(25,3),	DMGE0020
	8 APK(3),BPK(3),EXP1(25),EXP2(25),EXP3(25)	DMGE0021
C	ONLY READ DATA WHEN REQUESTED	DMGE0022
	IF (.NOT. RDT) GO TO 116	DMGE0023
C	READ NUMBER OF STREAM REACHES	DMGE0024
	CALL READ(NRCH)	DMGE0025
C	READ CROP DAMAGE DATA	DMGE0026
	CALL READ(CIDF)	DMGE0027
	CALL READ(NSTP)	DMGE0028
	CALL READ(NCRP)	DMGE0029
	DO 108 KCRP = 1,NCRP	DMGE0030

- 95 -

DO 100 KMO = 1,12	DMGE0031
100 CALL READ(CBDN(KCRP,KMO))	DMGE0032
DO 101 KMO = 1,12	DMGE0033
101 CALL READ(CDPF(KCRP,KMO))	DMGE0034
DO 102 KMO = 1,12	DMGE0035
102 CALL READ(CDRF(KCRP,KMO))	DMGE0036
DO 103 KMO = 1,12	DMGE0037
103 CALL READ(CDDI(KCRP,KMO))	DMGE0038
DO 104 KMO = 1,12	DMGE0039
104 CALL READ(CMDF(KCRP,KMO))	DMGE0040
105 CALL READ(CPRICE(KCRP))	DMGE0041
DO 106 KFY = 1,2	DMGE0042
106 CALL READ(LFY(KCRP,KFY))	DMGE0043
DO 107 KSTP = 1,NSTP	DMGE0044
107 CALL READ(YIELD(KCRP,KSTP))	DMGE0045
DO 108 KSTP = 1,NSTR	DMGE0046
DO 108 KFZ = 1,3	DMGE0047
108 CALL READ(CSTFZ(KCRP,KSTP,KFZ))	DMGE0048
DO 110 KRCH = 1,NRCH	DMGE0049
CALL READ(FLF(KRCH))	DMGE0050
C READ CHANNEL REACH DATA	DMGE0051
CALL READ(QCAP(KRCH))	DMGE0052
CALL READ(QZD(KRCH,1),QZD(KRCH,2),QZD(KRCH,3),	DMGE0053
1 DZD(KRCH,1),DZD(KRCH,2),DZD(KRCH,3),	DMGE0054
2 AZD(KRCH,1),AZD(KRCH,2),AZD(KRCH,3))	DMGE0055
DO 109 KSTP = 1,NSTP	DMGE0056
DO 109 KFZ = 1,3	DMGE0057
109 CALL READ(STZD(KRCH,KSTP,KFZ))	DMGE0058
110 CALL READ(EXP1(KRCH),EXP2(KRCH),EXP3(KRCH))	DMGE0059
C READ FIELD DAMAGE DATA AND SET FDDF	DMGE0060
CALL READ(FBDM,FDRF,FDPF,FDDI)	DMGE0061
IF(FDDI .NE. 0.0)FDDF = 0.5*FDRF/ABS(FDDI)	DMGE0062
IF(FDDI .EQ. 0.0) FDDF = 40.0	DMGE0063
C READ VALUE OF STORED CROPS - \$/ACRE BY ZONE ON DECEMBER 1	DMGE0064
DO 112 KRCH = 1,NRCH	DMGE0065
DO 111 KFZ = 1,3	DMGE0066

111 CALL READ(SCDA(KRCH,KFZ)) :	DMGE0067
SCDA(KRCH,1)=SCDA(KRCH,1)/AZD(KRCH,1)	DMGE0068
SCDA(KRCH,2) = SCDA(KRCH,2)/(AZD(KRCH,2)-AZD(KRCH,1))	DMGE0069
112 SCDA(KRCH,3) = SCDA(KRCH,3)/(AZD(KRCH,3)-AZD(KRCH,2))	DMGE0070
C READ URBAN DAMAGE DATA	DMGE0071
DO 113 KRCH = 1,NRCH	DMGE0072
DO 113 KFZ = 1,3	DMGE0073
113 CALL READ(UZD(KRCH,KFZ))	DMGE0074
CALL READ(UDPF,UDRF,UDDI,UPDD,UIDF)	DMGE0075
C READ PUBLIC FACILITY DAMAGE DATA	DMGE0076
DO 114 KRCH = 1,NRCH	DMGE0077
DO 114 KFZ = 1,3	DMGE0078
114 CALL READ(PZD(KRCH,KFZ))	DMGE0079
CALL READ(PDPF,PIDF,PPDD)	DMGE0080
C CALCULATE REACH CONSTANTS FOR ESTIMATING MAXIMUM DEPTH AND	DMGE0081
C AREA OF FLOODING.	DMGE0082
C RKD1-3 = MAXIMUM DEPTH/Q**EXP	DMGE0083
C RKA1-3 = ACRES FLOODED/MAXIMUM DEPTH	DMGE0084
DO 115 KRCH = 1,NRCH	DMGE0085
QEX = (QZD(KRCH,1)-QCAP(KRCH))	DMGE0086
RKD1(KRCH)=DZD(KRCH,1)/QEX**EXP1(KRCH)	DMGE0087
QEX = (QZD(KRCH,2)-QZD(KRCH,1))	DMGE0088
RKD2(KRCH)=(DZD(KRCH,2)-DZD(KRCH,1))/QEX**EXP2(KRCH)	DMGE0089
QEX = (QZD(KRCH,3)-QZD(KRCH,2))	DMGE0090
RKD3(KRCH)=(DZD(KRCH,3)-DZD(KRCH,2))/QEX**EXP3(KRCH)	DMGE0091
RKA1(KRCH)=AZD(KRCH,1)/DZD(KRCH,1)	DMGE0092
RKA2(KRCH)=(AZD(KRCH,2)-AZD(KRCH,1))/(DZD(KRCH,2)-DZD(KRCH,1))	DMGE0093
RKA3(KRCH)=(AZD(KRCH,3)-AZD(KRCH,2))/(DZD(KRCH,3)-DZD(KRCH,2))	DMGE0094
IF(LWRITE)	DMGE0095
1 WRITE(6,1) RKD1(KRCH),RKD2(KRCH),RKD3(KRCH),RKA1(KRCH),	DMGE0096
1 RKA2(KRCH),RKA3(KRCH)	DMGE0097
1 FORMAT(10X,'RKS=',3F10.7,3F10.4)	DMGE0098
115 CONTINUE	DMGE0099
116 CONTINUE	DMGE0100
C INITIALIZE DURATIONS FOR LONG TIME SINCE THE LAST FLOOD.	DMGE0101
IF(.NOT. RIN) GO TO 118	DMGE0102

DO 117 KLZ = 1.3
CDRHR(KLZ) = 0.0
DRHR(KLZ) = 0.0
FFHR(KLZ) = 500.0
PFZD(KLZ) = 0.0
PDRHR(KLZ) = 0.0
PCDRHR(KLZ) = 0.0
APK(KLZ) = 0.0

117 BPK(KLZ) = 0.0

C INITIALIZE FOR NO UNREPAIRED FLOOD DAMAGE OF ANY TYPE WITHIN
C WATERSHED.

AFDM = 0.0
AFD12 = 0.0
AFD23 = 0.0
BAFDM = 0.0
BAFD12 = 0.0
BAFD23 = 0.0
BAUDM = 0.0
BAUD12 = 0.0
BAUD23 = 0.0
BAPDM = 0.0
BAPD12 = 0.0
BAPD23 = 0.0
AUDM = 0.0
AUD12 = 0.0
AUD23 = 0.0
APDM = 0.0
APD12 = 0.0
APD23 = 0.0
TCD1MX = 0.0
TCD2MX = 0.0
TCD3MX = 0.0

118 CONTINUE

C INITIALIZE PEAK FLOW AT BENINNING OF STORED CROP SEASON.
IF(RIN .OR. (MONTH .EQ. 11 .AND. DAY .EQ. 1)) SPKDP = 0.0
IF(RIN .OR. (MONTH .EQ. 11 .AND. DAY .EQ. 1)) PRKDP = 0.0

DMGE0103
DMGE0104
DMGE0105
DMGE0106
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DMGE0114
DMGE0115
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DMGE0121
DMGE0122
DMGE0123
DMGE0124
DMGE0125
DMGE0126
DMGE0127
DMGE0128
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DMGE0130
DMGE0131
DMGE0132
DMGE0133
DMGE0134
DMGE0135
DMGE0136
DMGE0137
DMGE0138

	IF(MONTH .EQ. 12 .AND. DAY .EQ. 1) .OR. RIN) GO TO 119	DMGE0139
	GO TO 121	DMGE0140
C	FRACTION OF INITIALLY STORED CROPS REMAINING ON FLOOD PLAIN AS OF	DMGE0141
C	INITIALIZING DATE.	DMGE0142
	119 IF(.NOT. RIN) GO TO 120	DMGE0143
	IF(MONTH .LE. 11 .AND. MONTH .GE. 5) DTG = 0.0	DMGE0144
	IF(MONTH .EQ.4) DTG = 30 - DAY	DMGE0145
	IF(MONTH .EQ.3) DTG = 61 - DAY	DMGE0146
	IF(MONTH .EQ.2) DTG = 89 - DAY	DMGE0147
	IF(MONTH .EQ.1) DTG =120 - DAY	DMGE0148
	IF(MONTH .EQ.12)DTG =151 - DAY	DMGE0149
	FDTG = DTG/151.0	DMGE0150
C	INITIALIZING DATE VALUE OF STORED CROPS - \$/ACRE BY ZONE.	DMGE0151
	120 IF(MONTH .EQ. 12 .AND. DAY .EQ. 1) FDTG = 1.0	DMGE0152
	SCDC(KREACH,1)=FDTG*SCDA(KREACH,1)	DMGE0153
	SCDC(KREACH,2)=FDTG*SCDA(KREACH,2)	DMGE0154
	SCDC(KREACH,3)=FDTG*SCDA(KREACH,3)	DMGE0155
	121 IF(.NOT. (RIN .OR. (MONTH.EQ.1.AND. DAY.EQ.1))) GO TO 124	DMGE0156
C	INITIALIZES VARIABLES FOR STORING PASSED CROP DAMAGES (ASSUMES	DMGE0157
C	FLOODS OCCURRING BEFORE JANUARY 1 DO NOT DAMAGE CROPS DURING THE	DMGE0158
C	FOLLOWING YEAR).	DMGE0159
	DO 122 KCRP = 1,NCRP	DMGE0160
	CDM(KCRP) = 0.0	DMGE0161
	CD1(KCRP)=0.0	DMGE0162
	CD12(KCRP) = 0.0	DMGE0163
	CD2(KCRP) = 0.0	DMGE0164
	CD23(KCRP) = 0.0	DMGE0165
	CD3(KCRP) = 0.0	DMGE0166
	CD3M(KCRP) = 0.0	DMGE0167
	DO 122 KFZ = 1,3	DMGE0168
	122 CPDM(KCRP,KFZ) = 1.0	DMGE0169
	DO 123 KLZ = 1,3	DMGE0170
	123 LMONTH(KLZ) = MONTH	DMGE0171
	124 CONTINUE	DMGE0172
C	CALCULATE AREA (FZA(3)) AND MAXIMUM DEPTH (FZD(3)) OF FLOODING IN THE	DMGE0173
C	THREE ZONES	DMGE0174

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DO 125 KLZ = 1,3
FZA(KLZ) = 0.0
FZD(KLZ) = 0.0
C NO DAMAGES OF ANY KIND IF NO FLOODING
FZCD(KLZ) = 0.0
FZFD(KLZ) = 0.0
FZUD(KLZ) = 0.0
FZPD(KLZ) = 0.0
125 FZTD(KLZ) = 0.0
C CALCULATE OVBANK FLOW
QFED = Q6HR - QCAP(KREACH)
C NO FLOODING
IF(QFLD .LE. 0.0) GO TO 128
C DURATION OF FLOODING IN ZONE 1
DRHR(1) = DRHR(1) + 6.0
CDRHR(1) = CDRHR(1) + 6.0
FFHR(1) = 0.0
IF(Q6HR .GT. QZD(KREACH,1)) GO TO 126
C FLOODING CONFINED TO ZONE 1
FZD(1) = RKD1(KREACH)*QFLD**EXP1(KREACH)
FZA(1) = RKA1(KREACH)*FZD(1)
GO TO 128
C CALCULATE FLOOD FLOW INTO ZONE 2
126 QFLD = Q6HR - QZD(KREACH,1)
C DURATION OF FLOODING IN ZONE 2
DRHR(2) = DRHR(2) + 6.0
CDRHR(2) = CDRHR(2) + 6.0
FFHR(2) = 0.0
IF(Q6HR .GT. QZD(KREACH,2)) GO TO 127
C FLOODING IN ZONES 1 AND 2
FZD(2) = RKD2(KREACH)*QFLD**EXP2(KREACH)
FZA(2) = RKA2(KREACH)*FZD(2)
FZD(1) = FZD(2) + DZD(KREACH,1)
FZA(1) = AZD(KREACH,1)
GO TO 128
C FLOODING IN ALL THREE ZONES

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DMGEO175
DMGEO176
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DMGEO204
DMGEO205
DMGEO206
DMGEO207
DMGEO208
DMGEO209
DMGEO210

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C  CALCULATE FLOOD FLOW INTO ZONE 3
127 QFLD = Q6HR - QZD(KREACH,2)
C  DURATION OF FLOODING IN ZONE 3
   DRHR(3) = DRHR(3) + 6.0
   CDRHR(3) = CDRHR(3) + 6.0
   FFHR(3) = 0.0
   FZD(3) = RKD3(KREACH)*QFLD**EXP3(KREACH)
   FZA(3) = RKA3(KREACH)*FZD(3)
   FZD(2) = FZD(3) + DZD(KREACH,2) - DZD(KREACH,1)
   FZA(2) = AZD(KREACH,2) - AZD(KREACH,1)
   FZD(1) = FZD(3) + DZD(KREACH,2)
   FZA(1) = AZD(KREACH,1)
128 CONTINUE
   IF(FZD(1) .GT. 0.0 .AND. LWRITE)
1WRITE(6,2) FZD(1), FZD(2), FZD(3), FZA(1), FZA(2), FZA(3)
2  FORMAT(10X, 'FZS=', 6F10.4)
C  ADD SIX HOURS TO THE TIME SINCE THE LAST FLOOD IF NO FLOODING.
   IF(FZD(1) .LE. 0.0) FFHR(1) = FFHR(1) + 6.0
   IF(FZD(2) .LE. 0.0) FFHR(2) = FFHR(2) + 6.0
   IF(FZD(3) .LE. 0.0) FFHR(3) = FFHR(3) + 6.0
C  TEST WHETHER 15 DAYS HAVE PASSED SO RESTORING OF CROPS AND
C  FIELDS CAN START.
   IF(FFHR(1) .GT. 363.0) DRHR(1) = 0.0
   IF(FFHR(2) .GT. 363.0) DRHR(2) = 0.0
   IF(FFHR(3) .GT. 363.0) DRHR(3) = 0.0
   IF(FFHR(1) .GT. 363.0) APK(1) = 0.0
   IF(FFHR(2) .GT. 363.0) APK(2) = 0.0
   IF(FFHR(3) .GT. 363.0) APK(3) = 0.0
C  TEST WHETHER FLOOD HAS RECEDED SO REPAIR OF BUILDINGS AND ROADS
C  CAN BEGIN.
   IF(FFHR(1) .GT. 0.0) CDRHR(1) = 0.0
   IF(FFHR(2) .GT. 0.0) CDRHR(2) = 0.0
   IF(FFHR(3) .GT. 0.0) CDRHR(3) = 0.0
   IF(FFHR(1) .GT. 0.0) BPK(1) = 0.0
   IF(FFHR(2) .GT. 0.0) BPK(2) = 0.0
   IF(FFHR(3) .GT. 0.0) BPK(3) = 0.0

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DMGE0211
DMGE0212
DMGE0213
DMGE0214
DMGE0215
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DMGE0218
DMGE0219
DMGE0220
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DMGE0222
DMGE0223
DMGE0224
DMGE0225
DMGE0226
DMGE0227
DMGE0228
DMGE0229
DMGE0230
DMGE0231
DMGE0232
DMGE0233
DMGE0234
DMGE0235
DMGE0236
DMGE0237
DMGE0238
DMGE0239
DMGE0240
DMGE0241
DMGE0242
DMGE0243
DMGE0244
DMGE0245
DMGE0246

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C	FIELD DAMAGES REPAIRED AT RATE OF 80 CENTS PER ACRE PER DAY.	DMGEO247
	IF(DRHR(1) .EQ. 0.0) AFDM = AFDM - 0.2	DMGEO248
	IF(AFDM .LT. 0.0) AFDM = 0.0	DMGEO249
	IF(DRHR(2) .EQ. 0.0) AFD12= AFD12- 0.2	DMGEO250
	IF(AFD12 .LT. 0.0) AFD12 = 0.0	DMGEO251
	IF(DRHR(3) .EQ. 0.0) AFD23= AFD23- 0.2	DMGEO252
	IF(AFD23 .LT. 0.0) AFD23 = 0.0	DMGEO253
C	AFTER 15-FLOOD-FREE DAYS, RENEWED FLOODING IS CONSIDERED A NEW	DMGEO254
C	EVENT WHEN ESTIMATING CROP AND FIELD DAMAGES.	DMGEO255
	IF(DRHR(1) .LE. 6.0) BAFDM = AFDM	DMGEO256
	IF(DRHR(2) .LE. 6.0) BAFD12= AFD12	DMGEO257
	IF(DRHR(3) .LE. 6.0) BAFD23= AFD23	DMGEO258
	IF(DRHR(1) .EQ. 0.0) TCD1MX = 0.0	DMGEO259
	IF(DRHR(2) .EQ. 0.0) TCD2MX = 0.0	DMGEO260
	IF(DRHR(3) .EQ. 0.0) TCD3MX = 0.0	DMGEO261
	FRM = 1.0 - 0.01*BAFDM	DMGEO262
	FR12 = 1.0 - 0.01*BAFD12	DMGEO263
	FR23 = 1.0 - 0.01*BAFD23	DMGEO264
C	BUILDING DAMAGES REPAIRED AT A RATE OF 1.15 PERCENT PER SIX HOURS	DMGEO265
C	LEADING TO 99 PERCENT REPAIR AFTER 100 DAYS.	DMGEO266
	IF(CDRHR(1) .EQ.0.0) AUDM = AUDM *0.9885	DMGEO267
	IF(CDRHR(2) .EQ.0.0) AUD12= AUD12*0.9885	DMGEO268
	IF(CDRHR(3) .EQ.0.0) AUD23= AUD23*0.9885	DMGEO269
C	AS SOON AS FLOOD STAGE DROPS OUT OF ZONE, RENEWED FLOODING IS	DMGEO270
C	CONSIDERED A NEW EVENT.	DMGEO271
	IF(CDRHR(1) .LE.6.0) BAUDM = AUDM	DMGEO272
	IF(CDRHR(2) .LE.6.0) BAUD12 = AUD12	DMGEO273
	IF(CDRHR(3) .LE.6.0) BAUD23 = AUD23	DMGEO274
	UFM = (0.63 - BAUDM)/0.63	DMGEO275
	UF12 = (0.63 - BAUD12)/0.63	DMGEO276
	UF23 = (0.63 - BAUD23)/0.63	DMGEO277
C	PUBLIC FACILITY DAMAGES REPAIRED AT A RATE OF 50 PERCENT PER SIX	DMGEO278
C	HOURS LEADING TO 99 PERCENT REPAIR AFTER 23 DAYS.	DMGEO279
	IF(CDRHR(1) .EQ. 0.0) APDM = APDM *0.95	DMGEO280
	IF(CDRHR(2) .EQ. 0.0) APD12= APD12*0.95	DMGEO281
	IF(CDRHR(3) .EQ. 0.0) APD23= APD23*0.95	DMGEO282

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C AS SOON AS FLOOD STAGE DROPS OUT OF ZONE, RENEWED FLOODING IS
C CONSIDERED A NEW EVENT.
  IF(CDRHR(1) .LE. 6.0) BAPDM = APDM
  IF(CDRHR(2) .LE. 6.0) BAPD12 = APD12
  IF(CDRHR(3) .LE. 6.0) BAPD23 = APD23
  PFM = 1.0 - BAPDM
  PF12 = 1.0 - BAPD12
  PF23 = 1.0 - BAPD23
  IF(LWRITE)
  1WRITE(6,3) AFDM,AFD12,AFD23,AUDM,AUD12,AUD23,APDM,APD12,APD23
  3 FORMAT(5X,'AF-AU-AP',9F9.5)
  IF(LWRITE)
  1WRITE(6,4) BAFDM,BAFD12,BAFD23,BAUDM,BAUD12,BAUD23,BAPDM,
  1BAPD12,BAPD23
  4 FORMAT(5X,'BF-BU-BP',9F9.5)
  LAPK = .FALSE.
  LBPK = .FALSE.
  IF(FZD(1) .LE. 0.0) GO TO 173
C FLOOD DEPTHS AND DURATIONS
  KT2 = 1
  DEPTH = FZD(1)
  IF(DEPTH .GT. APK(1)) LAPK = .TRUE.
  IF(DEPTH .GT. BPK(1)) LBPK = .TRUE.
  A1 = APK(1)
  A2 = APK(1)
  B1 = BPK(1)
  B2 = BPK(1)
  PDEPTH = PFZD(1)
  DRTN = DRHR(1)
  PDRTN = PDRHR(1)
  LMN = LMONTH(1)
  PCDRTN = PCDRHR(1)
  CDRTN = CDRHR(1)
  KFZ = 1
  LKFZ = .TRUE.
  LPK = .FALSE.

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DMGE0283
DMGE0284
DMGE0285
DMGE0286
DMGE0287
DMGE0288
DMGE0289
DMGE0290
DMGE0291
DMGE0292
DMGE0293
DMGE0294
DMGE0295
DMGE0296
DMGE0297
DMGE0298
DMGE0299
DMGE0300
DMGE0301
DMGE0302
DMGE0303
DMGE0304
DMGE0305
DMGE0306
DMGE0307
DMGE0308
DMGE0309
DMGE0310
DMGE0311
DMGE0312
DMGE0313
DMGE0314
DMGE0315
DMGE0316
DMGE0317
DMGE0318

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```

C TEST FOR WHETHER CURRENT FLOOD FLOW IS LARGEST YET DURING CROP
C FLOOD EVENT.
  IF (DEPTH .LT. SPKDP) GO TO 129
  PPKDP = SPKDP
  SPKDP = DEPTH
  PKDP = DEPTH
  PKDIF = PKDP - PPKDP
  LPK = .TRUE.
129 FRTO = FRM
  PRTO = PFM
  URTO = UFM
  AUD = AUDM
  DO 130 KCRP = 1, NCRP
130 CDD(KCRP) = CDM(KCRP)
C BEGINNING OF LOOP FOR CALCULATING FLOOD DAMAGE IN SPECIFIED ZONES
131 CONTINUE
C SAVE SMALLER OF LARGEST DEPTH PREVIOUSLY EXPERIENCED DURING THE
C FLOOD EVENT AND CURRENT FLOOD DEPTH.
  ADEPTH = PDEPTH
  BDEPTH = PDEPTH
  IF(.NOT. LAPK) ADEPTH = DEPTH
  IF(.NOT. LBPK) BDEPTH = DEPTH
  ADP = (A1 + A2) / 2.0
  IF(LAPK .AND. ADP .GT. PDEPTH) ADEPTH = ADP
  BDP = (B1 + B2) / 2.0
  IF(LBPK .AND. BDP .GT. PDEPTH) BDEPTH = BDP
  IF(LWRITE)
    1WRITE(6,5)DEPTH,PDEPTH,ADEPTH,BDEPTH,DRTN,PDRTN,CDRTN,PCDRTN,
    1 LMN,FRTO,URTO,PRTO
5 FORMAT(5X,'FLOOD FACTORS',4F8.3,4F8.0,I3,3F8.5)
C IF CONSIDERING A DIFFERENT FLOOD ZONE, ESTIMATE AVERAGE YIELD
C AND VALUES OF CROPS GROWN IN THAT ZONE.
  IF (.NOT. LKFZ) GO TO 134
  DO 133 KCRP = 1, NCRP
  ZYLD = 0.0
  DO 132 KSTP = 1, NSTP

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DMGE0319
DMGE0320
DMGE0321
DMGE0322
DMGE0323
DMGE0324
DMGE0325
DMGE0326
DMGE0327
DMGE0328
DMGE0329
DMGE0330
DMGE0331
DMGE0332
DMGE0333
DMGE0334
DMGE0335
DMGE0336
DMGE0337
DMGE0338
DMGE0339
DMGE0340
DMGE0341
DMGE0342
DMGE0343
DMGE0344
DMGE0345
DMGE0346
DMGE0347
DMGE0348
DMGE0349
DMGE0350
DMGE0351
DMGE0352
DMGE0353
DMGE0354

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132 ZYLD=ZYLD+YIELD(KCRP,KSTP)*GSTFZ(KCRP,KSTP,KFZ)*STZD(KREACH,KSTP, DMGE0355
    1 KFZ) DMGE0356
133 CCD(KCRP) = CPRICE(KCRP)*ZYLD*FLF(KREACH) DMGE0357
C VALUE OF STORED CROPS DEPLETED BY USE DMGE0358
    SCDC(KREACH,KFZ)=SCDC(KREACH,KFZ)-SCDA(KREACH,KFZ)/604.0 DMGE0359
    IF(SCDC(KREACH,KFZ).LT.0.0) SCDC(KREACH,KFZ)=0.0 DMGE0360
C ZONE VALUES OF STORED CROPS, BUILDINGS, AND PUBLIC FACILITIES. DMGE0361
    SCP = SCDC(KREACH,KFZ) DMGE0362
    UDV = UZD(KREACH,KFZ) DMGE0363
    PDV = PZD(KREACH,KFZ) DMGE0364
134 CONTINUE DMGE0365
    TCDD = 0.0 DMGE0366
    IF(DEPTH.LT.PDEPTH) PDEPTH = DEPTH DMGE0367
C ESTIMATE CROP DAMAGES DMGE0368
    DO 147 KCRP = 1,NCRP DMGE0369
    PCDF = 0.0 DMGE0370
    LMO = MONTH DMGE0371
    NMO = MONTH + 1 DMGE0372
    IF(NMO.EQ. 13) NMO = 1 DMGE0373
    IF(DAY.GE. 16) GO TO 135 DMGE0374
    LMO = MONTH - 1 DMGE0375
    IF(LMO.EQ. 0) LMO = 12 DMGE0376
    NMO = MONTH DMGE0377
135 MO = LMO DMGE0378
    KT1 = 1 DMGE0379
C ESTIMATE THE DAMAGE WHICH WOULD BE CAUSED BY THE CURRENT FLOOD DMGE0380
C PEAK UNDER CROP CONDITIONS AT THE BEGINNING AND END OF THE DMGE0381
C CURRENT MONTH. DMGE0382
136 CPKDP = ADP DMGE0383
    IF(LAPK) CPKDP = DEPTH DMGE0384
    DRTM = CDRF(KCRP,MO) + CDDI(KCRP,MO)*CPKDP DMGE0385
    IF(DRTM.LT. 0.1) DRTM = 0.1 DMGE0386
    CDF = CBDM(KCRP,MO)*(1.0+CDPF(KCRP,MO)*DEPTH)*(1.0+DRTM*DRTN) DMGE0387
    IF(CDF.GT. CMDF(KCRP,MO)) CDF = CMDF(KCRP,MO) DMGE0388
    IF(KT1.EQ. 2) GO TO 137 DMGE0389
    CDF1 = CDF DMGE0390

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```

KT1 = 2
MO = NMO
GO TO 136
C INTERPOLATE FOR CURRENT DAY BETWEEN DAMAGES FOR CROPS AT THE
C BEGINNING AND END OF THE CURRENT MONTH.
137 CDF2 = CDF
FDAY = DAY + 15
IF(DAY .GT. 16) FDAY = DAY - 15
CDF = CDF1 + (CDF2-CDF1)*(FDAY/30.0)
IF(PDRTN .LE. 0.0) GO TO 140
MO = LMO
KT1 = 1
C ESTIMATE THE DAMAGE WHICH WOULD BE CAUSED BY THE PREVIOUS FLOOD
C PEAK UNDER CROP CONDITIONS AT THE BEGINNING AND END OF THE
C CURRENT MONTH.
138 IF(CPKDP .GT. ADP) CPKDP = ADP
DRTM = CDRF(KCRP,MO)+CDDI(KCRP,MO)*CPKDP
IF(DRTM .LT. 0.1) DRTM = 0.1
PCDF = CBDM(KCRP,MO)*(1.0+CDPF(KCRP,MO)*ADEPTH)*(1.0+DRTM*PDRTN)
IF(PCDF .GT. CMDF(KCRP,MO)) PCDF = CMDF(KCRP,MO)*PDRTN/DRTM
IF(KT1 .EQ. 2) GO TO 139
PCDF1 = PCDF
KT1 = 2
MO = NMO
GO TO 138
C INTERPOLATE FOR CURRENT DAY BETWEEN PREVIOUS DAMAGES FOR CROPS AT
C THE BEGINNING AND END OF THE CURRENT MONTH.
139 PCDF2 = PCDF
PCDF = PCDF1 + (PCDF2-PCDF1)*(FDAY/30.0)
C ESTIMATE CROP DAMAGE DURING 6-HOUR PERIOD AS TOTAL ACCUMULATED
C DAMAGE LESS PREVIOUS ACCUMULATED TOTAL.
140 CDF = CDF - PCDF
IF(LWRITE)
1WRITE(6,6)KCRP,CDF,PCDF,CDD(KCRP)
6 FORMAT(10X,'KCRP,CDF,PCDF,CDD',I2,3F8.4)
IF(CDF .GE. 0.0) GO TO 141

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DMGE0391
DMGE0392
DMGE0393
DMGE0394
DMGE0395
DMGE0396
DMGE0397
DMGE0398
DMGE0399
DMGE0400
DMGE0401
DMGE0402
DMGE0403
DMGE0404
DMGE0405
DMGE0406
DMGE0407
DMGE0408
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DMGE0419
DMGE0420
DMGE0421
DMGE0422
DMGE0423
DMGE0424
DMGE0425
DMGE0426

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CDF = 0.0
GO TO 143
C IF IT IS TOO LATE IN THE SEASON FOR REPLANTING, SAVE ACCUMULATED
C CROP DAMAGE SO THAT IT WILL NOT BE ESTIMATED AGAIN FOR A
C SUBSEQUENT FLOOD.
141 IF((MONTH.LT.LFY(KCRP,1) .OR. (MONTH.EQ.LFY(KCRP,1) .AND. DAY .LT.
1 LFY(KCRP,2))) .AND. (LFY(KCRP,1).LT. 8)) GO TO 143
IF(PORTN .GT. 0.0 .OR. KT2 .EQ. 4 .OR. KT2.EQ.7) GO TO 142
CPDM(KCRP,KFZ) = 1.0
IF(CMDF(KCRP,LMN) .GT. 0.0)
ICPDM(KCRP,KFZ)=1.-CDD(KCRP)/CMDF(KCRP,LMN)
IF(CPDM(KCRP,KFZ).LT.0.0) CPDM(KCRP,KFZ) = 0.0
IF(.NOT.(KT2.EQ.4.OR.KT2.EQ.7))CDD(KCRP)=CDD(KCRP)+CDF
142 CDF = CDF*CPDM(KCRP,KFZ)
GO TO 146
C ADD LOSS IN YIELD DAMAGE WHERE FLOODING DELAYS SPRING PLANTING.
143 MM = LFY(KCRP,1)
MD = LFY(KCRP,2)
IF(MD .GE. 15) GO TO 144
MD = MD + 15
MM = MM - 1
IF(MM .EQ. 0) MM = 12
GO TO 145
144 MD = MD - 15
145 IF((MONTH.LT.MM) .OR. (MONTH.EQ.MM .AND. DAY.LT.MD)) GO TO 146
CDF = CDF + 0.003
C SUM ALL CROP DAMAGES
146 TCDD = TCDD + CCD(KCRP)*CDF*GIDF
147 IF(LWRITE)
1WRITE(6,7)KCRP,CCD(KCRP),CDD(KCRP),CPDM(KCRP,KFZ),CDF
7 FORMAT(15X,I2,4F8.4)
C ESTIMATE FIELD DAMAGES
C COMPUTE CURRENT DAMAGES
CPKDP = ADP
IF(LAPK) CPKDP = DEPTH
DRTM = FORF*0.7**((CPKDP/FDDF))

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DMGE0427
DMGE0428
DMGE0429
DMGE0430
DMGE0431
DMGE0432
DMGE0433
DMGE0434
DMGE0435
DMGE0436
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DMGE0438
DMGE0439
DMGE0440
DMGE0441
DMGE0442
DMGE0443
DMGE0444
DMGE0445
DMGE0446
DMGE0447
DMGE0448
DMGE0449
DMGE0450
DMGE0451
DMGE0452
DMGE0453
DMGE0454
DMGE0455
DMGE0456
DMGE0457
DMGE0458
DMGE0459
DMGE0460
DMGE0461
DMGE0462

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      CFD = FBDM*(1.0+FDRF*DEPTH)*(1.0+DRTM*DRTN)
      IF(CFD .GT. 100.0) CFD = 100.0
C   COMPUTE PREVIOUS DAMAGES
      PCFD = 0.0
      IF(PDRTN .LE. 0.0) GO TO 148
      IF(CPKDP .GT. ADP) CPKDP = ADP
      DRTM = FDRF*0.7**(CPKDP/FDDF)
      PCFD = FBDM*(1.0+FDPF*ADEPTH)*(1.0+DRTM*PDRTN)
C   COMPUTE NET ADDITIONAL FIELD DAMAGE DURING PERIOD
148  CFD = (CFD - PCFD)*CIDF*FRTD
      IF(CFD .LT. 0.0) CFD = 0.0
C   ESTIMATE STORED CROP DAMAGE
      SCD = 0.0
      IF(MONTH .GE. 5 .AND. MONTH .LE. 11) GO TO 149
      IF (.NOT. LPK) GO TO 149
      IF(PPKDP .LT. 0.0) PPKDP = 0.0
      IF(PKDP .GT. 20.0) PKDP = 20.0
      SCD = SCP*(PKDP - PPKDP)*0.05*CIDF
      IF(SCD .LT. 0.0) SCD = 0.0
      IF(LWRITE)
1WRITE(6,8)SCD,SCP,PKDP,PPKDP
      8  FORMAT(10X,'STORED CROP VALUES',2F10.2,2F8.4)
C   ESTIMATE BUILDING DAMAGE
149  CUD = 0.0
      IF(AUD .GE. 0.63) GO TO 150
C   COMPUTE CURRENT DAMAGES
      DRTM = UDRF + UDDI*DEPTH
      IF(DRTM .LT. 0.0) DRTM = 0.0
      CUDI = UDPF*DEPTH*(1.0+DRTM*CDRTN)
      IF (UDPF*DEPTH .GT. 0.25) CUDI = (0.25 + 0.25 * UDPF *
1  (DEPTH - 0.25/ UDPF)) * (1.0 + DRTM * CDRTN)
      IF(CUDI.GT. 0.63) CUDI = 0.63
C   COMPUTE PREVIOUS DAMAGES
      DRTM = UDRF + UDDI*BDEPTH
      IF(DRTM .LT. 0.0) DRTM = 0.0
      PCUD = UDPF*BDEPTH*(1.0+DRTM*PCDRTN)

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DMGE0463
DMGE0464
DMGE0465
DMGE0466
DMGE0467
DMGE0468
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DMGE0470
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DMGE0475
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DMGE0481
DMGE0482
DMGE0483
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DMGE0486
DMGE0487
DMGE0488
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DMGE0490
DMGE0491
DMGE0492
DMGE0493
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DMGE0495
DMGE0496
DMGE0497
DMGE0498

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	IF (UDPF * BDEPTH .GT. 0.25) PCUD = (0.25 + 0.25 * UDPF * 1 (BDEPTH - 0.25 / UDPF)) * (1.0 + DRTM * PCDRTN)	DMGE0499
C	COMPUTE NET ADDITIONAL BUILDING DAMAGE DURING PERIOD	DMGE0500
	CUD = (CUDI - PCUD) * URTO	DMGE0501
	IF (CUD .LT. 0.0) CUD = 0.0	DMGE0502
150	UFD = CUD * UDV * UIDF	DMGE0503
C	ADD DAMAGES FROM LOSS OF OCCUPANCY	DMGE0504
	UFD = UFD + UPDD * CUDI * UDV / 80000.0	DMGE0505
	IF (LWRITE)	DMGE0506
	1WRITE (6,9) CUDI, PCUD, CUD, UDV	DMGE0507
	9 FORMAT (10X, 'BUILDING VALUES', 3F8.4, F10.0)	DMGE0508
C	ESTIMATE PUBLIC DAMAGE	DMGE0509
C	COMPUTE CURRENT DAMAGES	DMGE0510
	CPD1 = PDPF * DEPTH	DMGE0511
	IF (PDPF * DEPTH .GT. 0.5) CPD1 = 0.5 + 0.25 * PDPF * (DEPTH - 0.5 / PDPF)	DMGE0512
	IF (CPD1 .GT. 1.0) CPD1 = 1.0	DMGE0513
C	COMPUTE PREVIOUS DAMAGES	DMGE0514
	PCPD = PDPF * BDEPTH	DMGE0515
	IF (PDPF * BDEPTH .GT. 0.5) PCPD = 0.5 + 0.25 * PDPF * (BDEPTH - 0.5 / PDPF)	DMGE0516
C	COMPUTE NET ADDITIONAL PUBLIC FACILITY DAMAGE DURING PERIOD AND	DMGE0517
C	ADD DAMAGES FROM LOST OF FACILITY USE.	DMGE0518
	CPD = (CPD1 - PCPD) * PRTO	DMGE0519
	IF (CPD .LT. 0.0) CPD = 0.0	DMGE0520
	PFD = CPD * PDV * PIDF	DMGE0521
	PFD = PFD + PPDD * CPD1 * PDV * 0.25	DMGE0522
	IF (LWRITE)	DMGE0523
	1WRITE (6,10) CPD1, PCPD, CPD, PDV	DMGE0524
	10 FORMAT (10X, 'FACILITY VALUES', 3F8.4, F10.0)	DMGE0525
C	END OF LOOP FOR CALCULATING FLOOD DAMAGE IN SPECIFIED ZONES.	DMGE0526
	IF (KT2 .GT. 1) GO TO 153	DMGE0527
C	STORE DAMAGES AT STREAMBANK BY DAMAGE TYPE	DMGE0528
	DO 151 KCRP = 1, NCRP	DMGE0529
151	CDM (KCRP) = CDD (KCRP)	DMGE0530
	TCDM = TCDD	DMGE0531
	FDM = CFD	DMGE0532
	AFDM = AFDM + FDM / CIDF	DMGE0533
		DMGE0534

FDM = FDM + SCD
AUDM = AUDM + CUD
UDM = UFD
APDM = APDM + CPD
PDM = PFD

C FLOOD DEPTHS AND DURATIONS AT MIDDLE OF ZONE 1

KT2 = 2
DEPTH = 0.5*(FZD(1) + FZD(2))
PDEPTH = 0.5*(PFZD(1) + PFZD(2))
DRTN = 0.5*(DRHR(1) + DRHR(2))
PDRTN = 0.5*(PDRHR(1) + PDRHR(2))
CDRTN = 0.5*(CDRHR(1) + CDRHR(2))
PCDRTN = 0.5*(PCDRHR(1) + PCDRHR(2))
PRTO = 0.5*(PFM + PF12)
URTO = 0.5*(UFM + UF12)
FRTO = 0.5*(FRM + FR12)
AUD = 0.5*(AUDM + AUD12)
LKZ = .FALSE.

IF(LPK) PKDP = DEPTH - PKDIF

IF(LPK) PKDP = DEPTH

A2 = APK(2)

B2 = BPK(2)

DO 152 KCRP = 1, NCRP

152 CDD(KCRP) = CD1(KCRP)

GO TO 131

C RETURN TO LOOP TO CALCULATE FLOOD DAMAGES AT MIDDLE OF ZONE 1

153 CONTINUE

IF(KT2 .GT. 2) GO TO 156

C STORE DAMAGES AT MIDDLE OF ZONE 1 BY DAMAGE TYPE

DO 154 KCRP = 1, NCRP

154 CD1(KCRP) = CDD(KCRP)

TCO1 = TCDD

IF(LAPK .AND. FZD(2) .LE. 0.0 .AND. TCO1 .LT. TCO1MX) TCO1 = TCO1MX

IF(LAPK .AND. FZD(2) .LE. 0.0) TCO1MX = TCO1

FD1 = CFD + SCD

UD1 = UFD

DMGE0535
DMGE0536
DMGE0537
DMGE0538
DMGE0539
DMGE0540
DMGE0541
DMGE0542
DMGE0543
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DMGE0546
DMGE0547
DMGE0548
DMGE0549
DMGE0550
DMGE0551
DMGE0552
DMGE0553
DMGE0554
DMGE0555
DMGE0556
DMGE0557
DMGE0558
DMGE0559
DMGE0560
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DMGE0562
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DMGE0565
DMGE0566
DMGE0567
DMGE0568
DMGE0569
DMGE0570

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1  AZD(KREACH,1)
  FZTD(2) = FZCD(2) + FZFD(2) + FZUD(2) + FZPD(2)
C  NO ADDITIONAL DAMAGES IF FLOODING CONFINED TO ZONE 2
  IF(FZD(3) .LE. 0.0) GO TO 173
  KT2 = 7
  LKFZ = .TRUE.
  KFZ = 3
  IF(DEPTH .GT. APK(3)) LAPK = .TRUE.
  IF(DEPTH .GT. BPK(3)) LBPK = .TRUE.
  GO TO 131
C  RETURN TO LOOP TO CALCULATE FLOOD DAMAGES ABOVE BOUNDARY
C  BETWEEN ZONES 2-3
167 CONTINUE
  IF(KT2 .GT. 7) GO TO 171
  TCD23 = TCDD
  FD23 = CFD + SCD
  UD23 = UFD
C  FLOOD DEPTHS AND DURATIONS AT MIDDLE OF ZONE 3
  KT2 = 8
  DEPTH = 0.5*FZD(3)
  PDEPTH = 0.5*PFZD(3)
  DRTN = 0.5*DRHR(3)
  PDRFN = 0.5*PDRHR(3)
  CDRTN = 0.5*CDRHR(3)
  PCDRTN = 0.5*PCDRHR(3)
  IF(LBPK) GO TO 168
  PRTO = PF23
  URTO = UF23
  FRTO = FR23
  AUD = AUD23
  GO TO 169
168 PRTO = 0.5*(PF23+1.0)
  URTO = 0.5*(UF23+1.0)
  FRTO = 0.5*(FR23+1.0)
  AUD = 0.5*AUD23
169 LKFZ = .FALSE.

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DMGE0715
DMGE0716
DMGE0717
DMGE0718
DMGE0719
DMGE0720
DMGE0721
DMGE0722
DMGE0723
DMGE0724
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DMGE0736
DMGE0737
DMGE0738
DMGE0739
DMGE0740
DMGE0741
DMGE0742
DMGE0743
DMGE0744
DMGE0745
DMGE0746
DMGE0747
DMGE0748
DMGE0749
DMGE0750
DMGE0751

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IF(LPK) PPKDP = DEPTH - PKDIF
IF(LPK) PKDP = DEPTH
A2 = 0.0
B2 = 0.0
DO 170 KCRP = 1, NCRP
170 CDD(KCRP) = CD3M(KCRP)
GO TO 131
C RETURN TO LOOP TO CALCULATE FLOOD DAMAGES AT MIDDLE OF ZONE 3
171 CONTINUE
DO 172 KCRP = 1, NCRP
172 CD3M(KCRP) = COD(KCRP)
TCO3 = TCDD
IF(LAPK .AND. TCO3.LT.TCO3MX) TCO3=TCO3MX
IF(LAPK) TCO3MX=TCO3
FD3 = CFD + SCD
UD3 = UFD
PD3 = PFD
IF(LAPK) APK(3) = FZD(3)
IF(LBPK) BPK(3) = FZD(3)
C TOTAL DAMAGES IN ZONE 3
FZCD(3) = FZA(3) * (TCO23 + 4.0*TCO3)/6.0
FZFD(3) = FZA(3) * (FD23 + 4.0*FD3)/6.0
FZUD(3) = ((UD23+4.0*UD3)/6.0)*FZA(3)/(AZD(KREACH,3)-AZD(KREACH,
1 2))
FZPD(3) = ((PD23+4.0*PD3)/6.0)*FZA(3)/(AZD(KREACH,3)-AZD(KREACH,
1 2))
FZTD(3) = FZCD(3) + FZFD(3) + FZUD(3) + FZPD(3)
173 CONTINUE
C VALUES FOR CURRENT PERIOD BECOME PREVIOUS VALUES FOR NEXT PERIOD
DO 174 KLZ = 1,3
PFZD(KLZ) = FZD(KLZ)
PDRHR(KLZ) = DRHR(KLZ)
PCDRHR(KLZ) = CORHR(KLZ)
IF(DRHR(KLZ) .EQ. 6.0) LMONTH(KLZ) = MONTH
174 CONTINUE
C TOTAL FLOOD DAMAGES OVER ALL ZONES

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DMGE0752
DMGE0753
DMGE0754
DMGE0755
DMGE0756
DMGE0757
DMGE0758
DMGE0759
DMGE0760
DMGE0761
DMGE0762
DMGE0763
DMGE0764
DMGE0765
DMGE0766
DMGE0767
DMGE0768
DMGE0769
DMGE0770
DMGE0771
DMGE0772
DMGE0773
DMGE0774
DMGE0775
DMGE0776
DMGE0777
DMGE0778
DMGE0779
DMGE0780
DMGE0781
DMGE0782
DMGE0783
DMGE0784
DMGE0785
DMGE0786
DMGE0787

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IF(LWRITE)	DMGE0788
1WRITE(6,3)AFDM,AFD12,AFD23,AUDM,AUD12,AUD23,APDM,APD12,APD23	DMGE0789
TC = 0.0	DMGE0790
TF = 0.0	DMGE0791
TU = 0.0	DMGE0792
TP = 0.0	DMGE0793
TT = 0.0	DMGE0794
DO 175 KFZ = 1,3	DMGE0795
IF(LWRITE)	DMGE0796
1WRITE(6,11) KFZ,FZCD(KFZ),FZFD(KFZ),FZUD(KFZ),FZPD(KFZ),FZTD(KFZ)	DMGE0797
11 FORMAT(5X,'ZONE',I2,' DAMAGES: CROP =',F9.0,' FIELD =',F9.0,	DMGE0798
1 ' BUILDING =',F9.0,' PUBLIC =',F9.0,' TOTAL =',F9.0)	DMGE0799
TC = TC + FZCD(KFZ)	DMGE0800
TF = TF + FZFD(KFZ)	DMGE0801
TU = TU + FZUD(KFZ)	DMGE0802
TP = TP + FZPD(KFZ)	DMGE0803
175 TT = TT + FZTD(KFZ)	DMGE0804
IF(LWRITE)	DMGE0805
1WRITE(6,12) TC,TF,TU,TP,TT	DMGE0806
12 FORMAT(6X,'TOTAL DAMAGES: CROP =',F9.0,' FIELD =',F9.0,	DMGE0807
1 ' BUILDING =',F9.0,' PUBLIC =',F9.0,' TOTAL =',F9.0)	DMGE0808
FDM6HR = TT	DMGE0809
RETURN	DMGE0810
END	DMGE0811

APPENDIX B

APPENDIX B

DATA FOR SUBROUTINE DAMAGE

13 * NUMBER OF STREAM REACHES (CONTROL POINTS)

* CROP DAMAGE DATA

1.10 * CROP INDIRECT DAMAGE MULTIPLIER

3 * NUMBER OF SOIL TYPES, MAXIMUM OF 3

6 * NUMBER OF CROPS, MAXIMUM OF 10

* CORN

*JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
0.0	0.0	0.0	.0067	.0622	.2230	.1120	.0356	.0085	.0047	0.0040	0.0	* CBDM
0.0	0.0	0.0	0.0	.1300	.2200	.7900	1.0600	2.3300	3.0000	1.0000	0.0	* CDPF
0.0	0.0	0.0	.0420	.0130	.0090	.0080	.0170	.0220	.0180	.0140	0.0	* CDRF
0.0	0.0	0.0	0.0	-.0015	-.0035	-.0040	-.0095	-.0170	-.0120	.0070	0.0	* CDDI
0.0	0.0	0.0	.0223	.2023	.5759	.6977	.6977	.6629	.4535	.0872	0.0	* CMDF

1.01 * CROP UNIT PRICE

5 * LAST MONTH FOR PLANTING WITH FULL YIELD

15 * DAY OF THAT MONTH

110.	80.	60.		* YIELD BY SOIL TYPE - (B, M, W)
.6894		.7656	.8417	* USE FRACTION, SOIL TYPE 1
.3807		.4230	.4653	* USE FRACTION, SOIL TYPE 2
.1184		.1311	.1438	* USE FRACTION, SOIL TYPE 3

* WINTER WHEAT

*JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0.0	0.0	.0241	.2250	.2700	.3710	.1680	.0415	.0264	.0295	.0241	0.0
0.0	0.0	.1900	.2500	.2800	.2400	.3500	.4200	.4000	.4200	.3000	0.0
0.0	0.0	.1100	.0080	.0110	.0070	.0060	.0060	.0280	.0380	.0470	0.0
0.0	0.0	.0395	-.0025	.0020	-.0015	-.0050	-.0065	.0015	-.0020	.0025	0.0
.4215	.4215	.6099	.8458	.8809	.6675	.4524	.2545	.1055	.2940	.4215	.4215

1.24 * CROP UNIT PRICE

10 * LAST MONTH FOR PLANTING WITH FULL YIELD

15 * DAY OF THAT MONTH

50.	35.	20.		* YIELD BY SOIL TYPE - (B, M, W)
-----	-----	-----	--	----------------------------------

.0923 .1026 .1129 * USE FRACTIONS, ST1, ZONES 1-3
 .1154 .1283 .1411 * USE FRACTIONS, ST2, ZONES 1-3
 .0230 .0256 .0282 * USE FRACTIONS, ST3, ZONES 1-3

* OATS

*JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
0.0	0.0	0.0	.1846	.0720	.2920	.1720	0.0	0.0	0.0	0.0	0.0	* CBDM
0.0	0.0	0.0	.3000	.2200	.2300	.2600	0.0	0.0	0.0	0.0	0.0	* CDPF
0.0	0.0	0.0	.0100	.0030	.0020	.0010	0.0	0.0	0.0	0.0	0.0	* CDRF
0.0	0.0	0.0	-.0065	-.0010	-.0040	-.0045	0.0	0.0	0.0	0.0	0.0	* CDDI
0.0	0.0	.3128	.9422	.2680	.6883	.4508	0.0	0.0	0.0	0.0	0.0	* CMDF
0.63 * CROP UNIT PRICE												
3 * LAST MONTH FOR PLANTING WITH FULL YIELD												
31 * DAY OF THAT MONTH												

75. 55. 40. * YIELD BY SOIL TYPE - (B, M, W)

.0507 .0564 0.0620 * USE FRACTIONS, ST1, ZONES 1-3
 .0634 .0705 .0775 * USE FRACTIONS, ST2, ZONES 1-3
 .0126 .0141 .0155 * USE FRACTIONS, ST3, ZONES 1-3

* SOYBEANS

*JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
0.0	0.0	0.0	.0123	.0730	.4020	.5860	.4450	.1610	.0720	0.0	0.0	* CBDM
0.0	0.0	0.0	0.0	.2500	.2100	.1700	.2500	.5800	.3300	0.0	0.0	* CDPF
0.0	0.0	0.0	.0420	.0110	.0020	.0005	.0030	.0100	.0060	0.0	0.0	* CDRF
0.0	0.0	0.0	.0105	.0030	-.0065	-.0073	-.0070	-.0080	-.0110	0.0	0.0	* CDDI
0.0	0.0	0.0	.0359	.2375	.6783	.8656	.8656	.7141	.1731	0.0	0.0	* CMDF
2.47 * CROP UNIT PRICE												
5 * LAST MONTH FOR PLANTING WITH FULL YIELD												
31 * DAY OF THAT MONTH												

35. 25. 20. * YIELD BY SOIL TYPE - (B, M, W)

.0372 .0414 .0455 * USE FRACTIONS, ST1, ZONES 1-3
 .0248 .0276 .0303 * USE FRACTIONS, ST2, ZONES 1-3
 0.0 0.0 0.0 * USE FRACTIONS, ST3, ZONES 1-3

* HAY

*JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
0.0	0.0	0.0	.0313	.1560	.1660	.1240	.0620	.0142	0.0	0.0	0.0	* CBDM
0.0	0.0	0.0	.3000	.1000	.2000	.2000	.1900	.2500	0.0	0.0	0.0	* CDPF
0.0	0.0	0.0	.0210	.0120	.0060	.0080	.0080	.0140	0.0	0.0	0.0	* CDRF

0.0	0.0	0.0	-.0021	.0020	-.0010	.0010	-.0010	-.0035	0.0	0.0	0.0	* CDDI
0.0	0.0	0.0	.4634	.4403	.3359	.2548	.1391	.0232	0.0	0.0	0.0	* CMDF
24.2	* CROP UNIT PRICE											
3	* LAST MONTH FOR PLANTING WITH FULL YIELD											
31	* DAY OF THAT MONTH											
4.0	3.0	2.0	* YIELD BY SOIL TYPE - (B, M, W)									
.1802	.1802	.1802	* USE FRACTIONS, ST1, ZONES 1-3									
.2467	.2467	.2467	* USE FRACTIONS, ST2, ZONES 1-3									
.0474	.0474	.0474	* USE FRACTIONS, ST3, ZONES 1-3									
* PASTURE												
*JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
0.0	0.0	0.0	.0056	.0645	.0901	.0382	.0165	.0357	.0133	0.0	0.0	* CBDM
0.0	0.0	0.0	3.0000	.2500	.1700	.2500	.5000	.2000	.5000	0.0	0.0	* CDPF
0.0	0.0	0.0	.0150	.0190	.0100	.0190	.0210	.0120	0.0	0.0	0.0	* CDRF
0.0	0.0	0.0	-.0240	.0010	.0015	.0025	-.0035	.0020	0.0	0.0	0.0	* CDDI
0.0	0.0	0.0	.9001	.7250	.4500	.3650	.3150	.2251	.0750	0.0	0.0	* CMDF
14.18	* CROP UNIT PRICE											
3	* LAST MONTH FOR PLANTING WITH FULL YIELD											
31	* DAY OF THAT MONTH											
4.0	2.5	1.0	* YIELD BY SOIL TYPE - (B, M, W)									
.0430	.0430	.0430	* USE FRACTIONS, ST1, ZONES 1-3									
.0589	.0589	.0589	* USE FRACTIONS, ST2, ZONES 1-3									
.0113	.0113	.0113	* USE FRACTIONS, ST3, ZONES 1-3									
* REACH WC-1												
.2778	* FRACTION OF LAND FARMED - FLF											
11000.	* CHANNEL CAPACITY											
* FOR BOUNDARIES BETWEEN ZONES 1 AND 2, 2 AND 3 AND A VERY LARGE FLOOD												
30000.	54000.	100000.	* TOTAL STREAM FLOW									
12.0	20.0	31.0	* DEPTH OF WATER ABOVE FLOOD STAGE									
151.	298.	540.	* TOTAL AREA FLOODED									
* DISTRIBUTION OF FLOOD ZONE LAND BY SOIL TYPE												
*	ZONE 1	ZONE 2	ZONE 3									
.8476	.2993	0.0	* SOIL TYPE 1									
.1523	.7006	1.0	* SOIL TYPE 2									
0.0	0.0	0.0	* SOIL TYPE 3									
.8013	.8720	.8230	* REACH FLOW EXPONENTS									

* REACH WR-2
 .7774 * FRACTION OF LAND FARMED - FLF
 10200. * CHANNEL CAPACITY
 * FOR BOUNDARIES BETWEEN ZONES 1 AND 2, 2 AND 3 AND A VERY LARGE FLOOD
 14500. 40000. 250000. * TOTAL STREAM FLOW
 2.0 9.0 16.9 * DEPTH OF WATER ABOVE FLOOD STAGE
 700. 2020. 2915. * TOTAL AREA FLOODED
 * DISTRIBUTION OF FLOOD ZONE LAND BY SOIL TYPE
 * ZONE 1 ZONE 2 ZONE 3
 .6000 .3000 0.0 * SOIL TYPE 1
 .4 .7 1.0 * SOIL TYPE 2
 0.0 0.0 0.0 * SOIL TYPE 3
 .9999 .6307 .4565 * REACH FLOW EXPONENTS
 * REACH S-1
 .4138 * FRACTION OF LAND FARMED - FLF
 1000. * CHANNEL CAPACITY
 * FOR BOUNDARIES BETWEEN ZONES 1 AND 2, 2 AND 3 AND A VERY LARGE FLOOD
 2200. 20000. 150000. * TOTAL STREAM FLOW
 1.2 6.0 13.0 * DEPTH OF WATER ABOVE FLOOD STAGE
 1110. 1940. 3492. * TOTAL AREA FLOODED
 * DISTRIBUTION OF FLOOD ZONE LAND BY SOIL TYPE
 * ZONE 1 ZONE 2 ZONE 3
 .6 .2 0.0 * SOIL TYPE 1
 .4 .7 1.0 * SOIL TYPE 2
 0.0 .100 0.0 * SOIL TYPE 3
 .6479 .5417 .5857 * REACH FLOW EXPONENTS
 * REACH TR-2
 .7098 * FRACTION OF LAND FARMED - FLF
 10300. * CHANNEL CAPACITY
 * FOR BOUNDARIES BETWEEN ZONES 1 AND 2, 2 AND 3 AND A VERY LARGE FLOOD
 15000. 24000. 68000. * TOTAL STREAM FLOW
 2.0 5.5 15.0 * DEPTH OF WATER ABOVE FLOOD STAGE
 1610. 3380. 5010. * TOTAL AREA FLOODED
 * DISTRIBUTION OF FLOOD ZONE LAND BY SOIL TYPE
 * ZONE 1 ZONE 2 ZONE 3
 .5000 .20000 0.0 * SOIL TYPE 1

.5	.7	1.0	* SOIL TYPE 2
0.0	.100	0.0	* SOIL TYPE 3
.9130	.9523	.6914	* REACH FLOW EXPONENTS
	* REACH SC-2		
.3381	* FRACTION OF LAND FARMED - FLF		
960.	* CHANNEL CAPACITY		
	* FOR BOUNDARIES BETWEEN ZONES 1 AND 2, 2 AND 3 AND A VERY LARGE FLOOD		
2750.	6000.	60000.	* TOTAL STREAM FLOW
5.5	9.5	19.0	* DEPTH OF WATER ABOVE FLOOD STAGE
700.	1540.	2109.	* TOTAL AREA FLOODED
	* DISTRIBUTION OF FLOOD ZONE LAND BY SOIL TYPE		
	ZONE 1	ZONE 2	ZONE 3
.50000	0.0	0.0	* SOIL TYPE 1
.5	1.0	1.0	* SOIL TYPE 2
0.0	0.0	0.0	* SOIL TYPE 3
.4776	.8588	.4150	* REACH FLOW EXPONENTS
	* REACH SC-1		
.5987	* FRACTION OF LAND FARMED - FLF		
3100.	* CHANNEL CAPACITY		
	* FOR BOUNDARIES BETWEEN ZONES 1 AND 2, 2 AND 3 AND A VERY LARGE FLOOD		
6200.	10500.	225000.	* TOTAL STREAM FLOW
5.6	11.0	21.6	* DEPTH OF WATER ABOVE FLOOD STAGE
2050.	4000.	6337.	* TOTAL AREA FLOODED
	* DISTRIBUTION OF FLOOD ZONE LAND BY SOIL TYPE		
	ZONE 1	ZONE 2	ZONE 3
.5	0.0	0.0	* SOIL TYPE 1
.5	1.0	1.0	* SOIL TYPE 2
0.0	0.0	0.0	* SOIL TYPE 3
.9100	.8203	.8871	* REACH FLOW EXPONENTS
	* REACH TR-1		
.8082	* FRACTION OF LAND FARMED - FLF		
12200.	* CHANNEL CAPACITY		
	* FOR BOUNDARIES BETWEEN ZONES 1 AND 2, 2 AND 3 AND A VERY LARGE FLOOD		
23500.	80000.	180000.	* TOTAL STREAM FLOW
3.5	10.5	18.5	* DEPTH OF WATER ABOVE FLOOD STAGE
4800.	13200.	17950.	* TOTAL AREA FLOODED

* DISTRIBUTION OF FLOOD ZONE LAND BY SOIL TYPE

	ZONE 1	ZONE 2	ZONE 3	
.5000	.2000	0.0		* SOIL TYPE 1
.5	.7	1.0		* SOIL TYPE 2
0.0	.100	0.0		* SOIL TYPE 3
.7366	.7576	.7862		* REACH FLOW EXPONENTS

* REACH MR-1

.7515 * FRACTION OF LAND FARMED - FLF

3500. * CHANNEL CAPACITY

* FOR BOUNDARIES BETWEEN ZONES 1 AND 2, 2 AND 3 AND A VERY LARGE FLOOD

11000.	35000.	310000.		* TOTAL STREAM FLOW
5.0	12.0	23.0		* DEPTH OF WATER ABOVE FLOOD STAGE
900.	1640.	2286.		* TOTAL AREA FLOODED

* DISTRIBUTION OF FLOOD ZONE LAND BY SOIL TYPE

	ZONE 1	ZONE 2	ZONE 3	
.6000	.2000	0.0		* SOIL TYPE 1
.4	.8	1.0		* SOIL TYPE 2
0.0	0.0	0.0		* SOIL TYPE 3
.8340	.7067	.3472		* REACH FLOW EXPONENTS

* REACH MR-6

.5932 * FRACTION OF LAND FARMED - FLF

28000. * CHANNEL CAPACITY

* FOR BOUNDARIES BETWEEN ZONES 1 AND 2, 2 AND 3 AND A VERY LARGE FLOOD

60000.	100000.	250000.		* TOTAL STREAM FLOW
7.0	11.8	20.0		* DEPTH OF WATER ABOVE FLOOD STAGE
1760.	2775.	4449.		* TOTAL AREA FLOODED

* DISTRIBUTION OF FLOOD ZONE LAND BY SOIL TYPE

	ZONE 1	ZONE 2	ZONE 3	
.6000	.5004	.2998		* SOIL TYPE 1
.4	.4995	.7001		* SOIL TYPE 2
0.0	0.0	0.0		* SOIL TYPE 3
.8048	.6755	.9419		* REACH FLOW EXPONENTS

* REACH MR-5

.6513 * FRACTION OF LAND FARMED - FLF

13500. * CHANNEL CAPACITY

* FOR BOUNDARIES BETWEEN ZONES 1 AND 2, 2 AND 3 AND A VERY LARGE FLOOD

41000.	130000.	270000.	* TOTAL STREAM FLOW
9.0	23.0	37.0	* DEPTH OF WATER ABOVE FLOOD STAGE
3450.	5370.	6114.	* TOTAL AREA FLOODED
* DISTRIBUTION OF FLOOD ZONE LAND BY SOIL TYPE			
* ZONE 1 ZONE 2 ZONE 3			
.6000	.5000	.4005	* SOIL TYPE 1
.4	.5	.5994	* SOIL TYPE 2
0.0	0.0	0.0	* SOIL TYPE 3
.8591	.7543	.8181	* REACH FLOW EXPONENTS
* REACH MR-4			
.3895	* FRACTION OF LAND FARMED - FLF		
45000.	* CHANNEL CAPACITY		
* FOR BOUNDARIES BETWEEN ZONES 1 AND 2, 2 AND 3 AND A VERY LARGE FLOOD			
85000.	160000.	290000.	* TOTAL STREAM FLOW
9.4	21.4	34.8	* DEPTH OF WATER ABOVE FLOOD STAGE
1425.	2225.	2806.	* TOTAL AREA FLOODED
* DISTRIBUTION OF FLOOD ZONE LAND BY SOIL TYPE			
* ZONE 1 ZONE 2 ZONE 3			
.7003	.5000	0.0	* SOIL TYPE 1
.2996	.5	1.0	* SOIL TYPE 2
0.0	0.0	0.0	* SOIL TYPE 3
.9528	.7937	.8332	* REACH FLOW EXPONENTS
* REACH MR-3			
.4648	* FRACTION OF LAND FARMED - FLF		
45000.	* CHANNEL CAPACITY		
* FOR BOUNDARIES BETWEEN ZONES 1 AND 2, 2 AND 3 AND A VERY LARGE FLOOD			
85000.	160000.	290000.	* TOTAL STREAM FLOW
9.4	21.4	34.8	* DEPTH OF WATER ABOVE FLOOD STAGE
1900.	3075.	4217.	* TOTAL AREA FLOODED
* DISTRIBUTION OF FLOOD ZONE LAND BY SOIL TYPE			
* ZONE 1 ZONE 2 ZONE 3			
.8500	.2000	0.0	* SOIL TYPE 1
.15	.8	1.0	* SOIL TYPE 2
0.0	0.0	0.0	* SOIL TYPE 3
.9528	.7937	.8332	* REACH FLOW EXPONENTS
* REACH MR-2			

.4201 * FRACTION OF LAND FARMED - FLF
24000. * CHANNEL CAPACITY
* FOR BOUNDARIES BETWEEN ZONES 1 AND 2, 2 AND 3 AND A VERY LARGE FLOOD
38500. 125000. 325000. * TOTAL STREAM FLOW
2.4 10.6 15.4 * DEPTH OF WATER ABOVE FLOOD STAGE
1220. 2260. 3540. * TOTAL AREA FLOODED
* DISTRIBUTION OF FLOOD ZONE LAND BY SOIL TYPE
* ZONE 1 ZONE 2 ZONE 3
.8500 .2000 0.0 * SOIL TYPE 1
.15 .8 1.0 * SOIL TYPE 2
0.0 0.0 0.0 * SOIL TYPE 3
.8515 .8369 .7796 * REACH FLOW EXPONENTS
* FIELD DAMAGE DATA
.24 .0331 .4561 -.0068 * FBDM, FDRF, FDRF, FDDI
* VALUE OF STORED CROPS (DECEMBER 1)
* ZONE 1 ZONE 2 ZONE 3
0.0 0.0 0.0 * WC-1
0.0 0.0 0.0 * WR-2
0.0 0.0 14000. * S-1
0.0 0.0 0.0 * TR-2
0.0 0.0 0.0 * SC-2
0.0 0.0 0.0 * SC-1
0.0 80000. 100000. * TR-1
0.0 0.0 0.0 * WR-1
0.0 2000. 16000. * MR-6
0.0 18000. 110000. * MR-5
0.0 0.0 0.0 * MR-4
0.0 12000. 75500. * MR-3
0.0 0.0 42000. * MR-2
* MARKET VALUE OF BUILDINGS AND CONTENTS
* ZONE 1 ZONE 2 ZONE 3
49000. 102000. 0.0 * WC-1
210000. 562000. 6060000. * WR-2
0.0 3067000. 15900000. * S-1
300000. 674000. 44700000. * TR-2
100000. 902000. 4200000. * SC-2

441000.	850000.	23100000.	* SC-1
3066000.	12275000.	42600000.	* TR-1
68000.	119000.	1785000.	* WR-1
2455000.	15000000.	29400000.	* MR-6
0.0	830000.	8887000.	* MR-5
1239000.	290000.	510000.	* MR-4
12755000.	21795000.	71400000.	* MR-3
0.0	5396000.	13950000.	* MR-2

* BUILDING DAMAGE FACTORS

0.10	0.001	-0.00008	* UDPF, UDRF, UDDI
50.	* S/DAY COST OF LOST OCCUPANCY		
1.331	* BUILDING INDIRECT DAMAGE MULTIPLIER		

* DAMAGEABLE VALUE OF PUBLIC FACILITIES

	ZONE 1	ZONE 2	ZONE 3	
15000.	90000.	0.0		* WC-1
40000.	290000.	185000.		* WR-2
0.0	966000.	1087000.		* S-1
397000.	1113000.	5188000.		* TR-2
512000.	2471000.	5062000.		* SC-2
204000.	351000.	766000.		* SC-1
4065000.	3073000.	2597000.		* TR-1
200000.	94000.	131000.		* WR-1
2616000.	1700000.	4677000.		* MR-6
0.0	1401000.	1450000.		* MR-5
1500000.	58000.	243000.		* MR-4
3602000.	4274000.	2660000.		* MR-3
0.0	1396000.	824000.		* MR-2

* PUBLIC FACILITY DAMAGE FACTORS

0.25	* DAMAGE FRACTION / FOOT OF FLOOD DEPTH		
1.2080	* FACILITY INDIRECT DAMAGE MULTIPLIER		
.03	* DAILY LOSS OF USE VALUE, FRACTION OF VALUE OF FACILITIES FLOODED		

APPENDIX C

APPENDIX C

DICTIONARY OF PROGRAM VARIABLES

<u>Variable</u>	<u>Type</u>	<u>Units</u>	<u>Definition</u>
A1	R	feet	Maximum depth of flooding which has occurred at lowest point in zone since farmers could last enter fields.
A2	R	feet	Maximum depth of flooding which has occurred at highest point in zone since farmers could last enter fields.
ADEPTH	R	feet	Depth currently flooded which had previously been flooded at some time since farmers were last able to enter fields.
ADP	R	feet	Maximum depth of flooding since farmers could last enter fields.
AFDM	R	dollars/ acre	Amount of unrepaired field damage in fields next to stream.
AFD12	R	dollars/ acre	Amount of unrepaired field damage in fields at boundary between zones one and two.
AFD23	R	dollars/ acre	Amount of unrepaired field damage in fields at boundary between zones two and three.
APDM	R	-----	Amount of unrepaired damage to public facilities next to stream as a fraction of their damageable value.
APD12	R	-----	Amount of unrepaired damage to public facilities at boundary between zones one and two as a fraction of their damageable value.

APD23	R	-----	Amount of unrepaired damage to public facilities at boundary between zones two and three as a fraction of their damageable value.
APK (3)	R	feet	Maximum depth of flooding which has occurred in designated zone since farmers were last able to get into their fields.
AUD	R	-----	Current value of unrepaired building damage as a fraction of their market value.
AUDM	R	-----	Amount of unrepaired damage for buildings next to stream as a fraction of their market value.
AUD12	R	-----	Amount of unrepaired damage for buildings at boundary between zones one and two as a fraction of their market value.
AUD23	R	-----	Amount of unrepaired damage for buildings at boundary between zones two and three as a fraction of their market value.
AZD (25, 3)	R	acres	Area flooded by flowrate of corresponding element in QZD.
B1	R	feet	Maximum depth of flooding which has occurred at lowest point in zone during current period of continuous flooding.
B2	R	feet	Maximum depth of flooding which has occurred at highest point in zone during current period of continuous flooding.
BAFDM	R	dollars/ acre	Amount of unrepaired field damage next to the stream at the last time farmers could get into their fields.

BAFD12	R	dollars/ acre	Amount of unrepaired field damage at boundary between zones one and two at the last time farmers could get into their fields.
BAFD23	R	dollars/ acre	Amount of unrepaired field damage at boundary between zones two and three at the last time farmers could get into their fields.
BAPDM	R	-----	Amount of unrepaired damage for public facilities next to stream as a fraction of their damageable value at the beginning of the current period of continuous flooding.
BAPD12	R	-----	Amount of unrepaired damage for public facilities at boundary between zones one and two as a fraction of their damageable value at the beginning of the current period of continuous flooding.
BAPD23	R	-----	Amount of unrepaired damage for public facilities at boundary between zones two and three as a fraction of their damageable value at the beginning of the current period of continuous flooding.
BAUDM	R	-----	Amount of unrepaired damage for buildings next to stream as a fraction of their market value at the beginning of the current period of continuous flooding.
BAUD12	R	-----	Amount of unrepaired damage for buildings at boundary between zones one and two as a fraction of their market value at the beginning of the current period of continuous flooding.

BAUD23	R	-----	Amount of unrepaired damage for buildings at boundary between zones two and three as a fraction of their market value at the beginning of the current period of continuous flooding.
BDEPTH	R	feet	Depth currently flooded which had previously been under water during the current period of continuous flooding.
BDP	R	feet	Maximum depth of flooding during the current period of continuous flooding.
BPK (3)	R	feet	Maximum depth of flooding which has occurred in designated zone during duration of continuous flooding.
CBDM (10, 12)	R	-----	Damage caused to designated crop in designated month by minimal flooding as a fraction of annual income from growing crop.
CCD (10)	R	dollars/ acre	Average annual income from raising subscribed crop.
CDD (10)	R	-----	Fraction of value of subscribed crop which has already been lost by flooding.
CDDI (10, 12)	R	1/foot- hours	Crop depth-duration interaction factor used to account for the fact that damage for the designated crop in the designated month may not increase linearly with both depth and duration.
CDF	R	dollars/ acre	Crop damage at end of and then during current six hours of flooding.

CDM (10)	R	-----	Fraction of value of subscribed crop right next to stream which has already been lost to flooding.
CDPF (10,12)	R	1/feet	Incremental increase per foot of flood depth in damage to designated crop in designated month as an increase in the fraction of annual income lost.
CDRHR (3)	R	hours	Duration of continuous flooding in designated zone.
CDRF (10,12)	R	1/hours	Incremental increase per hour of flood duration in damage to designated crop in designated month as an increase in the fraction of annual income lost.
CDRTN	R	hours	Current duration of continuous flooding.
CD1 (10)	R	-----	Fraction of value of subscribed crop located midway in zone one which has already been lost to flooding.
CD12 (10)	R	-----	Fraction of value of subscribed crop located at boundary of zones one and two which has already been lost to flooding.
CD2 (10)	R	-----	Fraction of value of subscribed crop located midway in zone two which has already been lost to flooding.
CD23 (10)	R	-----	Fraction of value of subscribed crop located at boundary of zones two and three which has already been lost to flooding.

CD3 (10)	R	-----	Fraction of value of subscribed crop located midway in zone three which has already been lost to flooding.
CD3M (10)	R	-----	Same as CD3 (10).
CDF1	R	dollars/ acre	Crop damage rate at beginning of period for interpolating for CDF.
CDF2	R	dollars/ acre	Crop damage rate at end of period for interpolating for CDF.
CFD	R	dollars/ acre	Damage caused to growing crops during current six-hour period.
CIDF	R	-----	Multiplier for incorporating indirect crop flood damages.
CMDF (10, 12)	R	-----	Maximum fraction of income which can be lost by flooding of designated crop in designated month.
CPD	R	-----	Fraction of damageable value of public facilities lost during current six-hour period.
CPD1	R	-----	Fraction of damageable value of public facilities lost by end of current six-hour period.
CPDM (10, 3)	R	-----	Fraction of value of subscribed crop in subscribed zone previously as yet not harmed by flood damage.
CPKDP	R	feet	Maximum depth of flooding, since farmers could last enter fields, through current six-hour period.
CPRICE (10)	R	dollars/ unit	Market value per production unit of designated crop.

CSTFZ (10, 3, 3)	R	-----	Fraction of land area normally planted to designated crop in designated soil and flood hazard zone.
CUD	R	-----	Fraction of market value of buildings and contents lost during current six-hour period.
CUDI	R	-----	Fraction of market value of buildings and contents lost by end of current six-hour period.
DAY	I	-----	Current day of the calendar month.
DEPTH	R	feet	Current depth of flooding.
DRHR (3)	R	hours	Duration farmers have been kept by flooding from working fields in the subscribed zone.
DRTM	R	hour ⁻¹	Incremental increase in damage per hour of duration adjusted for current depth of flooding.
DRTN	R	hours	Current duration since farmers were last able to enter fields.
DTG	R	days	Remaining time until all stored crops are used.
DZD (25, 3)	R	feet	Maximum depth of flooding associated with flowrate in corresponding element in QZD.
EXP1 (25)	R	-----	Exponent used in Eq. 10 for interpolating flood depths and areas in zone one of designated reach.
EXP2 (25)	R	-----	Exponent used in Eq. 10 for interpolating flood depths and areas in zone two of designated reach.

EXP3 (25)	R	-----	Exponent used in Eq. 10 for interpolating flood depths and areas in zone three of designated reach.
FBDM	R	dollars/ acre	Damage caused to fields and fences by minimal flooding.
FDAY	R	days	Days into crop damage interpolation period.
FDDI	R	1/foot- hours	Field depth-duration interaction factor used to account for the fact that damage may not increase linearly with both depth and duration.
FDDF	R	feet	Base depth used in estimating increase in damage with duration to maintain a smooth curve.
FDM	R	dollars/ acre	Current rate of flood damage to fields right next to stream.
FDM6HR	R	dollars	Amount of flood damage during the current six-hour period.
FDPF	R	feet ⁻¹	Incremental increase per foot of flood depth in field damage as a fractional increase in FBDM.
FDRF	R	hour ⁻¹	Incremental increase per hour of flood duration in field damage as a fractional increase in FBDM.
FDTG	R	-----	Fraction of initial stored crops currently remaining stored on flood plain.
FD1	R	dollars/ acre	Current rate of flood damage to fields located midway in zone one.
FD12	R	dollars/ acre	Current rate of flood damage to fields located at boundary of zones one and two.

FD2	R	dollars/ acre	Current rate of flood damage to fields located midway in zone two.
FD23	R	dollars/ acre	Current rate of flood damage to fields located at boundary of zones two and three.
FD3	R	dollars/ acre	Current rate of flood damage to fields located midway in zone three.
FFHR (3)	R	hours	Duration since floodwaters last entered designated zone.
FLF (25)	R	-----	Fraction of land in designated reach normally planted to income producing crops.
FRM	R	-----	Fractional state of repair of fields next to stream as of last time farmers could get into their fields.
FRTO	R	-----	Fractional state of repair of fields as of last time farmers could get into their fields.
FR12	R	-----	Fractional state of repair of fields at boundary between zones one and two as of the last time farmers could get into their fields.
FR23	R	-----	Fractional state of repair of fields at boundary between zones two and three as of the last time farmers could get into their fields.
FZA (3)	R	acres	Area flooded in subscribed zone.
FZCD (3)	R	dollars	Crop damage during current six-hour period in subscribed flood zone.
FZD (3)	R	feet	Maximum depth of flooding in subscribed zone.

FZFD (3)	R	dollars	Field damage during current six-hour period in subscribed flood zone.
FZPD (3)	R	dollars	Damage to public facilities during current six-hour period in subscribed flood zone.
FZTD (3)	R	dollars	Total flood damage during current six-hour period in subscribed flood zone.
KCRP	I	-----	Number of the crop to which current computation applies.
KFY	I	-----	Counter distinguishing month from day in reading LFY.
KFZ	I	-----	Number of the flood zone to which current computation applies.
KLZ	I	-----	Same as KFZ.
KMO	I	-----	Number of the month to which current data element applies.
KRCH	I	-----	Number of the reach to which the data element currently being read applies.
KREACH	I	-----	Number of the reach for which a damage estimate is requested.
KSTP	I	-----	Number of the soil type to which current computation applies.
KT1	I	-----	Counter for distinguishing beginning from end of crop month.
KT2	I	-----	Counter for distinguishing flood zone location of damage estimates.

LAPK	L	-----	True if current depth of flooding is greater than any since farmers were last able to get into their fields.
LBPk	L	-----	True if current depth of flooding is greater than any during duration of continuous flooding.
LFY (10, 2)	I	-----	Number of last month and day in which subscribed crop can be planted for full yield.
LKFZ	L	-----	True when computations are shifting to a higher level flood zone.
LMN	I	-----	Month farmers were last able to enter fields.
LMO	I	-----	Number of crop month beginning interpolation period.
LMONTH	I	-----	Month farmers were last able to enter fields in subscribed zone.
LPK	L	-----	True if current flooding is deepest yet during stored crop season.
LWRITE	L	-----	Logical variable brought into the subroutine as true to request detailed output on flooding and damage characteristics.
MD	I	-----	Number of day in last month in which crop can be planted for full yield.
MM	I	-----	Number of last month in which crop can be planted for full yield.
MO	I	-----	Crop month for which data is needed.
MONTH	I	-----	Current month of the calendar year.

NCRP	I	-----	Number of crops for which descriptive data are to be read and stored in memory.
NMO	I	-----	Number of crop month ending interpolation period.
NRCH	I	-----	Number of reaches for which descriptive data are to be read and stored in memory.
NSTP	I	-----	Number of soil types for which descriptive data are to be read and stored in memory.
PCDF	R	dollars/ acre	Crop damage at beginning of current six-hours of flooding.
PCDF1	R	dollars/ acre	Crop damage rate at beginning of period for interpolating for PCDF.
PCDF2	R	dollars/ acre	Crop damage rate at end of period for interpolating for PCDF.
PCDRHR (3)	R	hours	Duration of continuous flooding up to the end of the previous six-hour period in the subscribed zone.
PCDRTN	R	hours	Duration of continuous flooding at beginning of current period.
PCFD	R	dollars/ acre	Damage caused to growing crops before beginning of current six-hour period.
PCPD	R	-----	Fraction of damageable value of public facilities lost before beginning of current six-hour period.

PCUD	R	-----	Fraction of market value of buildings and contents lost before beginning of current six-hour period.
PDEPTH	R	feet	Depth of flooding at beginning of current period.
PDM	R	dollars	Current rate of flood damage to public facilities right next to stream.
PDPF	R	feet ⁻¹	Incremental increase per foot of flood depth in damage to public facilities expressed as a fraction of their damageable value.
PDRHR (3)	R	hours	Duration up to the end of the previous six-hour period that farmers had been kept from working fields in the subscribed zone.
PDRTN	R	hours	Duration since farmers were able to enter fields at beginning of current period.
PDV	R	dollars	Damageable value of public facilities in area for which current damage estimate is being made.
PD1	R	dollars	Current rate of flood damage to public facilities located midway in zone one.
PD12	R	dollars	Current rate of flood damage to public facilities located at the boundary of zones one and two.
PD2	R	dollars	Current rate of flood damage to public facilities located midway in zone two.

PD23	R	dollars	Current rate of flood damage to public facilities located at the boundary of zones two and three.
PD3	R	dollars	Current rate of flood damage to public facilities located midway in zone three.
PFD	R	dollars	Damage caused to public facilities during current six-hour period.
PFM	R	-----	Fractional state of repair to public facilities next to stream at beginning of current period of continuous flooding.
PFZD (3)	R	feet	Maximum depth of flooding during previous six-hour period in subscribed zone.
PF12	R	-----	Fractional state of repair to public facilities at boundary between zones one and two at beginning of current period of continuous flooding.
PF23	R	-----	Fractional state of repair to public facilities at boundary between zones two and three at beginning of current period of continuous flooding.
PIDF	R	-----	Multiplier for incorporating indirect damage to public facilities.
PKDIF	R	feet	Distance by which current flood depth exceeds previous maximum during stored crop season.
PKDP	R	feet	Current flood depth if it exceeds any yet during stored crop season.

PPDD	R	day ⁻¹	Average loss per day that public facilities cannot be used when under flood water expressed as a fraction of the damageable value of the facilities inundated.
PPKDP	R	feet	Greatest depth of flooding to which stored crops have previously been exposed during current storage season.
PRTO	R	-----	Fractional state of repair to public facilities at beginning of current period of continuous flooding.
PZD (25, 3)	R	dollars	Damageable value of public facilities in designated reach and flood zone.
QCAP (25)	R	cfs	Flowrate at which flooding begins in designated reach.
QEX	R	cfs	Range in flowrate between when water first enters flood zone and begins to enter next higher zone.
QFLD	R	cfs	Excess of current flow rate over minimum required for flooding to begin in the zone.
QZD (25, 3)	R	cfs	Flowrate at which flooding in designated reach inundates the area in the corresponding element of AZD.
Q6HR	R	cfs	Peak streamflow during the current six-hour period.
RDT	L	-----	Logical variable brought into the subroutine as true if data is to be read.

RIN	L	-----	Logic variable brought into the subroutine as true to reinitialize property to a fully repaired condition to avoid reading a long sequence of low flows.
RKA1 (25)	R	acre/ foot	Incremental acreage inundated per foot of additional flood depth in flood zone one in designated reach.
RKA2 (25)	R	acre/ foot	Incremental acreage inundated per foot of additional flood depth in flood zone two in designated reach.
RKA3 (25)	R	acre/ foot	Incremental acreage inundated per foot of additional flood depth in flood zone three in designated reach.
RKD1 (25)	R	variable	Factor used in interpolating flood depth from flow in flood zone one of designated reach.
RKD2 (25)	R	variable	Factor used in interpolating flood depth from flow in flood zone two of designated reach.
RKD3 (25)	R	variable	Factor used in interpolating flood depth from flow in flood zone three of designated reach.
SCD	R	dollars/ acre	Damage caused to stored crops during current six-hour period.
SCDA (25, 3)	R	dollars/ acre	Normal value of crops stored each December 1 per acre of designated reach and flood zone (read as totals and divided by acres in program).
SCDC (25, 3)	R	dollars/ acre	Normal value of crops stored on current date per acre of designated reach and flood zone.

SCP	R	dollars/ acre	Value of crops currently being stored in area for which current damage estimate is being made.
SPKDP	R	feet	Greatest depth of flooding to which stored crops have been exposed in current storage season.
STZD (25, 3, 3)	R	-----	Fraction of cropland in designated reach and flood zone which is in soil type designated by the second dimension.
TC	R	dollars	Accumulator for summing damages to crops during current six-hour period.
TCDD	R	dollars/ acre	Accumulator for summing damages to all crops.
TCDM	R	dollars/ acre	Current rate of flood damage to crops right next to stream.
TCD1	R	dollars/ acre	Current rate of flood damage to crops located midway in zone one.
TCD12	R	dollars/ acre	Current rate of flood damage to crops located at the boundary of zones one and two.
TCD2	R	dollars/ acre	Current rate of flood damage to crops located midway in zone two.
TCD23	R	dollars/ acre	Current rate of flood damage to crops located at the boundary of zones two and three.
TCD3	R	dollars/ acre	Current rate of flood damage to crops located midway in zone three.

TCD1MX	R	dollars/ acre	Maximum rate of flood damage to crops located midway in zone one.
TCD2MX	R	dollars/ acre	Maximum rate of flood damage to crops located midway in zone two.
TCD3MX	R	dollars/ acre	Maximum rate of flood damage to crops located midway in zone three.
TF	R	dollars	Accumulator for summing damages to fields during current six-hour period.
TP	R	dollars	Accumulator for summing damages to public facilities during current six-hour period.
TT	R	dollars	Accumulator for summing flood damages during current six-hour period.
TU	R	dollars	Accumulator for summing damages to buildings and contents during current six-hour period.
UDDI	R	1/foot- hours	Building depth-duration interaction factor used to account for the fact that damage may not increase linearly with both depth and duration.
UDM	R	dollars	Current rate of damage to buildings and contents right next to stream.
UDPF	R	feet ⁻¹	Incremental increase per foot of flood depth in building damage expressed as a fraction of market value.

UDRF	R	hour ⁻¹	Incremental increase per hour of flood duration in building damage expressed as a fraction of market value.
UDV	R	dollars	Market value of buildings and contents in area for which current damage estimate is being made.
UD1	R	dollars	Current rate of flood damage to buildings and contents located mid-way in zone one.
UD12	R	dollars	Current rate of flood damage to building and contents located at the boundary of zones one and two.
UD2	R	dollars	Current rate of flood damage to buildings and contents located mid-way in zone two.
UD23	R	dollars	Current rate of flood damage to buildings and contents located at the boundary of zones two and three.
UD3	R	dollars	Current rate of flood damage to buildings and contents located mid-way in zone three.
UFD	R	dollars	Damage caused to buildings and contents during current six-hour period.
UFM	R	-----	Fractional state of repair to buildings next to stream at beginning of current period of continuous flooding.
UF12	R	-----	Fractional state of repair to buildings at boundary between zones one and two at beginning of current period of continuous flooding.

UF23	R	-----	Fractional state of repair to buildings at boundary between zones two and three at beginning of current period of continuous flooding.
UIDF	R	-----	Multiplier for incorporating indirect building flood damages.
UPDD	R	dollars/ day	Average loss per day that building cannot be occupied during flood.
URTO	R	-----	Fractional state of repair to buildings at beginning of current period of continuous flooding.
UZD (25, 3)	R	dollars	Market value of buildings and contents in designated reach and flood zone.
YIELD (10, 3)	R	units/ acre	Yield of designated crop when grown in designated soil type.
ZYLD	R	units/ acre	Average crop yield over the respective soil types.

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