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Flood Warning Benefit Evaluation - Susquehanna River Basin (Urban Residences)

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FLOOD WARNING BENEFIT EVALUATION - SUSQUEHANNA RIVER BASIN (URBAN RESIDENCES)

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FLOOD WARNING BENEFIT EVALUATION - SUSQUEHANNA RIVER BASIN (URBAN RESIDENCES)

Harold J. Day

ABSTRACT

The effectiveness of a warning service coupled with either temporary flood proofing or evacuation of residential structures in reducing flood damage is the subject of this report. Communities in the floodplain of the Susquehanna River Basin in New York, Pennsylvania, and Maryland were used for a computer simulation of flood-related action; however, four cities, Harrisburg, Pa., Milton, Pa., Carbondale, Pa., and Owego, N. Y., received detailed investigation. Field data collected by the Baltimore District of the U. S. Army Corps of Engineers and a computer program prepared by that office were used for this study.

The interagency comprehensive river basin planning effort for water and land resources motivated this Type II study in the Susquehanna and information contained herein may serve as part of it.

After a review of related literature, a detailed description of this investigation is presented. The results show that benefits from a warning service are not similar in all communities. The benefit-to-cost relationship is generally favorable since net benefits exist in 80 percent of the cases considered.

For the 116 reaches of the river system investigated, flood damage to residences--without any warning--was estimated to be $3 million (expected annual cost). Reducible damages represented one-third of this value, $1 million. Reliable warnings, allowing 6 to 12 hours of action time, could be expected to provide at least two-thirds of the reducible damage as net benefits. Evacuation was generally economically advantageous compared to temporary flood proofing. Efficient local disaster organizations and total public response and compliance with action decisions are assumed. Damage reduction, considering limited reaction by residents, is considered for only four cities. Loss of life has not been included due to the difficulties in evaluating either the effect of a warning on reduced casualties or the dollar value of a life.

It should be emphasized that commercial, rural, and industrial flood damages have not been considered in the study; therefore, the overall effectiveness of the warning service has not been estimated.

1. INTRODUCTION

Evacuation and temporary flood proofing, two alternatives of action on the floodplain for which costs have always been difficult to define, are used for flood damage reduction in this study. Both of these actions require an effective warning service and related response by individuals on the floodplain to be realistic elements of a floodplain management program. Participation by the Weather Bureau in the Federal interagency study (Type II) of water and land related resources in the Susquehanna River Basin provided the opportunity to contribute these elements of the overall study. The Baltimore District of the U. S. Army Corps of Engineers was the study coordinator. Basic data on the floodplain, both hydrologic and economic, and computer programs were provided by the Baltimore District.

Floodplain management has received special emphasis in recent years as evidence developed of rising flood damages in spite of a major Federal construction program. The Task Force on Flood Control Policy reported(1)* that physical protection works were not sufficient and that new initiative by both Federal and State agencies was required to reduce flood damages. Prior to, and since the Task Force report, the problem of selecting the best combination of structural and nonstructural actions to reduce flood damages in any particular floodplain has been under study. In addition to various structural means of dealing with floods--dams, land management, levees, diversions, and channel deepening or straightening--flood damages can also be reduced by zoning, flood proofing, and evacuating. Both costs and benefits must be quantified whenever possible to select the optimal combination of alternatives for a given floodplain. Experience gained here may be useful in future studies of other basins where flood proofing and evacuation are feasible alternatives.

2. TECHNICAL REVIEW

Previous Investigations

Problems of managing the floodplain have been considered for many years by a number of government agencies; namely, the Corps of Engineers, Soil Conservation Service, Tennessee Valley Authority, Weather Bureau, as well as by university-affiliated organizations or individuals such as the Stanford Research Institute and Dr. Gilbert White of the University of Chicago. White and his colleagues have pioneered in the study of structural and nonstructural actions to reduce flood damages. They suggested the following choices for floodplain damage reduction: protection works such as dams and levees, public-sponsored relief, flood insurance, land-use regulations, evacuation, and flood proofing(2,3). Sheaffer(4,5) and Kates(6,7) have reported on studies of flood proofing and industrial flood damage. The Stanford Research Institute also studied flood damages of various structures with emphasis on residential units(8). Lind recently discussed floodplain actions with emphasis on insurance(9), and James reported on a systems analysis of flood-damage reduction, including structural measures, flood

*Numbers refer to the references in section 7.

proofing, and land zoning(10). The Corps of Engineers has begun an extensive program of floodplain iden[illegible]cation in river basins throughout the Nation(11); several states; namely, Wisconsin and Connecticut, have enacted laws restricting development in the floodplain. In addition, floods and related losses have received special attention in the Federal interagency studies of the Water Resources Council, Types I and II.

An objective investigation of each major river basin suffering substantial flood losses would require the inclusion of both benefits and costs for all feasible corrective measures. A systems analysis, including all significant variables such as response to warning, depth and duration of flood, water velocity, weather conditions, time of day, and time since last flood, that interrelate the corrective measures is not possible at this time since the benefits and costs for some alternatives such as zoning, flood insurance, evacuation and flood proofing have not been adequately quantified. Special attention to the variables affecting evacuation and temporary flood proofing, two alternatives that require a flood forecast and warning, have recently been provided by Bower(12). He suggested that the following factors are relevant to the effectiveness of a flood warning in a community:

1. Length of warning time.--Damage reduction during floods is sensitive to the length of warning time provided. For a floodplain occupant, the time of warning is the period from the receipt of a warning, either formal such as a Weather Bureau forecast or informal such as a personal judgm[illegible]t based on the rising water of the adjacent stream to the commencement of potential damage. Such a time period varies due to hydrologic and sociopolitical conditions experienced by the individual. Headwater regions naturally experience short time lags following a warning before flood damage could occur. In such areas, 2 to 6 hours of warning is not uncommon, while downstream reaches of a river system receive longer warning periods extending to several weeks. Many communities in the floodplain maintain efficient, well organized disaster committees for formal warning dissemination. Others are apathetic and do not communicate effectively during pending flood periods. Some citizens may ignore early warnings and others may not listen to the radio or television at the time of first public announcement.

The time of warning for a particular local region may be approximated in several ways. Weather Bureau staff defines it as the period from release of the forecast, which usually is a predicted flood peak and related time of occurrence based on the precipitation already on the ground, to the occurrence of the related flood peak. Others, such as Bower and Sheaffer, define the time of warning as the period between the river at flood stage (bankfull) and at flood peak.

2. Magnitude of reducible damages.--A portion of flood damages will occur regardless of warning time or response to warning since some facilities such as railroad tracks, bridges, and buildings will be damaged unless they are removed from the floodplain. A family residence may incur several thousand dollars damage even if all movable items such as appliances, furniture, and dry goods are removed to high ground.

3. <u>Efficiency of response to warning</u>.--Occupants of the floodplain will respond to the warning with different levels of efficiency. Their response is affected by factors such as the time of day the warning is received, the time elapsed since the last flood, and the amount of preplanned activities for damage reduction. Industries often have elaborate disaster plans to cope with floods, while many families begin to plan only after receipt of the warning.

The task of evaluating costs and benefits for temporary flood proofing and evacuation from the floodplain has begun with several simplifying assumptions. As the need for floodplain management studies increases, further refinements can be developed by using more of the variables noted. Bhavnagri and Bugliarello included time of warning in a model for simulating nonstructural activities on the floodplain(13). They synthesized a stage damage curve for different structure types such as family residences with and without basements. The changes in time of warning were noted by creating a family of stage damage curves, with one curve for each warning time, as shown in figure 1. The reducible damages are determined by the difference between various curves at the same water stage. The effect of a flood warning can be estimated for a river reach by relating the flood-crest elevation to the water level in each inundated structure and by using the proper stage damage-time of warning curve for each structure. The probable annual damages for the river reach can then be calculated by combining the streamflow-frequency data with the stage damage-time data. Associated with a given flood is a stage*, which represents inundation over a certain portion of the floodplain as shown in figure 2. The expected annual flood loss for an "n" year period can be calculated by considering the particular loss associated with each flood and the probability of flood occurrence. Then

$$E(D) = \sum_{i=1}^{n} p_i \, D_i$$

where

$E(D)$ = expected annual loss

n = number of years

p_i = probability of a flood within the floodplain contour interval i-1 to i

D_i = community damage associated with flood reaching to top of Step i and a particular warning time

Two values for expected annual flood loss can be calculated, one with warning and one without warning. The difference will be the expected gross annual saving, S.

$$\text{Gross Saving, } S = E(D)_{\text{No Warning}} - E(D)_{\text{Warning}}$$

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*A stable channel providing unchanging stage-discharge relationship is assumed.

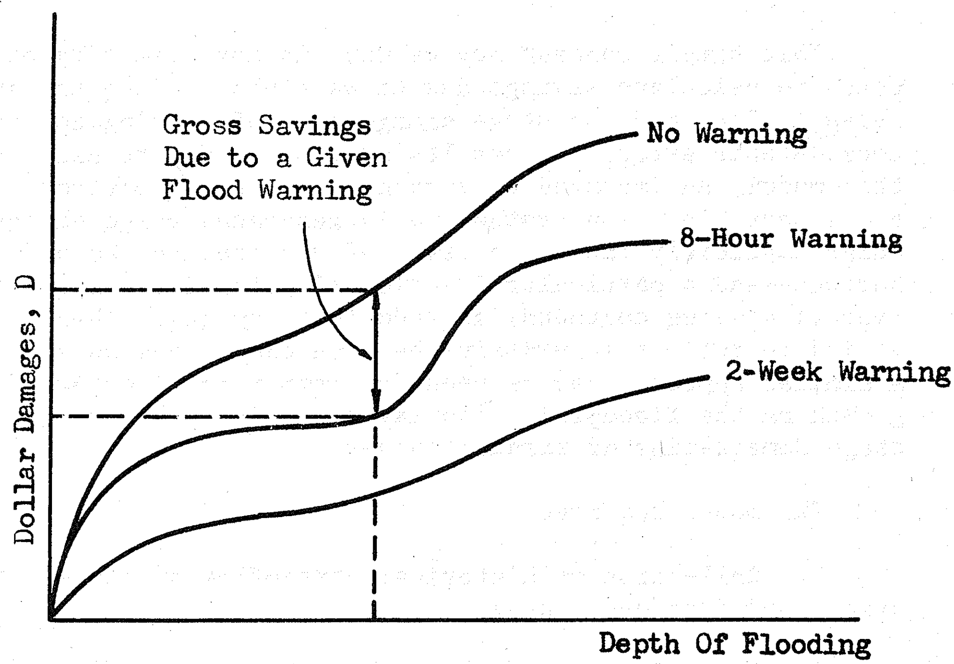

Figure 1

Sample Stage-Damage Curve

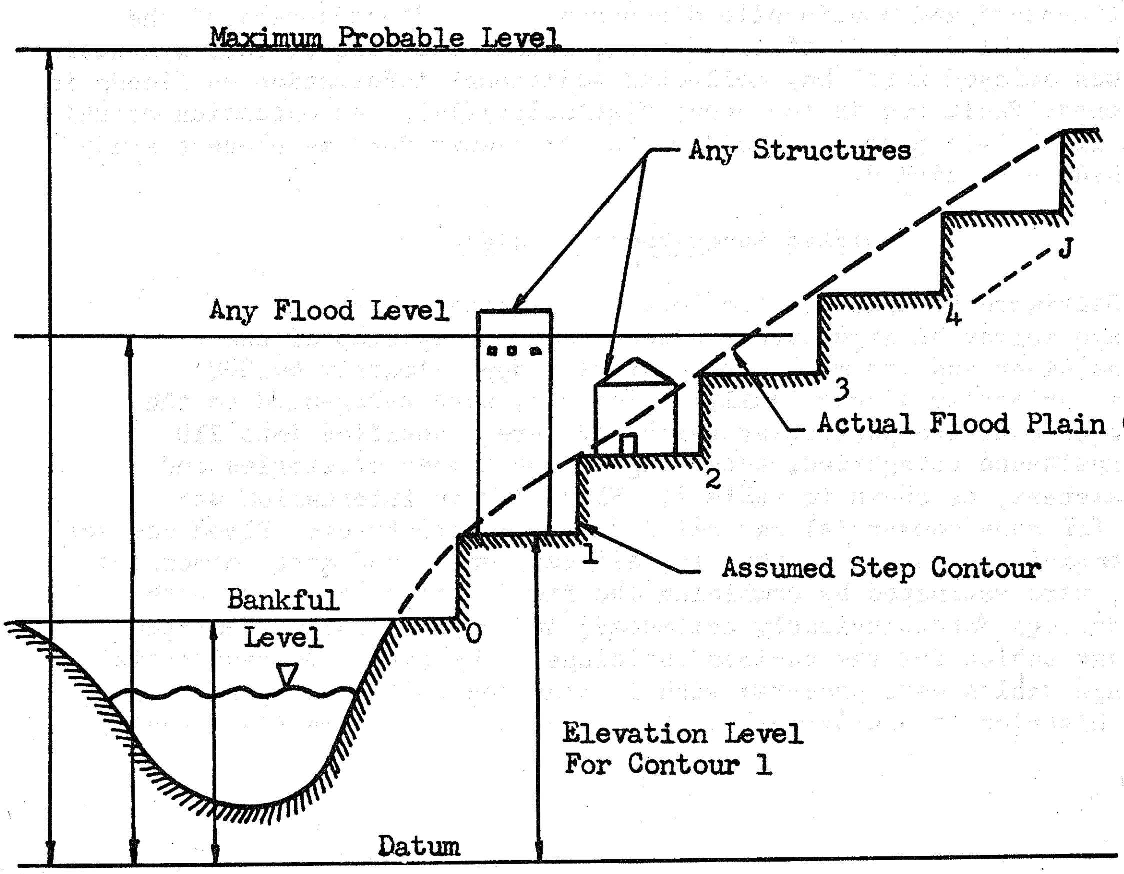

Figure 2

Flood Plain Definition Sketch

This simple concept may be used in any community or along a river reach to calculate savings due to warnings. Since the streamflow record is often limited and the stage damage-time of warning estimates are subject to considerable error, the results must be used with caution. However, from this model, an improved understanding of the importance of warning time seems possible. The synthetically generated stage damage-time relationships implicitly include a level of response to the warning--usually 100 percent--and a particular fraction of potential damages to each structure type (including contents) as reducible damages. These parameters may be varied to reflect accurately the true conditions on a particular floodplain. A similar approach may be used for temporary flood proofing. Economic growth on the floodplain also may be included by the use of additional stage damage-time of warning curves.

The model requires:

1. Collection of historical streamflow or stage data and preparation of a flood-frequency curve.

2. Determination of the number and type of structures at various locations on the floodplain and the water depth in each structure for a flood of any given probability.

Although Bhavnagri and Bugliarello did measure the effectiveness of the model with a limited amount of field data, a moderate test of this synthetic approach was delayed until Day collected additional information on floods in western Pennsylvania and in the upper Mississippi(14). An extension of this synthetic floodplain model was used as the framework for the present study as described in section 3.

Related Susquehanna Studies

The Baltimore District of the Corps of Engineers has conducted a flood-damage survey of structures on the urban floodplains of the Susquehanna River and its major tributaries. Approximately 60,000 structures, primarily single-family residences, were referenced to the flood of record at the particular reach and were classified into 210 possible residence categories, according to the number of stories and other parameters, as shown in table 1. Flood-damage information was collected for some commercial and all industrial structures. Flood damages for the remaining structures; that is, all residences and most commercial buildings, were estimated by combining the field data noted above with stream hydrology data previously collected, and synthetically generated stage-damage tables for the various buildings. The synthetic residential stage-damage tables were prepared with information collected by the Baltimore District at approximately 200 homes in the Potomac River Basin.

Table 1.--Residential characteristics used for synthetic stage-damage table generation

Characteristic	Code		
Market Value	A = $22,000 to $32,000	B = $12,000 to $22,000	C = $ 4,000 to $12,000
Number of Stories	1	1-1/2	2
Basement	Yes = Y	No = N	
Home Size	Small = S	Average = A	Large = L
Home Furnishings Value	Low = L	Average = A	High = H

Note: Cabins were also ranked according to size and furnishings; trailers were ranked according to size only.

A coding was used to identify each structure type. As an example, A1YAA describes a home valued above $22,000, of one story with basement, of average size, and with furnishings of average value.

The same approach was used for the preparation of stage-damage relations for the commercial structures that exist in sufficient number to warrant a synthetic generation. Both overland flooding (STADM) and inundation by seepage or sewer backup (STADS) were included. The only effect of action by residential and commerical floodplain occupants included in the Corps of Engineers study was an approximate 10 percent reduction in damage for commercial units. Since the Corps investigations did not account for reduced damages following receipt of a warning, the stage-damage curves as prepared may be considered a limiting condition represented by a total lack of warning and forecast. An example of such data is presented in figure 3.

The Corps of Engineers developed two computer programs. The first program had the following characteristics:

Input Data

a. Physical characteristics of each residential and commercial structure. The residential units were classified in 210 categories as described earlier.

b. Vertical location of each structure with reference to the flood of record.

Storage Data

a. Stage-damage tables for each selected structure type.

b. Computer program designed to methodically sort and match structures to the appropriate stage-damage table and to calculate related community flood damage data.

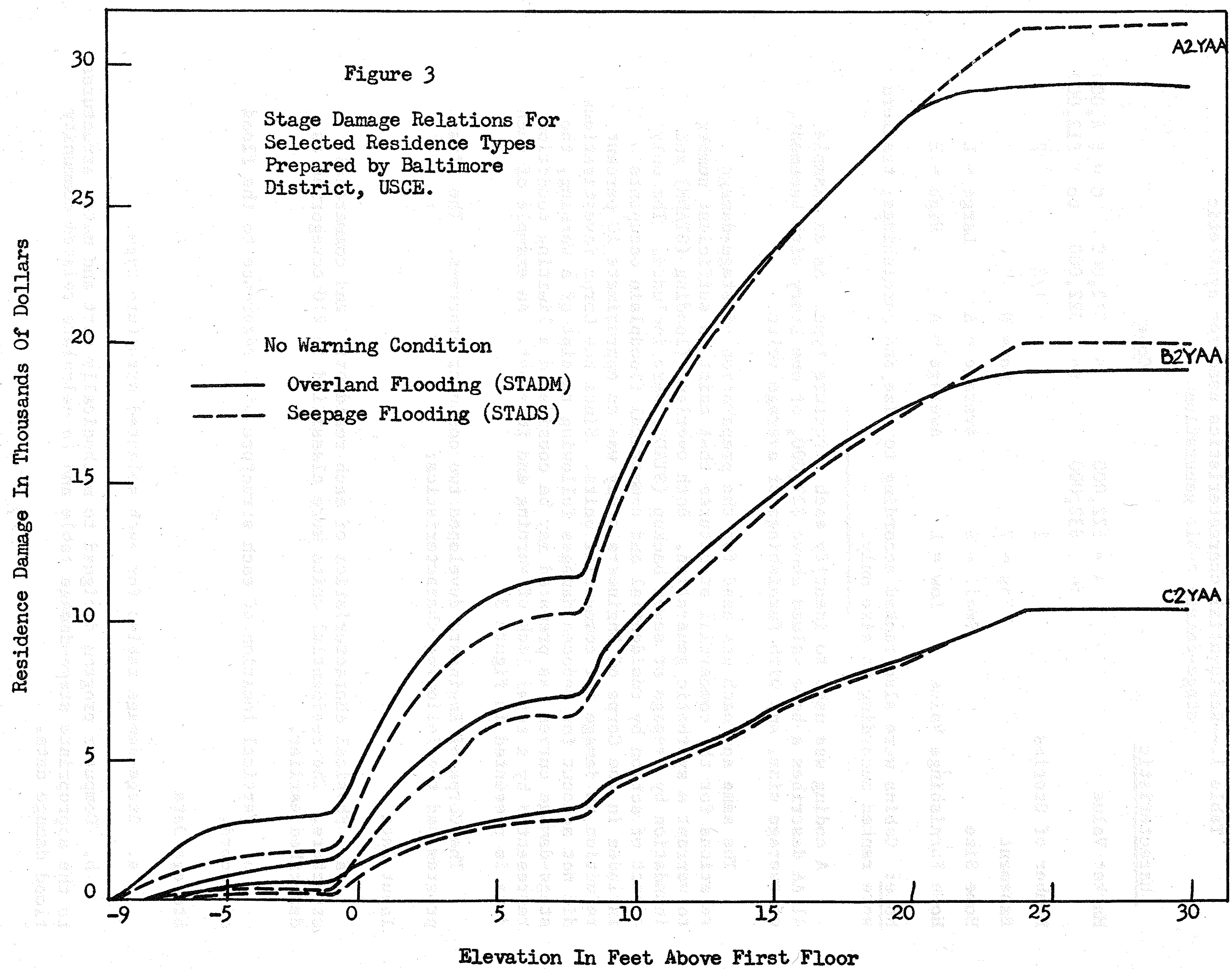

Figure 3

Stage Damage Relations For Selected Residence Types Prepared by Baltimore District, USCE.

Output Data

a. Summary table of damage in a community or river reach. The table contains the stage-damage values for the reach and related information such as the number of residences inundated at each river height.

The second program was related to the first and had the following characteristics:

Input Data

a. Community stage-damage tables provided by the output from the previous program.

b. Stage-frequency tables based on the historical streamflow data.

Storage Data

Computer program designed to calculate the flood damage-frequency relation which leads to evaluation of expected annual damages.

Output Data

Summary table of damage-frequency data and related expected annual damage for each community and reach.

The Baltimore District of the Corps of Engineers has details of these programs.

The Soil Conservation Service of the U. S. Department of Agriculture completed a report titled "Floodwater Damages of Upstream Watersheds" in June 1966. The study was directed to all agricultural and nonagricultural damages in the minor tributaries of the Susquehanna River. These areas were not included in the flood damage survey conducted by the Baltimore District of the Corps of Engineers. Damage data were collected in the following categories: (1) urban, (2) bridge, (3) roads, (4) railroads, (5) farm buildings, and (6) crops and pasture. Expected annual flood damage in the area was estimated at $4.5 million dollars, but less than $300,000 of this figure was agricultural. There may be opportunities to reduce the damage, especially the nonagricultural elements of the basin, through floodplain management, but additional information will be required for proper planning.

3. DESCRIPTION OF THE STUDY

The Study Area

The Susquehanna River Basin, a major watershed of Eastern United States, occupies about 26,000 square miles of New York, Pennsylvania, and Maryland. The main stem of the river, exceeding 400 miles in length, is fed by many tributaries before discharging into Chesapeake Bay. The River has historically served as a focal point for activities in the region; today, many small and large communities are located either on the floodplain or adjacent to it. Major cities are Harrisburg, Wilkes Barre, and Scranton in Pennsylvania, and Elmira and Binghamton in New York. A large portion of the Basin is mountainous and about 50 percent is covered with forests. The average slope of the main river stem is 2-1/2 feet per mile.

Flood damages have occurred since development of the floodplain began in the 19th century. Flood stages occur almost annually in the upper reaches of the main stem at Towanda, Pa., and on the average of every 3 years at Sunbury, Pa.--located 50 miles upstream of Harrisburg. The maximum flood-of-record for most of the basin occurred in March 1936. A formal program for river-stage forecasting has existed in the watershed since prior to 1937 when the Commonwealth of Pennsylvania, the U. S. Geological Survey, and the U. S. Weather Bureau formed the Federal-State River Forecasting Service

A basinwide effort to coordinate water resources development was demonstrated recently by the proposed Susquehanna River Basin Compact which will provide an organization similar to the Delaware River Basin Commission, and on which there will be representatives from Maryland, Pennsylvania, New York, and the Federal Government. Such a Compact could serve as a primary device in coordinating interstate activities, such as floodplain management, within the Basin.

The Study Plan

The primary purpose of this study is to measure the effectiveness of a flood-warning service to occupants of the Susquehanna River Basin. Although flood forecasts are provided to residential, commercial, and industrial floodplain occupants in urban areas, and to rural residents as well, throughout most of the Basin, this study has been restricted to urban residents. Accessibility of data from the Corps of Engineers, both synthetically generated and field-collected--in a form readily adaptable for use on a computer--is the primary reason for this restriction. The urban private resident undoubtedly represents the largest portion of floodplain occupants, but the commercial and industrial occupants are the largest potential beneficiaries of flood warnings. This study is an exploratory effort; in future investigations, additional users of the forecasts--such as commercial and industrial occupants--may be included to obtain an estimate of overall basinwide benefits and costs.

The basic plan included the development of appropriate residential stage-damage and stage-cost relationships which reflect variations in warning time and efficiency in response to warning. Evacuation and temporary flood proofing were both considered as the cause of the damage reduction. Following preparation of these data, the plan was implemented by use of the computer programs described in section 2.

Flood damages previously estimated by the Baltimore District of the Corps of Engineers for each category of residences were assumed to represent the situation of no warning, noted by the abbreviation NW. Three situations for damage reduction by evacuation and one, by temporary flood proofing were developed by altering the damage to appropriate items in the house, such as dining room furniture or basement tool storage, estimated by the Corps of Engineers. Detailed work sheets similar to those shown in appendix B served as the primary data source for the tables shown in appendix A. Typical data developed for these various situations are presented in figure 4. Detailed discussions of damage reductions and the related costs required for each case will clarify the background of each stage-damage relation.

A. Damages--Maximum Practical Evacuation (MPE).--The maximum damage reduction resulting from evacuation was estimated by eliminating all movable items from each house. This action, which is associated with warning times in excess of 24 hours and 100 percent response to the warning, also provides an estimate of the reducible damages in a dwelling.

B. Damages--Limited Warning Time (LWT).--The effect of a reduced warning time on residential flood damages was estimated by selecting only a fraction of the removable items chosen in the preceding MPE case for inclusion. This family of stage-damage values is associated with a warning time of 12 to 24 hours and 100 percent response to the warning.

C. Damages--Limited Response to Warning (LR).-- A reduced response to the flood warning was modeled by combining the no-warning (NW) and maximum practical evacuation (MPE) tables, using an appropriate weighting procedure. Floodplain occupants on the lower elevations prone to frequent flooding were assumed to respond more efficiently than those at higher elevations who would be damaged less frequently. MPE values were used for those occupants responding while NW values were used for those who did not respond. This combination of two extremes, 100 percent response by some residents and no response by others, probably does not accurately reflect true floodplain action, but the results should be useful as an indication of how sensitive the damage values are to response efficiency. The selected combinations of NW and MPE values are shown in table 2.

Table 2.--Limited response

Elevation in feet of flood of record referenced to first floor of each individual residence	Percentage of homeowners Who Act (MPE Data Used)	Percentage of homeowners Who do not act (NW Data Used)
Maximum to + 2	75	25
+ 2 to - 4 (inclusive)	50	50
Less than - 4	25	75

D. Damages--Temporary Flood Proofing (FP).--Temporary flood proofing implies the use of warning time to protect lower elevations of the structure and its contents so that damage will be minimum with little or no evacuation. Alterations in the home construction, such as the installation of valves in sewer lines, are sometimes required for temporary flood proofing to be successful. Shaeffer has described the preparations required for this alternative(5). Damages at elevations up to 2 feet above the first floor were estimated at dollar values less than used in the MPE case, while NW damages were used for flood levels above that line. The selection of NW damages for the higher levels of a home during this action is, of course, a conservative choice. In reality, the occupants would usually evacuate some movable items before water reached the line 2 feet above the first floor. Thus, the FP curve shown in figure 4 would probably trend toward the NW curve but would not join it as indicated.

E. Costs--Evacuation Actions--MPE, LWT, LR.--An estimate of the cost required to reduce flood damages through evacuation action was made by considering the value of labor and materials required to evacuate and return appropriate movable items located in the home area to be inundated. The labor required to move household items to higher elevations within the house or outside the house on higher ground if no dry storage existed within the structure was estimated for each residential structure type on the floodplain. The estimates were restricted to average home size and value of furnishings; the same multiplier table used for damages, code name PAPP, was applied to these dollar values for cost estimates of other home sizes and furnishings values. The following wage scales were assumed for each classification of home-market values:

Class A (\$22,000 - \$32,000)	\$8 per man hour
Class B (\$12,000 - \$22,000)	\$6 per man hour
Class C (\$ 4,000 - \$12,000)	\$4 per man hour

Reoccupation costs are generally higher than those required during evacuation, according to Red Cross reports(15), since greater care is exercised in returning salvaged items; therefore, the total cost of evacuation and reoccupation was assumed to be 1.75 reoccupation cost. Truck rentals, space storage, and other costs occurring due to evacuation were assumed to be included in the wage rate.

The cost estimates for the MPE case ranged from \$85 for a home coded C2NSL (the SL indicates small size and low value furnishings) to \$425 for a home coded A1YLH (the LH indicates large size and high value furnishings). Evacuation and reoccupation costs associated with the LWT case ranged from \$30 to \$285 for similar home types. MPE costs were used for that portion of the LR case where response to the warning occurred. These dollar values are intended as rough indications of actual costs and are not based on any field data. In some cases, they may merely represent a willingness to pay; at other times, an expenditure of funds may occur. Figure 5 is a graphical presentation of typical evacuation costs. Naturally, homes without basements require no action until the flood crest approaches the first-floor level. Additional effort to move small kitchen utensils when the crest exceeds 3 feet above the first floor accounts for the slight increase in cost noted at that elevation. Inadequate warning time in the LWT case reduces the evacuation-reoccupation cost in general, but the costs related to flood crests above the 8-foot level were diminished substantially to this model.

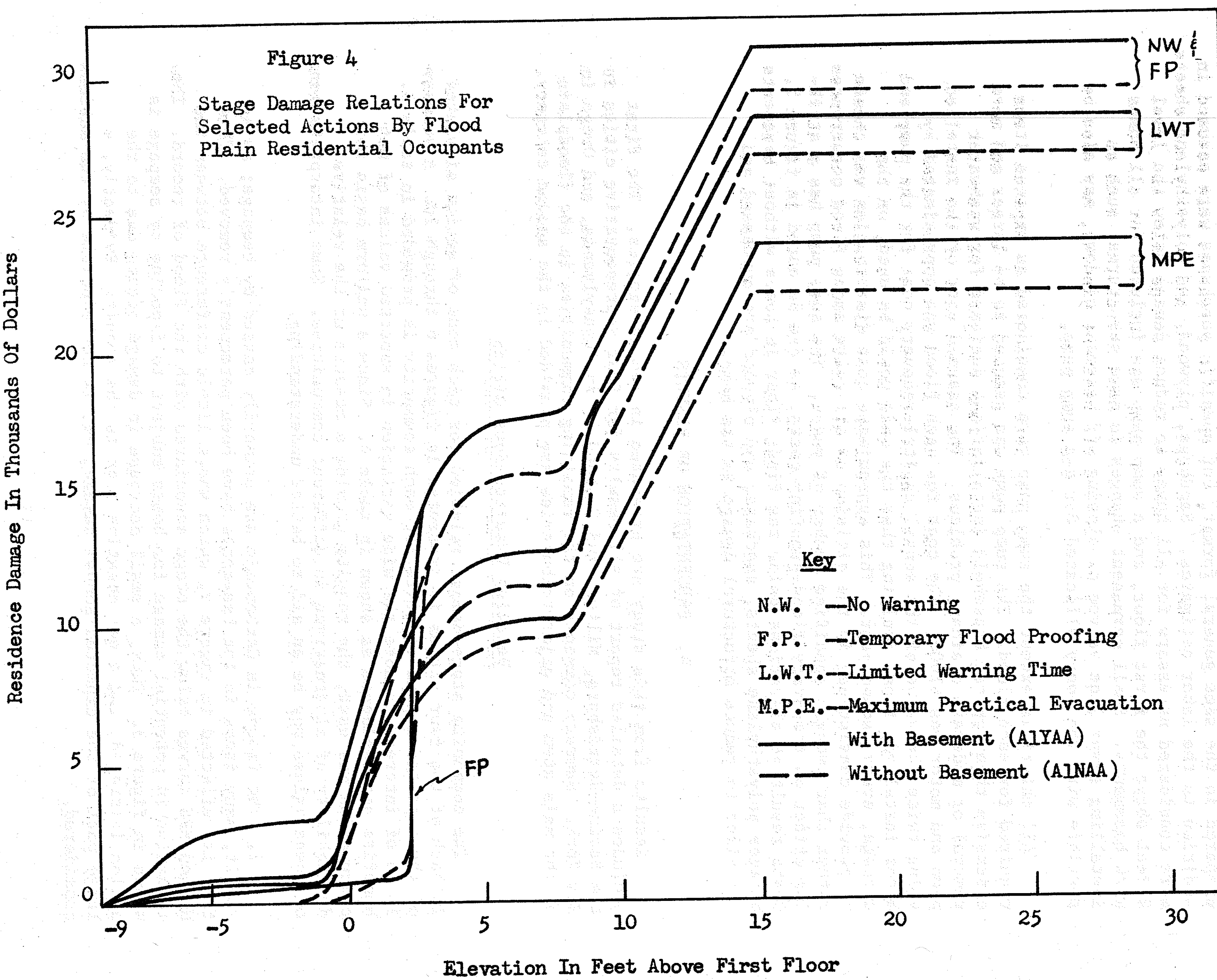

Figure 4

Stage Damage Relations For Selected Actions By Flood Plain Residential Occupants

F. Costs--Temporary Flood Proofing (FP).--Flood proofing costs were prepared in the same general format, but specific purchases were assumed in addition to the labor estimates. Sandbags, plywood, and polyethylene sheets were considered necessary for all homes to reduce damage below the level 2 feet above the first floor, and a sump pump was included for all homes with basements. Small permanent changes in some structures, such as installing sewer line valves or closing off basement windows, may also be possible with the money allocated for the sump pump.

All materials except the sump pump were considered as expense items required for each flood. The sump pump was assumed to be larger and more expensive than typical household installations designed for washwater removal or moderate drainage problems. The assumed cost of the installed pump and motor was $1000. The cost for each flood was approximated by using twice the value of the annual capital-recovery cost for the pump and motor installed; thus, implying that the unit would be used, on the average, every second year. This approximate cost distribution was chosen to provide consistency in the division of all costs among flood occurrences rather than among a specified number of years. The sump pump has a striking effect on temporary flood-proofing costs, as can be noted in figure 5. Costs result at elevations below the first floor in homes without basements because polyethylene sheets, sandbags, and plywood are purchased and installed to reduce structural damage to the home.

4. PRESENTATION OF RESULTS

Results from this study are presented in two categories. The first includes a detailed report of all results for four representative cities in the Basin--Harrisburg, Milton, and Carbondale in Pennsylvania, and Owego in New York. Summary comments on the remaining communities in the floodplain of the main stem and major tributaries are provided in the second category.

Detailed Results--Four Cities

The community stage-damage relation for each mode of action simulated in each of the four cities is presented in figures 6 through 10. A summary of the expected annual benefits for each community is provided in table 3. It is of interest to note the wide variation in expected values of net benefits per residence as shown in table 4. Since a uniform basis for calculation was used, the results provide a measure of the relative desirability of alternatives in different communities. Some interpretation of these values may be an aid to better understanding.

1. The floods in Carbondale are primarily caused by seepage; as a result, many items in the basements have been permanently removed. This fact is reflected in figure 9, which shows little difference between the NW and MPE curves below the stage associated with the flood of record. The reduction in potential damage for homes subject to flooding by seepage is shown in figure 3. Thus, a small decrease in damage occurs due to the action initiated, and a net negative cost is the result. Evidently, a large part of the expected annual damage, NW, is nonreducible by the actions considered.

Table 3.--Summary of expected annual damages and benefits from flood damage reduction alternatives - four cities

Alternative	Harrisburg, Pa.** Paxton Creek 851 Res.	1779 Res.	Milton, Pa. 1077 Res.	Carbondale Pa. 106 Res.	Owego, N. Y. 401 Res.
NW*					
Damages	$73,000	$12,000	$33,000	$19,000	$28,000
MPE					
Damages	36,000	7,500	22,000	19,000	24,000
Benefits	37,000	4,500	11,000	0	4,000
Costs	6,000	300	1,500	3,000	2,800
Net Benefits	31,000	4,200	9,500	- 3,000	1,200
LWT					
Damages	41,000	9,000	25,000	19,000	25,000
Benefits	32,000	3,000	8,000	0	3,000
Costs	5,000	200	1,000	2,700	2,300
Net Benefits	27,000	2,800	7,000	- 2,700	700
FP					
Damages	25,000	8,500	15,000	13,000	19,000
Benefits	48,000	3,500	18,000	6,000	9,000
Costs	44,000	1,600	9,000	22,000	17,000
Net Benefits	4,000	1,900	9,000	-16,000	- 8,000
LR					
Damages	47,000	9,900	26,200	18,900	26,300
Benefits	26,000	2,100	6,800	100	1,700
Costs	4,000	200	1,000	1,500	1,300
Net Benefits	22,000	1,900	5,800	- 1,400	400

*Note the abbreviations used elsewhere in the paper, i.e. NW - No Warning, MPE - Maximum Practical Evacuation, LWT - Limited Warning Time, FP - Temporary Flood Proofing and LR - Limited Response.

**The study of Harrisburg was subdivided into two parts--Reach S-5B, Paxton Creek and Reach S-5A. The reach code conforms to the Corps of Engineers Study

Table 4.--Summary of basin-wide simulation

Simulation Results, Expected Annual Values in Thousand Dollars*

River Segment	No Warning, NW	Max. Pract. Evacuation, MPE				Limited Warning Time, LWT				Temporary Flood Proofing, FP			
	Damages	Benefits,B	Costs,C	B/C	%B**	Benefits,B	Costs,C	B/C	%B	Benefits,B	Costs,C	B/C	%B
S	260	110	15	7.3	42	87	12	7.2	33	120	100	1.2	46
W	320	90	14	6.4	28	61	11	5.5	19	120	80	1.5	37
N	730	180	58	3.1	25	140	43	3.2	19	320	320	1.0	44
L	170	68	10	6.8	40	60	8	7.5	35	120	80	1.5	70
J	920	260	37	7.0	28	160	24	6.7	17	200	110	1.8	22
Others	640	210	39	5.4	33	170	30	5.7	27	320	220	1.4	50
TOTAL	3,040	918	173	5.3	30	678	128	5.3	22	1,200	910	1.3	39

River Segment Key (See Figure 12)

S = Susquehanna River, lower reaches
W = Susquehanna River, West Branch
N = Susquehanna River, upper reaches
L = Lackawanna River
J = Juniata River
Others = Other North Branch Tributaries

* Response to warning is assumed to be 100%

** %B = $\frac{\text{Benefits}}{\text{No Warning Damages}} \times 100$

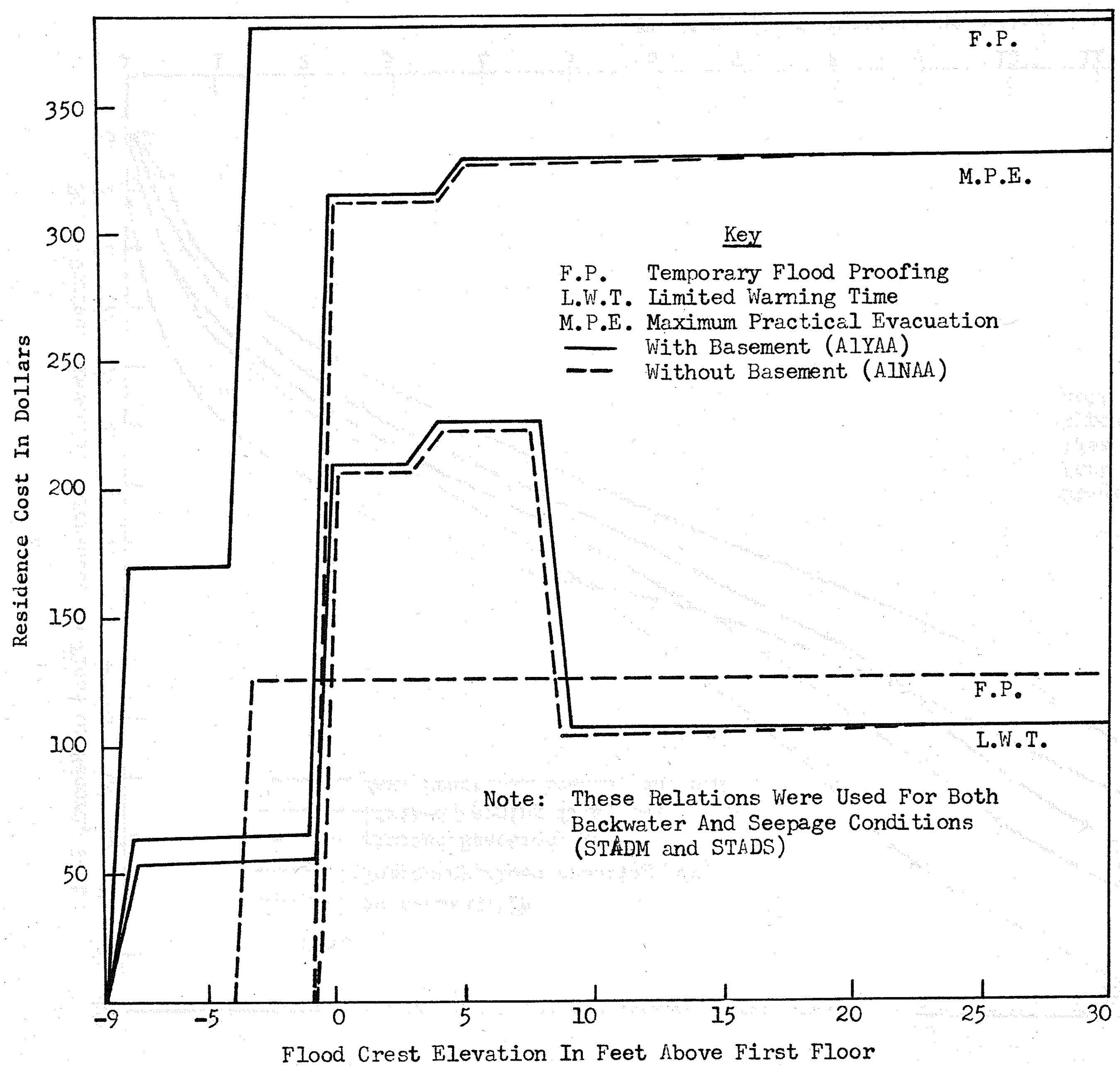

Figure 5
Stage Cost Relations for Selected Actions by Flood Plain Residential Occupants

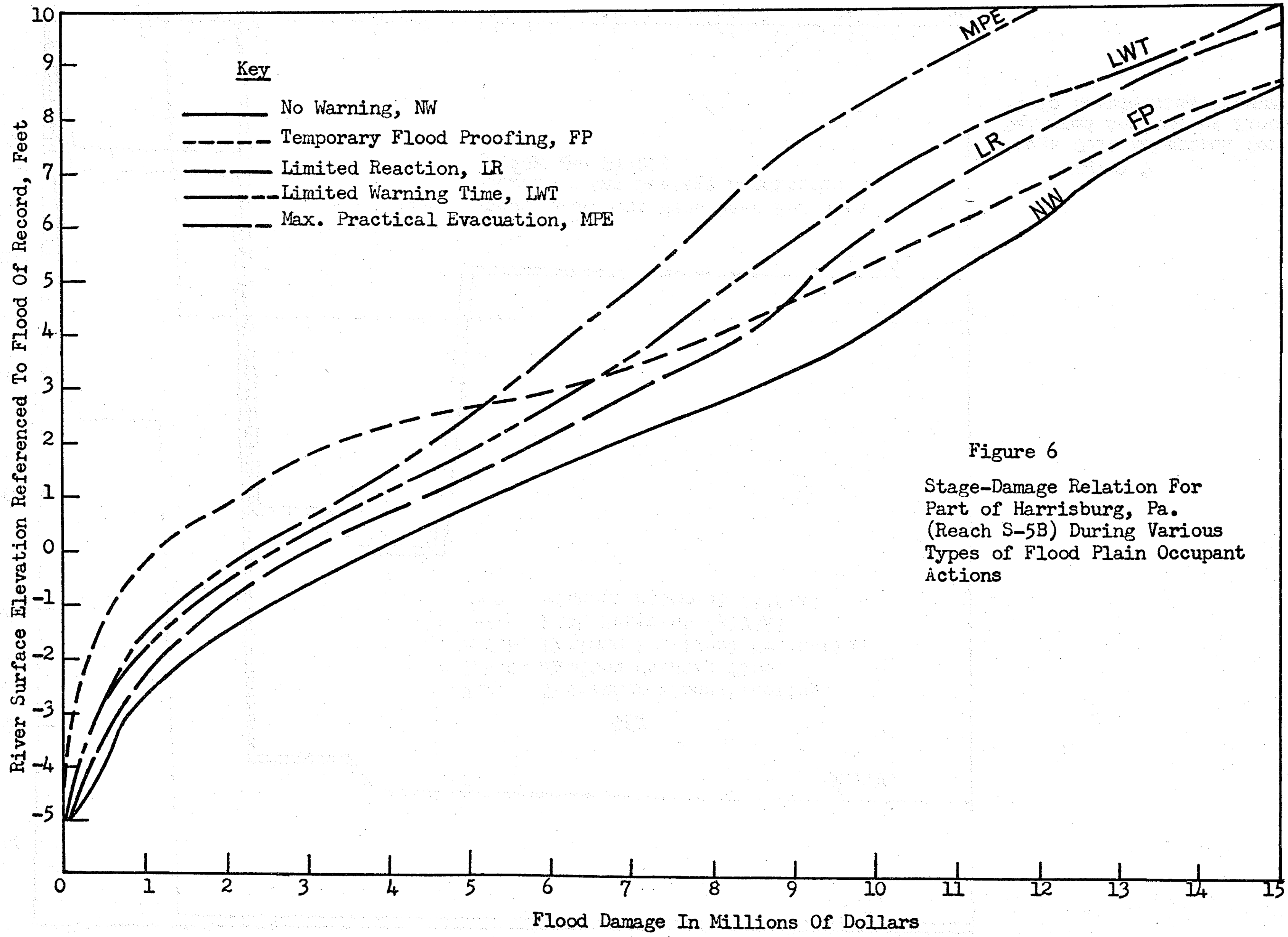

Figure 6

Stage-Damage Relation For Part of Harrisburg, Pa. (Reach S-5B) During Various Types of Flood Plain Occupant Actions

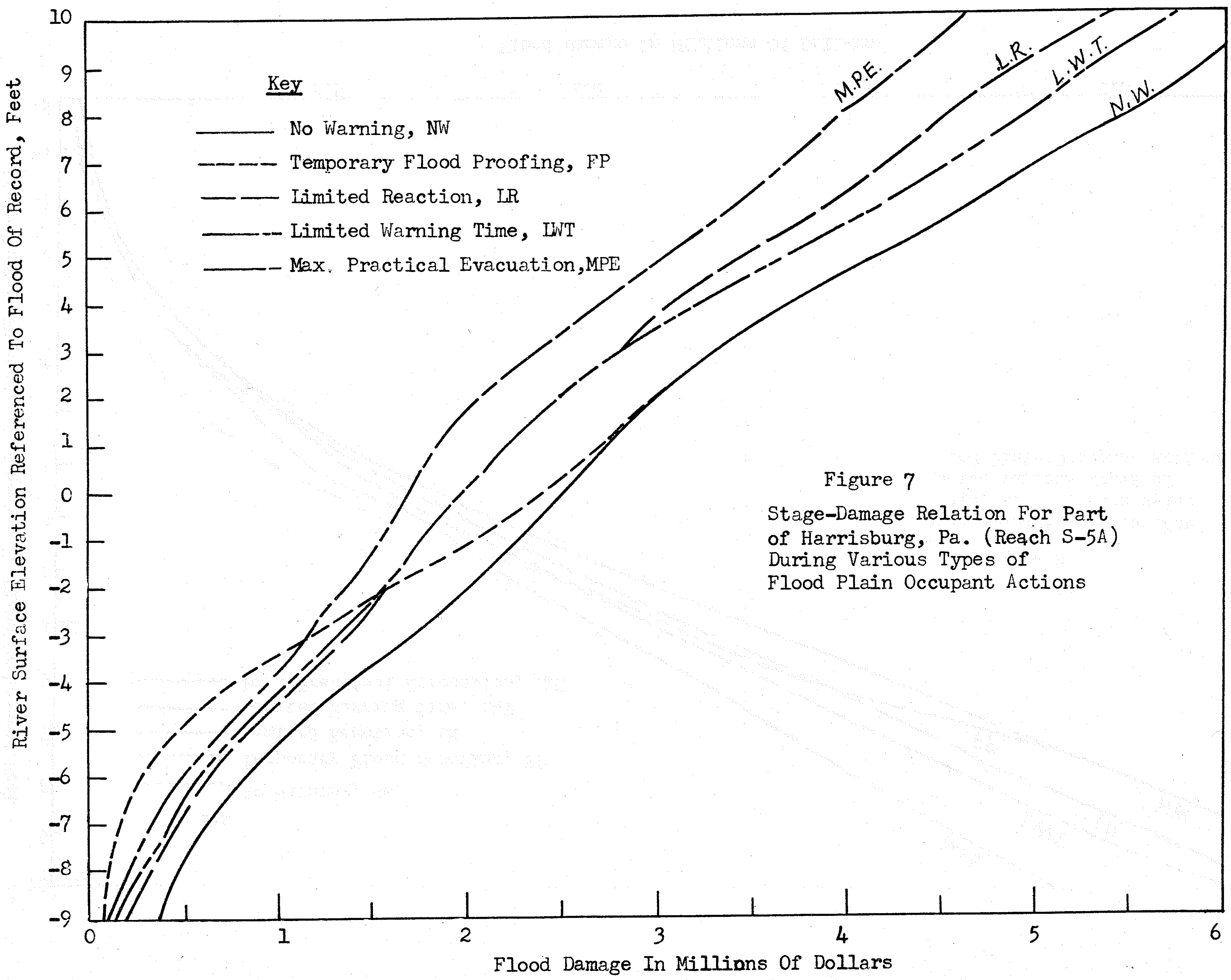

Figure 7
Stage-Damage Relation For Part of Harrisburg, Pa. (Reach S-5A) During Various Types of Flood Plain Occupant Actions

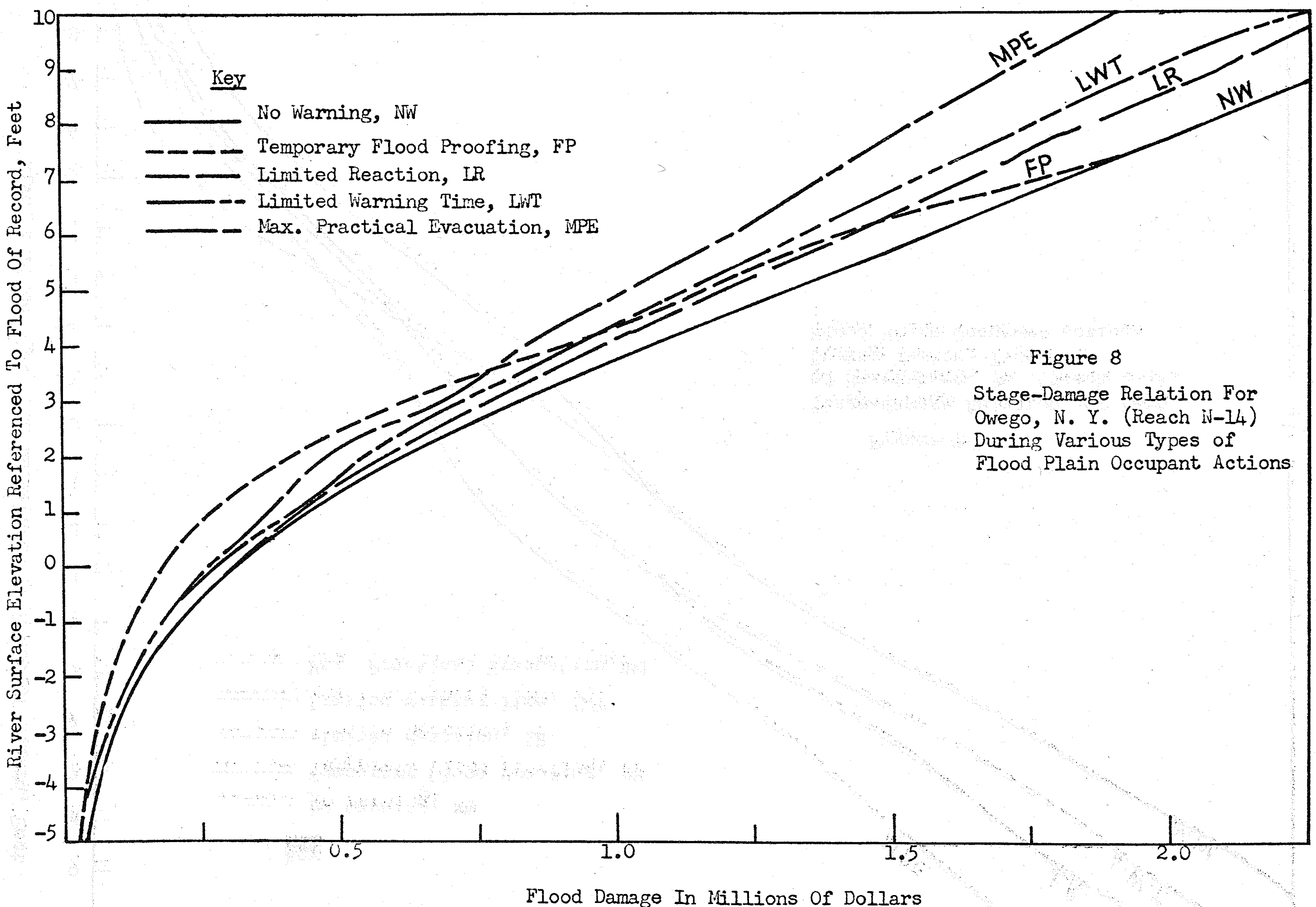

Figure 8

Stage-Damage Relation For Owego, N. Y. (Reach N-14) During Various Types of Flood Plain Occupant Actions

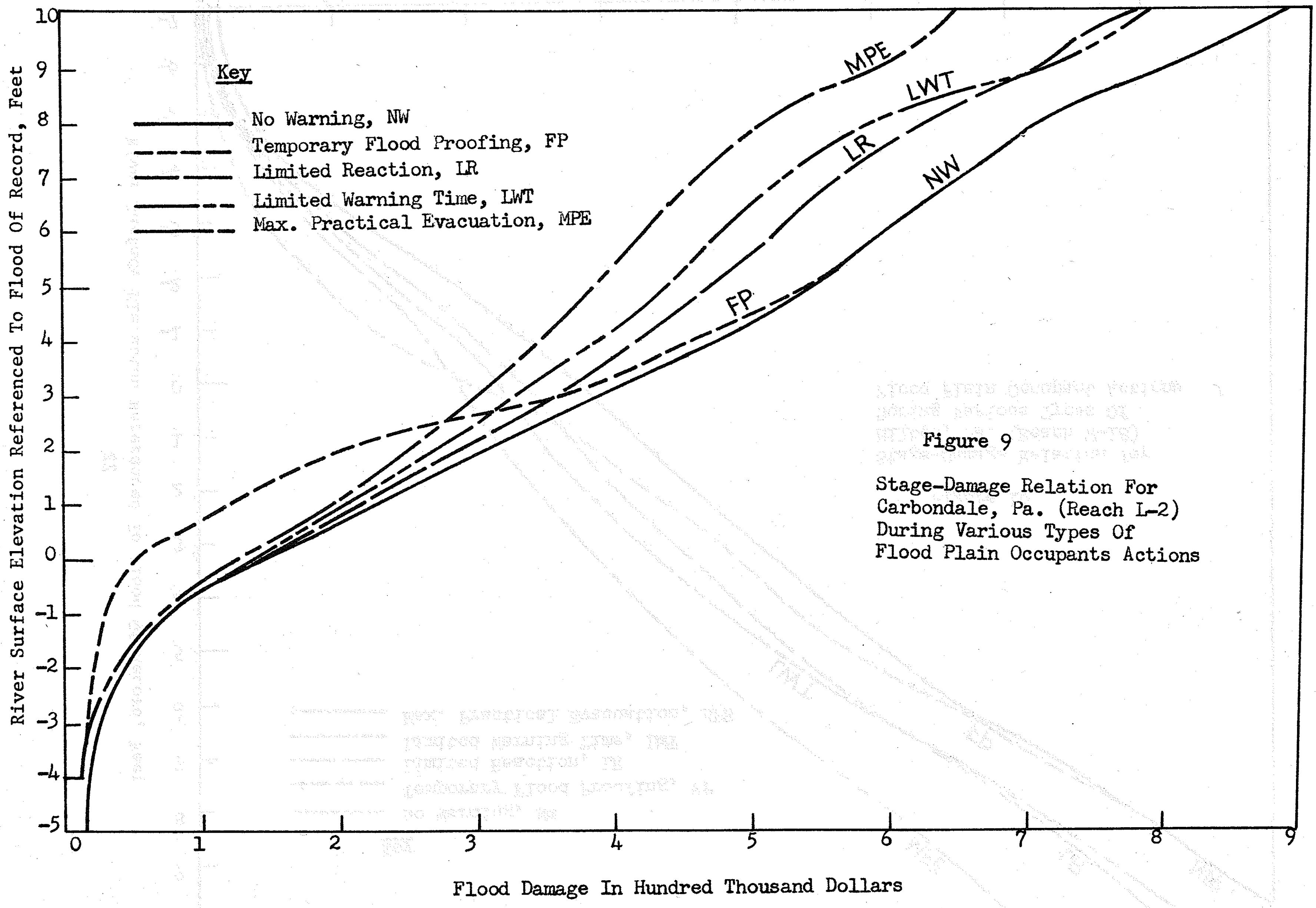

Figure 9

Stage-Damage Relation For Carbondale, Pa. (Reach L-2) During Various Types Of Flood Plain Occupants Actions

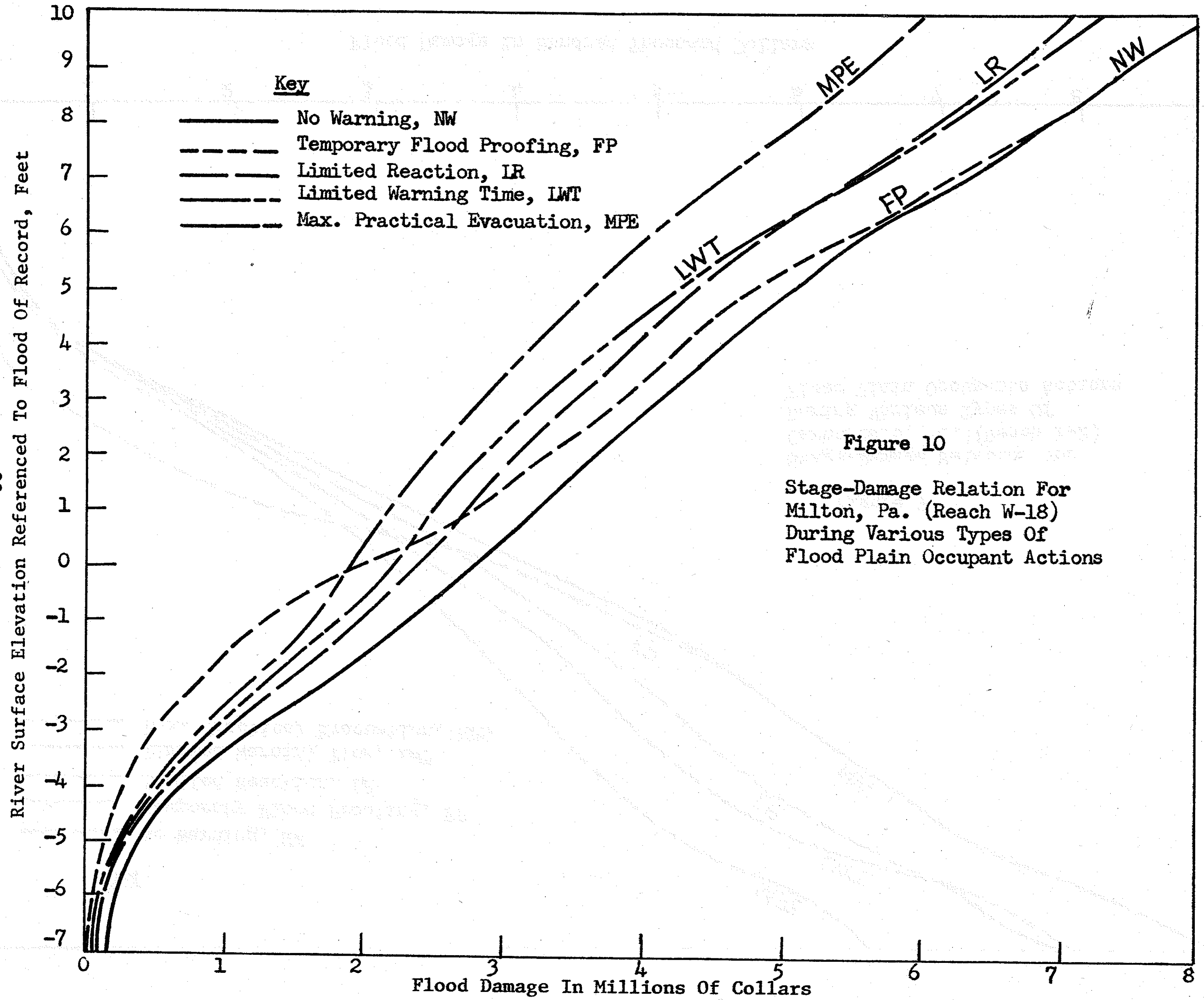

Figure 10

Stage-Damage Relation For Milton, Pa. (Reach W-18) During Various Types Of Flood Plain Occupant Actions

This interpretation of actions at Carbondale, as well as other communities throughout the Susquehanna Basin, is based on the model detailed earlier in this report and may not accurately reflect the true conditions. The costs associated with the various alternatives have been assumed to be the same for homes flooded by seepage and by overland flow. This assumption may be incorrect; therefore, it would be desirable to conduct detailed investigations at other communities similar to Carbondale.

2. The distribution of homes by elevation on the floodplain has a marked effect on the savings per structure. The two reaches in Harrisburg serve as examples. Over 90 percent of the homes are located 5 feet below the flood of record in the Paxton Creek area, while less than 10 percent of the homes in the other portions of the Harrisburg floodplain are at or below this elevation. Thus, the benefit to a large number of homes on low sections of the floodplain becomes evident when compared to the adjacent area. The elevation distribution of homes in the four cities is presented in figure 11.

3. The gross savings resulting from temporary flood proofing are generally larger than from the evacuation alternatives, but the costs are also greater and a reduced net benefit occurs. The costs associated with the sump pump in homes with basements may be excessive as a larger-than-usual sump pump was assumed, and extra costs were included for installation. (See appendix B for details.) Perhaps this alternative should be considered only in areas where the flood level seldom exceeds the line 2 feet above the first floor, such as the higher sections of the floodplain.

4. The results of the limited-response simulation demonstrate that benefits will not be seriously reduced by limited action in communities with most homes located out of areas frequently flooded. Homes at low elevations represent a large fraction of floodplain residences in both Paxton Creek and Carbondale; so, limited reaction could create extensive damage.

Summary Results--Remainder of Basin

The simulation of flood damages to urban residences throughout the Basin provided extensive detailed results for 116 reaches of the Susquehanna River and major tributaries as defined by the Baltimore District, Corps of Engineers. A summary of the results is presented in tables 4 and 5. An interpretation of the values, which are based on the model described earlier, may aid in the study of these tables.

1. Approximately one-fifth to one-third of urban residential flood damages may be reduced through use of a warning system (when coupled with 100 percent response) in the Basin. The No-Warning (NW) damages were \$3,040,000, while the benefits (reduction in damages) from the three actions studies range from \$678,000 to \$1,200,000 for Limited Warning Time (LWT) and Temporary Flood Proofing (FP), respectively. An improved estimate of reducible damages could be obtained by using the appropriate warning time for each reach. Downstream reaches, such as exist in part of the lower Susquehanna (segment S in table 4), receive warning times of at least

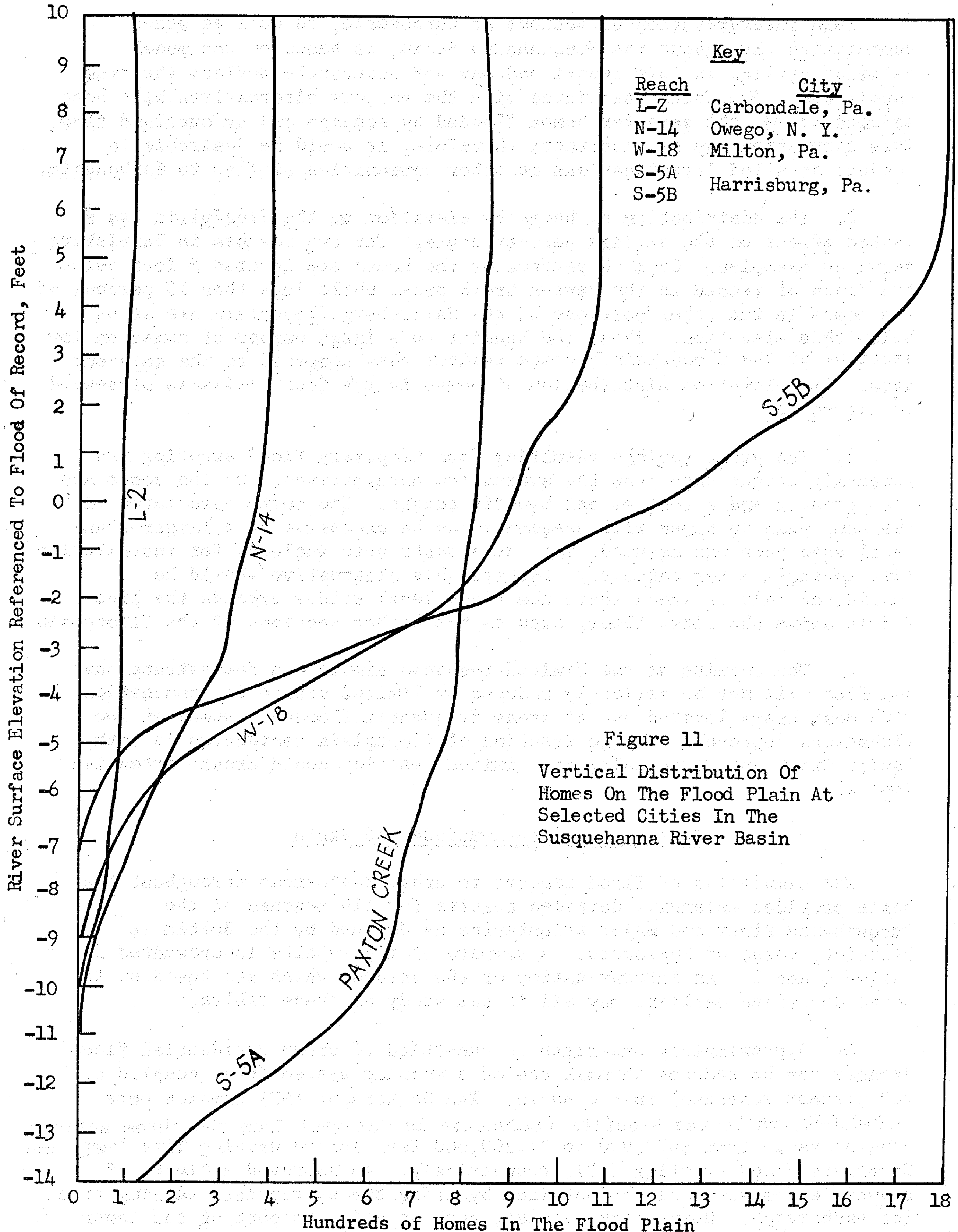

Figure 11

Vertical Distribution Of Homes On The Flood Plain At Selected Cities In The Susquehanna River Basin

Table 5.--Basin distribution of net savings

River Segment	No. of Reaches	No. of Simulation Cases (MPE, LWT or FP) + Net Savings	- Net Savings
S	10	29	1
W	22	60	6
N	32	67	29
L	6	12	6
J	16	45	3
Others	30	64	26
Totals	116	277	71

Net Savings are positive in 277/348 (80%) of the cases

River Segment Key (See Figure 12)

S = Susquehanna River, lower reaches
W = Susquehanna River, West Branch
N = Susquehanna River, upper reaches
L = Lackawanna River
J = Juniata River
Others = Other North Branch Tributaries

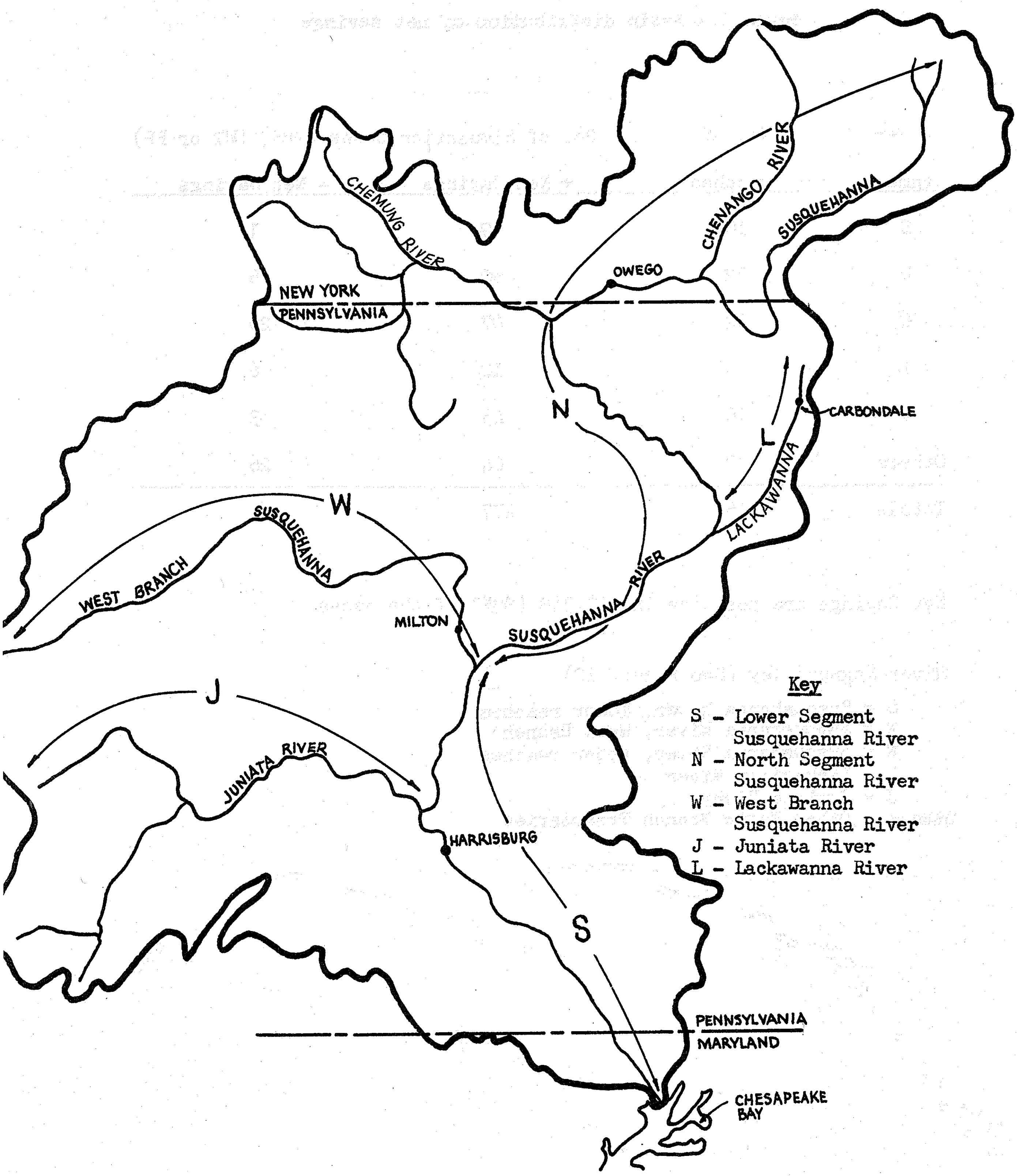

Figure 12

Susquehanna River Basin - Major Segments of River System

24 hours; therefore, the MPE damages are appropriate. Elsewhere in the Basin the LWT values could be used to indicate reducible damages. The result of such an improved calculation would probably indicate reducible damages to be approximately one-quarter of the total.

2. The estimated costs for evacuation and reoccupation vary widely according to the river segment and type of action. Flood-proofing (FP) costs consistently exceed those of the MPE and LWT alternatives. Benefit-to-cost ratios vary from 1.0 to 7.5; the MPE and LWT ratios range from 3.1 to 7.5, and the FP ratio varies from 1.0 to 1.8.

3. Benefit-to-cost ratios exceed one in over 80 percent of the reach calculations. Most of the reaches exhibiting negative values of net savings exist in the North Branch or its tributaries (noted as "Others" in table 5). Flood-proofing actions developed costs exceeding the benefits in 35 to 71 simulations which indicated negative net savings.

5. CONCLUSIONS AND RECOMMENDATIONS

The ability to simulate action of floodplain occupants has been demonstrated to a limited extent in this report. Conclusions, both specific and general, from the investigation seem apparent. The specific conclusions are:

1. Both evacuation and temporary flood proofing would be desirable actions for residences in three of the four cities described in detail if the costs to reduce damages and response to warning were similar to those used in the model. The assumed actions would not be warranted in Carbondale, according to the simulation results, since negative benefits would occur. Evacuation, even with the reduced warning time assumed in the LWT program, generally provides more benefits than temporary flood proofing, although Milton, Pa., is an exception.

2. Actions by urban residents throughout most of the Susquehanna River Basin to reduce flood damages, when based on receipt of a warning, will provide benefits exceeding the costs. Although the cost estimates, which are detailed in the appendices, were based on limited field information and are incomplete, it is unlikely that benefit-to-cost ratios in the vicinity of 3 to 7 will be reduced to values less than one after detailed study and improvement. The annual cost of providing the warning service in the basin is approximately $100,000, of which only a fraction--perhaps one-third--would be associated with residences. Therefore, this additional cost would not affect the overall results. A substantial increase in residential benefits would occur at a marginal-cost increase when the evacuation of private automobiles is included in the analysis. Those reaches reflecting negative net savings will require special consideration to determine the best way for serving the populace. If the model used is appropriate for that particular community, some other action such as zoning, flood insurance, or a structural measure may be more desirable.

3. The results cannot be used alone to estimate the total benefits accruing from the river forecast service. This would require additional

information on industrial and commercial damage reductions resulting from a flood warning (not available at the time of the study) and costs associated with the warning service.

Some general conclusions are:

1. Comparative studies of nonstructural alternatives in the floodplain can be made using this simulation technique. The results can be a significant contribution to a comprehensive river basin study if the basic data used are representative of the area.

2. The framework for additional studies that include other variables affecting the effectiveness of a warning system has been defined. Variations in warning time and response were included for evacuation only and no attempt was made to simulate changes in economic development on the floodplain. Although many commercial facilities can be simulated in addition to residences, unique commercial units and all industrial installations do not have sufficient similar characteristics for study in this manner. The availability of floodplain survey data in a form readily adaptable to the computer will increase the opportunity for such studies.

3. Many intangible areas still exist that have not yet been quantified, and may never be, for possible inclusion in a simulation of activities by floodplain occupants such as mental anguish, or, in some cases, elation, associated with a flood. There is opportunity for major progress toward a more objective view of alternative actions, however, and the effort should be directed toward areas where such progress is promising.

Recommendations apparent from this investigation include the following:

1. Continue the study of nonstructural alternatives for flood damage reduction by collecting floodplain physical data in a form appropriate for simulation with a computer. Include automobiles in the data collection program.

2. Make a sensitivity study of the variables involved to determine where model improvements can be made. Stage damage tables with less detail may provide adequate reliability, and community organization, as reflected in response to warning, may be more crucial to reducing damages than estimated.

3. Conduct public opinion surveys, both factual and attitudinal, to determine more accurate measures of the costs and benefits associated with floods and the related actions. Perhaps a measure of the willingness to pay and the consumer's surplus would help to quantify some of the present intangibles.

4. Direct future stages of the continuing flood damage investigations toward the eventual integration of all elements into a floodplain management program that will indicate desirable combinations of alternative actions, both structural and nonstructural, to approach optimal development of the floodplain.

6. ACKNOWLEDGMENTS

This investigation was initiated by the author as a U. S. Government employee in the Office of Hydrology, Weather Bureau, Environmental Science Services Administration, during the summer of 1967. Many individuals have participated since then, but space permits mention of only a few.

Several permanent staff members in the Office of Hydrology provided crucial assistance throughout the period of the study. Mr. R. F. Kresge coordinated and directed all phases of the effort. Mr. W. W. Lamoreux and his colleagues provided the necessary computer-oriented services. Messrs. W. E. Hiatt and M. A. Kohler reviewed the program periodically during the study.

The Corps of Engineers has provided the opportunity for this investigation. Messrs. W. G. Sutton and R. W. Plott, Office of the Chief of Engineers, and R. H. Resta and K. W. Murdock, Baltimore District Office, assisted in the acquisition of data and made helpful suggestions during early stages of the study.

Informal discussions with Mr. B. T. Bower, Resources For The Future, clarified several issues and contributed to the study.

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APPENDIX A

STAGE-DAMAGE, STAGE-COST TABLES AND CORRECTION TABLE FOR VARIOUS RESIDENCES

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*These are shown in the pages of computer output which were omitted from this Memorandum to reduce its size; the STADM and STADS are given on the computer output.

PAPP - CORRECTION TABLE FOR VARIOUS RESIDENCES

To convert any AA (Average size, Average furnishings) base curve to various combinations of size and furnishings, the following factors apply.

	For Class A Residences	For Class B Residences	For Class C Residences	For Cabins
LH*	= AA X 1.30	= AA X 1.34	= AA X 1.54	= AA X 2.18
LA	= AA X 1.11	= AA X 1.20	= AA X 1.21	= AA X 1.37
LL	= AA X .95	= AA X 1.06	= AA X .88	= AA X .59
AH	= AA X 1.17	= AA X 1.14	= AA X 1.35	= AA X 1.69
AA	= AA X 1.00	= AA X 1.00	= AA X 1.00	= AA X 1.00
AL	= AA X .84	= AA X .86	= AA X .70	= AA X .43
SH	= AA X 1.06	= AA X .91	= AA X 1.10	= AA X 1.00
SA	= AA X .90	= AA X .78	= AA X .79	= AA X .76
SL	= AA X .74	= AA X .67	= AA X .57	= AA X .27

For all trailers, use the base curve.

* LH is Large size, High furnishings
LA is Large size, Average furnishings
LL is Large size, Low furnishings
AH is Average size, High furnishings
AA is Average size, Average furnishings
AL is Average size, Low furnishings
SH is Small size, High furnishings
SA is Small size, Average furnishings
SL is Small size, Low furnishings

APPENDIX B

SAMPLE WORK SHEET FOR PREPARATION OF SYNTHETIC STAGE-DAMAGE TABLE

PREPARED BY BALTIMORE DISTRICT, USCE

TYPE A1YAA RESIDENCE UNDER CONDITIONS OF NO WARNING

Description	Elevation Of Water In Residence									First Floor			
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3
Furnishings: 1st Floor													
Living Room										0	300	650	950
Dining Room										0	100	325	475
Kitchen with Nook										0	20	50	150
Food										0	0	25	25
Refrigerator										0	25	50	75
Stove										0	0	0	0
Garbage Disposal										0	0	0	25
Exhaust Fan										0	0	0	0
Clean Up 1st Floor										0	100	200	300
Master Bedroom										0	100	525	900
2 Each--Single Bedrooms										0	100	700	1150
Linen										0	0	25	50
Furnishings: Basement													
TV--Phono--Records	0	200	500	825	825	825	825						
Hot Water Heater	0	25	50	125	125	125	125						
Automatic Washer	0	25	50	75	100	150	150	1500	1500	1500	1500	1500	1500
Dryer	0	25	25	50	75	100	125						
Tools and Chattels	0	75	150	225	275	275	275						
Heating Unit	0	50	75	100	100	100	100	100	100	100	800	800	800
Central Air Condit.	0	0	25	50	75	75	75	75	75	75	75	75	75
Storage	0	100	250	400	600	750							
Recr. Room	0	50	125	200	250	330	1230	1230	1230	1230	1230	1230	1230
Clear Up Basement	0	50	100	150	150	150							
Grounds, Fences, Out Buildings						0	50	100	150	200	200	200	200
Structural													
Shell									0	2430	4320	5800	6750
Foundation													
TOTAL DAMAGE	0	600	1350	2200	2575	2880	2955	3005	3055	5535	8870	12155	14655

SAMPLE WORK SHEET FOR PREPARATION OF SYNTHETIC STAGE-DAMAGE TABLE

PREPARED BY BALTIMORE DISTRICT, USCE

TYPE A1YAA RESIDENCE UNDER CONDITIONS OF NO WARNING

Description	Elevation Of Water In Residence											
	+4	+5	+6	+7	+8	+9	+10	+11	+12	+13	+14	+15
Furnishings: 1st Floor												
Living Room	1025	1130	1130	1130								
Dining Room	600	780	780	780								
Kitchen with Nook	250	350	400	475	2710	2710	2710	2710	2710	2710	2710	2710
Food	50	75	75	75								
Refrigerator	250	250	250	250								
Stove	50	75	75	75	75	90	110	130	150	170	190	200
Garbage Disposal	50	50	50	50	50	50						
Exhaust Fan	0	25	25	25	25	50						
Clean Up 1st Floor	300	300	300	300	300	300						
Master Bedroom	1100	1280	1280	1280	1280	1280	3230	3230	3230	3230	3230	3230
2 Each--Single Bedrooms	1250	1400	1400	1400	1400	1400						
Linen	75	100	125	150	150	150						
Furnishings: Basement												
TV--Phono--Records												
Hot Water Heater	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Automatic Washer												
Dryer												
Tools and Chattels												
Heating Unit	800	800	800	800	800	910	1020	1130	1240	1350	1460	1600
Central Air Condit.	75	75	75	75	75	175	275	375	475	575	675	800
Storage												
Recr. Room	1230	1230	1230	1230	1230	1230	1230	1230	1230	1230	1230	1230
Clear Up Basement												
Grounds, Fences, Out Buildings	200	200	200	200	200	200	200	200	200	200	200	200
Structural												
Shell	7430	7560	7700	7830	7970	9210	10450	11690	12930	14170	15410	16650
Foundation					0	390	780	1170	1560	1950	2340	2750
TOTAL DAMAGE	16235	17180	17395	17625	17765	19645	21505	23365	25225	27085	28945	30870

SAMPLE WORK SHEET FOR PREPARATION OF SYNTHETIC STAGE-DAMAGE TABLE

PREPARED BY BALTIMORE DISTRICT, USCE

TYPE B1NAA RESIDENCE UNDER CONDITIONS OF NO WARNING

Description	Elevation Of Water In Residence									
	-4	-3	-2	-1	First Floor 0	+1	+2	+3	+4	+5
Furnishings										
Master Bedroom					0	50	250	450	550	700
Single Bedroom					0	25	175	325	325	450
Single Bedroom					0	25	175	325	325	450
Living Room					0	175	375	575	600	680
Dining Area					0	50	125	200	250	300
Kitchen with Nook					0	20	50	100	150	200
TV--Phono--Records					0	50	200	400	400	400
Food					0	0	25	25	50	75
Linen					0	0	25	50	75	100
Refrigerator					0	25	50	75	200	200
Stove					0	0	25	25	50	100
Garbage Disposal					0	0	0	25	50	50
Clean Up 1st Floor					0	50	100	150	150	150
Heating Unit					0	50	75	100	100	100
Hot Water Heater					0	25	50	125	125	125
Automatic Washer					0	25	50	75	100	150
Dryer					0	25	25	50	75	100
Tools and Chattels					0	75	150	225	275	275
Storage										
Grounds, Fences, Out Buildings	0	25	50	75	100	100	100	100	100	100
Structural										
Shell				0	1625	2890	3880	4520	4970	5060
Foundation										
TOTAL DAMAGE	0	25	50	75	1725	3660	5905	7920	9020	9765

SAMPLE WORK SHEET FOR PREPARATION OF SYNTHETIC STAGE-DAMAGE TABLE

PREPARED BY BALTIMORE DISTRICT, USCE

TYPE B1NAA RESIDENCE UNDER CONDITIONS OF NO WARNING

Description	Elevation of Water In Residence									
	+6	+7	+8	+9	+10	+11	+12	+13	+14	+15
Furnishings										
Master Bedroom	700	700								
Single Bedroom	450	450								
Single Bedroom	450	450								
Living Room	680	680								
Dining Area	300	300								
Kitchen with Nook	250	300	4055	4055	4055	4055	4055	4055	4055	4055
TV--Phono--Records	400	400								
Food	75	75								
Linen	125	150								
Refrigerator	200	200								
Stove	150	150								
Garbage Disposal	50	50								
Clean Up 1st Floor	150	150								
Heating Unit	100	100	100	260	420	580	740	900	1060	1200
Hot Water Heater	125									
Automatic Washer	150									
Dryer	125									
Tools and Chattels	275	775	775	775	775	775	775	775	775	775
Storage				0	75	150	225	275	275	275
Grounds, Fences, Out Buildings	100									
Structural										
Shell	5150	5240	5330	6160	6990	7820	8650	9480	10310	11130
Foundation			0	120	240	360	480	600	720	850
TOTAL DAMAGE	10005	10170	10260	11370	12555	13740	14925	16110	17270	18360

DETAILS - COST OF REOCCUPATION CALCULATIONS, MPE

The cost of reoccupation was calculated by estimating the man hours required for moving household items to safe higher elevations either inside or outside of the house. Hourly labor rates were then used to provide dollar values. The wage rate was selected to include all related costs, such as truck rental, overhead, and storage. The rates chosen for A-, B-, and C-type residences were $8, $6, and $4 per hour, respectively. The following manpower requirement estimates served as the basis for the costs used in the study. The same number of man hours was used for each house type; i.e., A1YAA, B1YAA, and C1YAA, all received the same hourly estimate. Cost variations for different homes occurred due to the varying wage rates noted and also due to the correction multiplier, PAPP, which adjusts for residences of different sizes and for furnishings of different values than present with the AA situation. The total cost of both evacuation and reoccupation was estimated by multiplying the stated result by 1.75. The reduced cost of evacuation was noted by Red Cross officials and is discussed further on pages 9 through 13.

Cost estimates related to the LWT case were obtained in a similar manner; however, labor estimates reflected the smaller number of items which were moved due to the reduced warning time.

The existence of other significant costs which have not been included is recognized. Variations in the accuracy of the forecast would involve cost. Police, fire, and other disaster-oriented services in the local community would incur added cost as a result of the warning service. The lack of data related to these actions prevented their inclusion in this study; however, it seems unlikely that the overall results of this investigation would be changed if they had been included.

TYPICAL ESTIMATES - COST OF REOCCUPATION, MPE

A1YAA RESIDENCE USED FOR EXAMPLE

Flood Stage*	House Area	Action	Man Hours
0 and higher	Living Room	Reoccupy with 2 end tables 2 tablelamps, 2 floor lamps, 2 stuffed chairs, 1 rug, 1 davenport, 1 TV, 1 bookcase	4
0 and higher	Dining Room	Reoccupy with 1 dining room table, 6 chairs, 1 hutch or other buffet	4
0 and higher	Kitchen	Reoccupy with 1 kitchen table, 4 chairs, 1 refrig.	2
0 to 3 ft.	Kitchen	Replace pans, canned goods, etc. which had been placed on counter tops and higher shelves	1
3 ft.and higher	Kitchen	Replace pans, canned goods, etc. which had been evacuated from building	2
0 and higher	Master Bedroom	Reoccupy with 1 bed (frame and mattress), 1 dresser, 1 chest of drawers, 1 rug	2
and higher	Single Bedroom	Reoccupy with 1 bed (frame and mattress), 1 dresser, 1 rug	1 1/2
0 and higher	Single Bedroom	Same as above	1 1/2
-8 to 0	Basement	Replace from storage on 1st floor: TV, phono, records, tools, chattel washer and dryer (20% of homes) storage and recr. room	2 1/2 2
0 and higher	Basement	Reoccupy basement with items listed above that were removed from house (Same time as above + 2 hours)	6 1/2

The following stage-cost table for evacuation and reoccupation of an A1YAA house results from these estimates. The wage rate for "A" type homes is $8 per hour.

-8 to -1 feet	0 to +3 feet	+4 to +20 feet
$63	$315	$330

*Elevations referenced to first floor

DETAILS - COST OF TEMPORARY FLOOD PROOFING

The temporary flood-proofing action assumed for this study involves two types of costs--those related to each flood event as in the MPE and LWT actions and those related to capital costs for items that will serve for a number of floods. The costs related to each flood event are:

Purchase and placement of sandbags

Purchase and placement of polyethylene sheets

Purchase and placement of plywood

Labor required for limited evacuation and reoccupation of basement and first floor

Capital costs are assumed as a requirement only for homes with basements; a sump pump is installed in the basement. The pump installation is depreciated over a 20-year period. A value equal to twice the annual capital-recovery cost is assumed as the cost contribution to each flood from the sump pump installation. Sump pump operation to reduce flood damage every other year (on the average) is implied by this assumption.

Cost estimates for A-type homes are presented as a sample. The values stated represent the total cost; no multiplier was used to differentiate activity prior to and following a flood event.

TYPICAL ESTIMATES - COST OF TEMPORARY FLOOD PROOFING

Sump Pump (For Homes With Basement)

Pump, Motor and Regulator	$500
Installation (Elect. and mech.)	500
	$1000

Annual Capital Recovery Cost = 1000 X .087 = $87

Assume Cost Per Flood	= 87 X 2 =	174
+ Operating Cost		50
Cost Per Flood	=	$224 - Say $225

Plywood

"A: House (With Basement)

Purchase and Install 3 sheets of 4 ft. x 8 ft. x 3/4 in. plywood over windows and doors as required.

Purchase Cost	=	$48
Installations Cost	=	40
Cost Per Flood	=	$88 - Say $90

"A" House (Without Basement)

2 sheets of plywood (same as above)

Purchase Cost	=	$32
Installation Cost	=	30
Cost Per Flood	=	62 - Say $60

Sandbags

Assume purchase cost = $ .50 per bag
Assume sand and fill cost = $1.50 per bag

"A" House (With Basement)
100 bags at $2 per bag = $200 per flood

"A" House (Without Basement)
50 bags at $2 per bag = $100 per flood

Evacuation and Reoccupation

For houses with basements only

"A" House
MPE Cost of Evacuation and Reoccupation $63 - say $60

Polyethylene Sheets

"A" House	(With Basement)	(Without Basement)
Purchase Cost	= $40	$20
Install. Cost	= 40	20
Total Cost	= $80	40

The following stage-cost table for temporary flood proofing of an A1YAA house results from these estimates. The ground level is assumed to be 3 feet below the first floor:

-9 to -6 feet	-5 to -4 feet	-3 feet and higher
\$225	\$285	\$605

(Elevations referenced to first floor)