WORLD METEOROLOGICAL ORGANIZATION

Operational Hydrology
Report No. 3

BENEFIT AND COST ANALYSIS OF HYDROLOGICAL FORECASTS

A state-of-the-art report

by Professor Harold J. Day

IMO-WMO
CENTENARY

WMO - No. 341

Secretariat of the World Meteorological Organization · Geneva · Switzerland
1973

NOTE

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the World Meteorological Organization concerning the legal status of any country or territory or of its authorities, or concerning the delimitation of its frontiers.

CONTENTS

CONTENTS

FOREWORD

The establishment of some hydrological forecasting systems requires very large capital investments. The question therefore arises as to whether investment in an entirely new forecasting service is economically justifiable as a replacement of an existing forecasting system or whether it would be sufficient simply to improve the existing system.

Noting the acute shortage of guidance on this subject, the WMO Commission for Hydrology, at its third session (Geneva, 1968), assigned to its Working Group on Hydrological Forecasting the task of preparing a report on the methods available for benefit/cost assessment of systems of hydrological forecasting. The subject being of a very specialized nature, and the working group being engaged in other very important matters, WMO engaged Professor Harold J. Day (U.S.A.) to prepare a state-of-the-art report.

This report was revised in the light of the comments of the Working Group on Hydrological Forecasting and by other experts in the field.

In view of the fact that many nations are rapidly progressing towards a more formal process of planning of river-basin development, wherein the economics of each branch, including those of hydrological forecasting, become very important, publication of this report on benefit and cost analysis of hydrological forecasts is very timely.

I am pleased to have this opportunity of expressing to Professor Day the sincere appreciation of the World Meteorological Organization for the preparation of this useful publication.

D. A. Davies
Secretary-General

SUMMARY

This report contains a review of recent progress in evaluating the benefits and costs of hydrological forecasts. The combination of hydrology and economics provides valuable guidance in the decision-making process in water resources management and hydrological forecasts.

Lack of sufficient data prevents the use of systems-analysis techniques to seek optimal solutions to flood-plain management, which includes both structural (e.g. dam construction) and non-structural (e.g. evacuation) action. This report therefore describes one element (flood forecasting) of a comprehensive basin-analysis procedure which may serve as a basis for application to other types of forecast.

Concepts of hydraulics, hydrology and economics have been combined to develop an analysis procedure which is similar to that used for flood-damage evaluation studies related to structural changes. Difficulties in evaluating intangible benefits and costs, especially those associated with the potential loss of life, continue to prevent their inclusion.

The report emphasizes three factors with regard to a flood-damage reduction programme quite apart from the engineering works or the magnitude of the flood. These are: the length of warning time, the magnitude of reducible damage, and efficiency of response to warning. In theory, by considering the influence of such factors on flood damage, an estimate can be made of the benefit produced by each, and thereby permit decisions to be taken with regard to the whole flood-prevention scheme on economic grounds.

The report describes the use of generalized mathematical models for simulating flood-damage reduction alternatives. This is followed by a description of an actual study as an example of a benefit/cost analysis.

RESUME

Le présent rapport expose les progrès qui ont été récemment accomplis en ce qui concerne l'évaluation du coût des prévisions hydrologiques et des bénéfices que celles-ci apportent. Les données conjuguées de l'hydrologie et de l'économie fournissent de précieuses indications qui permettent d'arrêter des décisions judicieuses en ce qui concerne l'exploitation des ressources en eau et l'établissement de prévisions hydrologiques.

L'insuffisance des données dont on dispose empêche d'appliquer les méthodes de l'analyse des systèmes pour rechercher des solutions optimales aux problèmes posés par l'exploitation des plaines inondables aussi bien en ce qui concerne les travaux d'aménagement (par exemple construction de barrages) que l'exploitation proprement dite (par exemple évacuation). Le rapport décrit donc un exemple particulier (prévision des crues) d'une méthode générale d'analyse de bassin à partir duquel on peut généraliser l'application de la méthode à d'autres types de prévisions.

On a fait appel à des notions d'hydraulique, d'hydrologie et d'économie pour élaborer une méthode d'analyse analogue à celle qui est utilisée pour évaluer les dégâts que risquent de provoquer les crues en fonction des travaux d'aménagement effectués sur les cours d'eau. En raison des difficultés éprouvées pour évaluer les bénéfices et les coûts difficilement chiffrables, notamment pour ce qui touche les pertes en vies humaines, il est actuellement impossible de tenir compte de ces éléments dans l'analyse.

Le rapport insiste sur trois facteurs qui, indépendamment des travaux de génie civil ou de l'ampleur de la crue, sont d'une grande importance pour réduire les dégâts provoqués par les crues. Il s'agit du temps qui s'écoule entre l'annonce de la crue et l'arrivée de celle-ci, de l'importance des dégâts qui peuvent être évités et de l'efficacité des réactions déclenchées par l'avis d'annonce de crue. Théoriquement, en examinant l'influence de ces facteurs sur les dégâts causés par les crues, on peut estimer le gain imputable à chacun de ces facteurs et l'on se trouve donc en situation de prendre des décisions économiquement motivées quant au système de prévention des crues considéré dans son ensemble.

Le rapport expose comment faire usage de modèles mathématiques généralisés pour simuler les diverses solutions envisageables pour réduire les dégâts causés par les crues, puis donne un exemple concret d'une analyse coût-bénéfice.

РЕЗЮМЕ

В настоящем докладе содержится обзор последних достижений по оценке пользы гидрологических прогнозов и затрат, связанных с ними. Сочетание гидрологии и экономики обеспечивает ценное руководство для принятия решений в области водного хозяйства и гидрологического прогнозирования.

Отсутствие достаточного количества данных не позволяет использовать методы анализа систем для отыскания оптимальных решений по организации работ в пойме, которые включают как строительные (т.е. строительство дамб), так и нестроительные (т.е. эвакуация) меры. В связи с этим в настоящем докладе описан один элемент (прогнозирование наводнений) процедуры всестороннего анализа бассейна, что может послужить в качестве основы для применения к другим типам прогнозов.

Для разработки процедуры анализа, аналогичной процедуре, используемой для исследований оценки ущерба,наносимого наводнением, связанного со структурными изменениями, были объединены концепции гидравлики, гидрологии и экономики. Трудности оценки пользы и затрат, не имеющих численного выражения, особенно тех, которые связаны с потенциальными человеческими жертвами, все еще не позволяют принять эти концепции.

Помимо инженерных работ и оценки величины наводнения, в докладе подчеркиваются три фактора, связанные с программой сокращения ущерба, наносимого наводнениями. Эти факторы таковы: заблаговременность предупреждения, величина сокращенного ущерба и эффективность реакции на предупреждение. Теоретически при рассмотрении влияния каждого фактора на ущерб, наносимый наводнением, можно сделать оценку пользы, приносимой каждым фактором, что позволит принять решение на экономической основе в отношении всей схемы предупреждения о наводнениях.

В докладе описано использование обобщенных математических моделей для воспроизведения возможных путей сокращения ущерба, наносимого наводнениями. За этим следует описание конкретного исследования в качестве примера анализа затраты/выгода.

RESUMEN

El presente informe contiene una reseña de los recientes progresos realizados en materia de evaluación del coste de las predicciones hidrológicas y de los beneficios originados por estas últimas. El estudio combinado de la hidrología y de sus aspectos económicos facilita una orientación muy valiosa para las decisiones que habrán de tomarse en materia de explotación de los recursos hídricos y para la preparación de predicciones hidrológicas.

La falta de datos suficientes impide la utilización de sistemas de análisis que permitan adoptar soluciones óptimas para el aprovechamiento de las zonas de inundación en las que intervienen medidas tanto de carácter estructural (por ejemplo, construcción de presas) como no estructural (es decir, evacuación). Así, pues, en el presente informe se describe uno de los elementos (predicción de crecidas) de un método general de análisis de cuencas que puede servir de base para establecer otros tipos de predicción.

Los conceptos de la hidráulica, la hidrología y la economía han sido combinados de forma que constituyan un procedimiento analítico análogo al utilizado en los estudios destinados a evaluar los daños que pueden originar las crecidas en función de los cambios de estructura introducidos en los cursos de agua. La dificultad de evaluar beneficios y costos difíciles de cifrar, especialmente aquellos que se refieren a las posibles pérdidas en vidas humanas, continúa impidiendo que se tengan en cuenta en los estudios de este tipo.

En el informe se insiste en tres factores relacionados con los programas de mitigación de los daños producidos por las crecidas, independientemente de los trabajos de ingeniería o de la importancia de esas crecidas. Esos factores son los siguientes: el tiempo necesario para avisar de esas crecidas, la importancia de los daños susceptibles de ser evitados y la eficacia de la reacción a los avisos de crecida. En teoría, si se considera la influencia de tales factores en los daños producidos por las crecidas, se puede llevar a cabo una estimación de los beneficios producidos por cada uno de esos factores y por consiguiente es posible tomar decisiones de índole económica con respecto al sistema general de prevención de crecidas considerado en su conjunto.

En el presente informe se describe la forma de utilizar los modelos matemáticos generalizados para simular las diversas soluciones destinadas a reducir los daños causados por las crecidas. Después de esa descripción, se presenta un ejemplo concreto de un análisis de la relación coste/beneficio.

BENEFIT AND COST ANALYSIS OF HYDROLOGICAL FORECASTS

1. INTRODUCTION

This report is a review of recent progress in evaluating the benefits and costs of hydrological forecasts. Such evaluations are important to a river-basin forecasting service, but until recently judgement of the beneficial effect has been largely subjective. As many nations progress towards a more formal process of planning river-basin water resource development, the economics of each programme segment become important. Single-purpose structures, such as dams for hydro-electric or irrigation development, have long been formally analysed on a basis of benefits and costs but non-structural actions, such as flood forecasting, have depended on social acceptance for implementation. Technological and sociological changes have encouraged the trend towards a formal economic evaluation of water resources developments. Expanded occupancy and use of flood plains and riverside areas have increased the need for public investments in economic evaluations; computer developments have provided a feasible means for analysing many alternative solutions. Mathematical models are not the total answer to resource-development planning questions. Although they serve as a powerful supplement to past planning practices, special care is required in blending the results from these computer simulations with subjective knowledge of the local situation in order to make effective decisions.

The need for hydrological forecasts varies widely in the nations of the world. The climate, topography, local population, and level of economic development are primary factors in a particular nation or watershed. The following hydrological requirements may be of sufficient importance to warrant a forecasting programme:

(a) Floods (time and magnitude of peak flow and stage);

(b) Low flow (time, duration and magnitude);

(c) Ice freeze-up;

(d) Volume of runoff (short-period, seasonal, and long-range);

(e) Wave heights (storm surge in coastal areas, estuaries and large inland lakes).

Other measurements may become equally important in the future as the need to use our water resources economically increases. Some of these measurements are:

(a) Soil-moisture content (agricultural irrigation);

(b) Groundwater level (rural and urban water supply);

(c) Water temperature (cooling water for thermal power generation);

(d) Water-quality indicators such as pH, nutrients, dissolved oxygen and heavy metal concentrations.

There may be some river basins with an economic justification for all of these forecasts, but such would be an exceptional case. Flood forecasting has received maximum attention in the United States during the last three or four decades, but other forecasts such as runoff volume and low flow have also been provided to a lesser degree. Forecasts in the U.S.S.R. have included river and lake freeze-up and thaw times in addition to those provided in the U.S.A. As the multiple-use concept is applied to more watershed development plans, hydrological forecasting will probably be used increasingly to enhance man's utilization of the available water resources.

2. FUNDAMENTALS OF HYDROLOGICAL FORECAST BENEFIT/COST ANALYSIS

Systems analysis techniques may be used effectively [6, 8]* to seek optimal solutions to the flood-plain management problem, which includes both structural and non-structural actions. The lack of sufficient data often prevents such studies from being made at present; this report describes one element of a comprehensive basin-analysis procedure.

2.1 Basic concepts

Concepts of hydraulics, hydrology and economics have been combined to develop an analysis procedure. The essence of the procedure may be stated simply as:

(a) Evaluate the economic consequences of man's presence in the river basin without any forecasting service;

(b) Evaluate the same economic consequences of man's presence when a forecast service is provided;

(c) On the basis of steps (a) and (b), evaluate the benefits versus costs of a forecasting service, taking into account the reliability of the hydrological analysis.

This procedure is, of course, similar to that used for flood-damage evaluation studies related to structural changes, such as dam construction or channel improvement. Accordingly, past discussions of limitations to this approach [4, 7, 9, 14] apply here also. Difficulties in evaluating intangible benefits and costs, especially those associated with the potential loss of life, continue to prevent their inclusion. Detailed discussion of existing evaluation techniques as applied to flood forecasting will clarify this general procedure and may serve as a basis for application to other types of forecast.

---

* See References (page 22).

2.2 Flood forecasting

2.2.1 General comments

Forecasts are important for the effective implementation of a flood-damage reduction programme. Both structural and non-structural elements of a basin-wide organization would use forecasts. Previous studies have been primarily concerned with the effect of forecasts on operation of in-stream structures such as dams and flood gates: little effort has been directed to understanding the effect of forecasts on non-structural elements such as evacuation and temporary flood-proofing. Factors other than predicted river stage significant in a particular flood-damage reduction programme include: (a) response to warning, (b) duration of flood, (c) water velocity, (d) length of warning time, (e) magnitude of reducible damage, (f) weather conditions, (g) rate of water-level rise, (h) frequency of flooding, and (i) time of occurrence of flood peak (day, season). Three of these factors are particularly important — length of warning time, magnitude of reducible damage, and efficiency of response to warning.

2.2.1.1 Length of warning time

The reduction of property damage and loss of life during floods is sensitive to the length of warning time provided. To the flood-plain occupant, the effective time of warning is the period from the receipt of a warning, either an official river forecast or a personal assessment based on the rate of rise of water in the adjacent stream, to the commencement of potential damage. Headwater catchments naturally experience short time-lags following a warning before flood damage occurs. In such areas two to six hours of warning is not uncommon, while down-stream reaches of a river system receive longer warning periods, extending to several weeks for very large rivers such as the Mississippi River. Many communities in a flood plain provide and maintain efficient, well-organized disaster committees for formal warning dissemination. Others are apathetic and do not communicate effectively during flood events. Unfortunately, some citizens may ignore early warnings and others may not receive them at the time of issuance.

The time of warning is generally defined as the period from release of the flood forecast, which usually consists of a predicted peak stage and its time of occurrence, to the occurrence of the flood peak. It has also been defined as the period between the river at flood stage (bank full) and at flood peak /13/.

2.2.1.2 Magnitude of reducible damage

Some flood damage will occur regardless of warning time or response to warning, since some property (such as railroad tracks, bridges, machinery, and buildings) cannot be removed from the flood plain. 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.

2.2.1.3 Efficiency of response to warning

Occupants of the flood plain will respond to the warning with different levels of efficiency. Efficiency of response is affected by factors such as the time of day the warning is received, the time elapsed since the last flood, and the accuracy of past forecasts. Industries often have elaborate disaster plans to cope with floods, while many families begin to plan only after receipt of the warning.

2.2.2 Mathematical model

The simulation of forecast effectiveness in a river basin would ideally include all segments of the society directly or indirectly affected by the forecast. This task, which would include land and water transportation, industrial, commercial, agricultural and residential occupancy of the flood plain, along with operation of water-control structures such as dams and wells, is very complex and only partial progress toward a more complete mathematical model has been made. The use of forecasts by urban residents of the flood plain is evident in many nations throughout the world; therefore, this element of flood-plain activity was selected for detailed analysis.

A generalized model for simulating non-structural flood-damage reduction alternatives has been developed by Bhavnagri and Bugliarello /1/. They synthesized a stage-damage curve for different structure types such as family residences with and without basements. The effects of time of warning were accounted for by creating a family of stage-damage curves, shown in Figure 1. The reducible damage is 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 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 flood peak frequency data with the stage-damage-time of warning data. Associated with a given flood is a stage*, which represents inundation over a certain portion of the flood plain as shown in Figure 2. The expected average 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: p_i = probability of a flood within the flood plain contour interval i-1 to i;

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

$E(D)$ = expected average annual loss; and

n = number of years.

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

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 benefit, B.

$$\text{Gross benefit } B = E(D)_{\text{No warning}} - E(D)_{\text{Warning}}$$

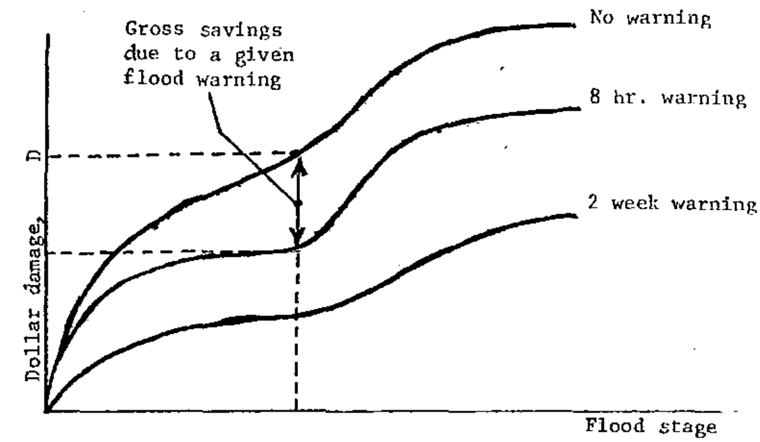

Figure 1 - Sample stage-damage curve — One structure type

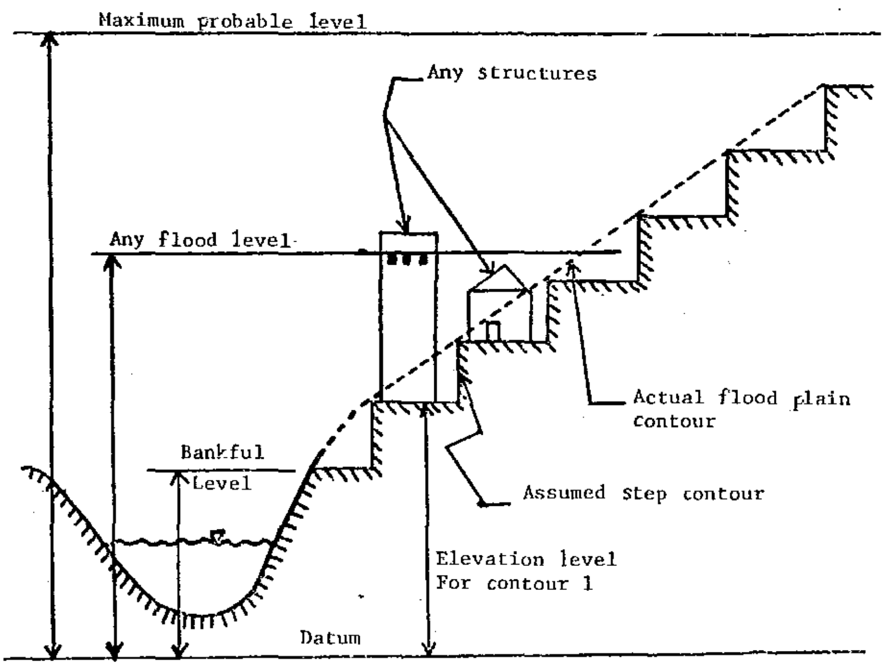

Figure 2 - Flood plain definition sketch

Costs associated with the forecast and related evacuation activities may also be included to provide values for a net benefit. These calculations may be represented graphically as shown in Figures 3, 4 and 5. The values for flood recurrence probability, p_i, may be calculated using established methods. The values for gross benefit, b, are determined from data used to prepare Figure 3, which is merely a composite of the many calculations based on individual structure types as shown typically in Figure 1.

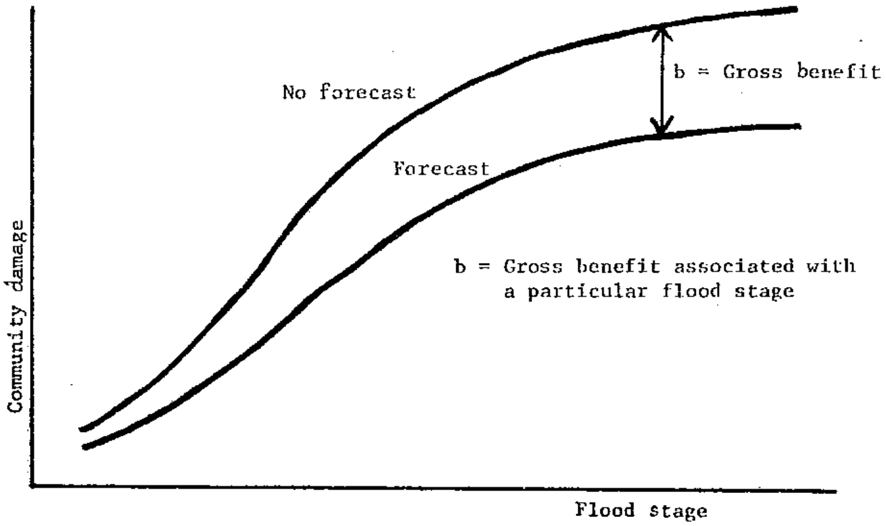

Figure 3 - Community stage-damage relation

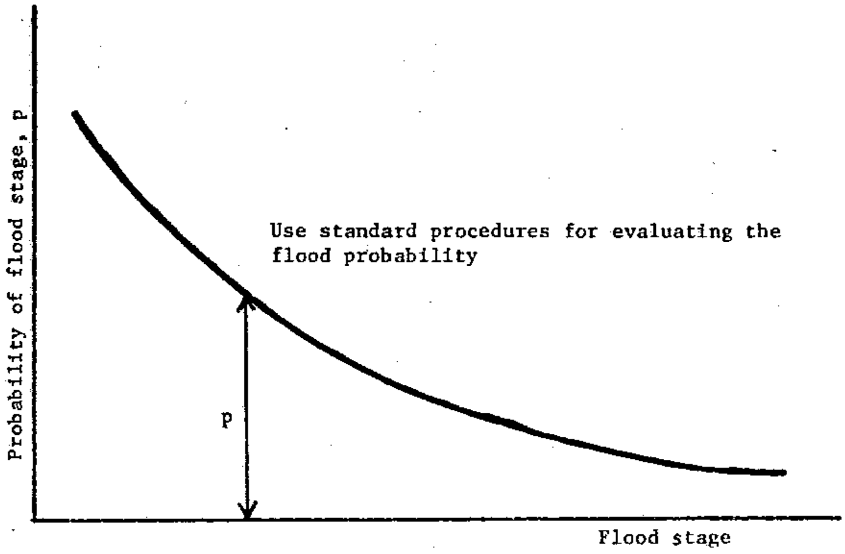

Figure 4 - Stage-probability relation

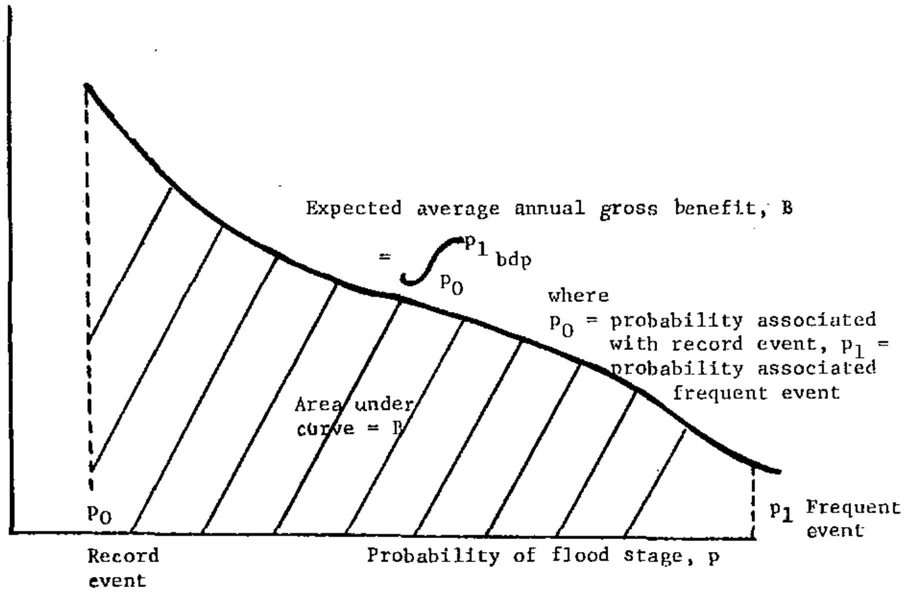

Figure 5 - Gross benefit-probability relation

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. The synthetically generated stage-damage-time relationships implicitly include a level of response to the warning, usually 100 per cent, and a particular fraction of potential damage to each structure type (including contents) as reducible damage. These parameters may be varied to reflect true conditions on a particular flood plain realistically. A similar approach may be used for temporary flood-proofing. Economic growth on the flood plain also may be included by the use of additional stage-damage-time of warning curves. It is important to realize the approximate nature of the results from such calculations. The flood-recurrence probability and the stage-damage estimates are both values which are uncertain; therefore, caution should be exercised in using the results for purposes other than relative comparison.

In summary, the model requires:

(a) Collection of historical streamflow or stage data and preparation of a flood-frequency curve;

(b) Determination of the number and type of structures at various locations on the flood plain and the water depth in each structure for a flood of any given probability;

(c) Preparation of stage-damage-time of warning curves for each structure type.

Flood plain occupants are often classified into at least four categories: residential, industrial, commercial, and agricultural. The lack of sufficient real data to measure the effectiveness of a forecast has encouraged the development of synthetic data based on physical principles and local knowledge of the flood plain. Residential flood damage can probably be synthesized with more confidence than the other types due to the large number of homes encountered and similar structural and economic characteristics /3/. Industrial and commercial /2, 5, 11/ damage has also been synthesized but special care is necessary to assure satisfactory results. Each plant possesses unique stage-damage-time of warning characteristics which must be updated frequently to account for plant alterations. Use of synthetic agricultural data has not been reported yet.

2.3 Other hydrological phenomena

The basic concepts described in section 2.1 may be applied to other hydrological phenomena for which a forecast could prove beneficial. Some events, such as stream low flow, may be predicted with moderate accuracy for days and sometimes weeks in advance; others, such as wave heights and the formation of ice jams, have only partially yielded to satisfactory prediction. Little effort, if any, has been directed towards benefit and cost evaluation of forecasts for these phenomena. A dual effort seems necessary, therefore, to learn more about the fundmental physical nature of these hydrological actions and about the economics related to them. Success in this effort would allow preparation of curves similar to those shown in Figures 6, 7 and 8.

The lack of satisfactory forecasting methods for a particular hydrological event need not delay these gross benefit calculations. Indeed, they may serve as a valuable guide in directing the research programme of a nation towards the hydrological event with an attractive pay-off.

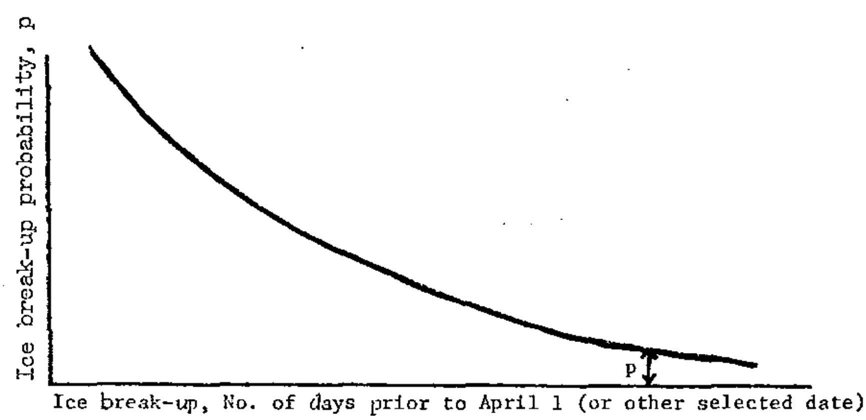

Figure 6 - Ice break-up probability vs. time of break-up

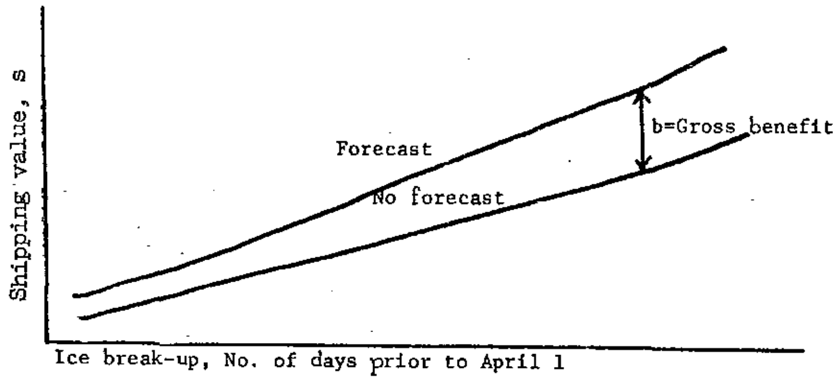

Figure 7 - Shipping value vs. ice break-up time

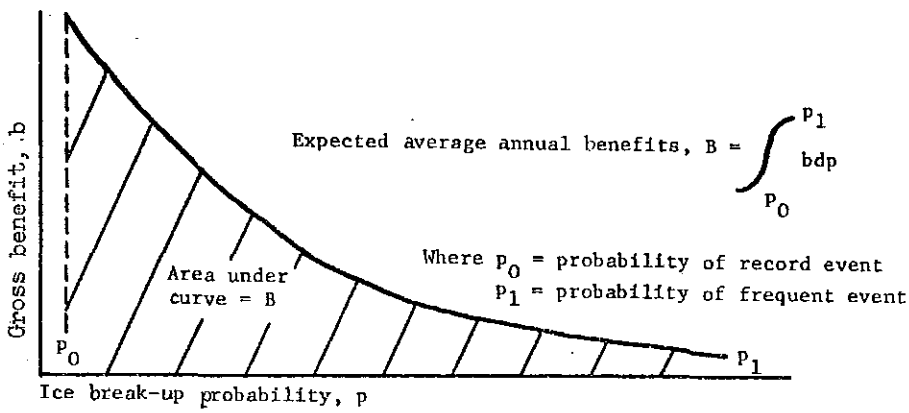

Figure 8 - Gross benefit vs. ice break-up probability

3. EXAMPLE: URBAN RESIDENTIAL FLOODING

3.1 General comments

A recent evaluation of benefits and costs associated with flood forecasts for urban residents in the flood plain of the Susquehanna River in the eastern portion of the United States is described in the literature /3/. This exploratory effort was restricted to urban residences due to accessibility of data in a form compatible with the digital computer. The urban private resident undoubtedly represents the largest portion of flood-plain occupants, but the largest potential beneficiaries of flood warnings are the commercial and industrial occupants. A brief description of this study serves as an example of a benefit/cost analysis.

3.2 Study plan and simulation details

The basic plan for the study was to simulate the response of flood plain residents to floods of different magnitudes under different conditions: (a) flood plain actions such as evacuation and temporary flood-proofing; (b) various warning times; and (c) responses to warning. The plan was implemented by preparation of digital computer programs designed to receive different families of synthetic stage-damage-warning time and stage-cost-time values. The stream hydrology at different reaches also served as input data to the program. Topographic, hydrological and house identification field work had been completed by the U.S. Army Corps of Engineers, Baltimore District, prior to this study; therefore, no field work was necessary for this specific study.

A plan for residential home classification was prepared by the Corps based on a small number of residences (approximately 200) studied in detail. The classification is shown in Table I. Approximately 60 000 homes in the basin were identified in this manner.

TABLE I

Residential characteristics used for synthetic stage-damage data 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 storeys	1	$1\frac{1}{2}$	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 one-storey home of average size and value of furnishings containing a basement and valued above \$22 000.

Synthetic stage-damage-time and stage-cost-time data were prepared to match this classification. Flood damage previously estimated by the Baltimore District of the Corps of Engineers for each category of residence was assumed to represent the situations of no warning, noted by the abbreviation NW. Three situations for damage

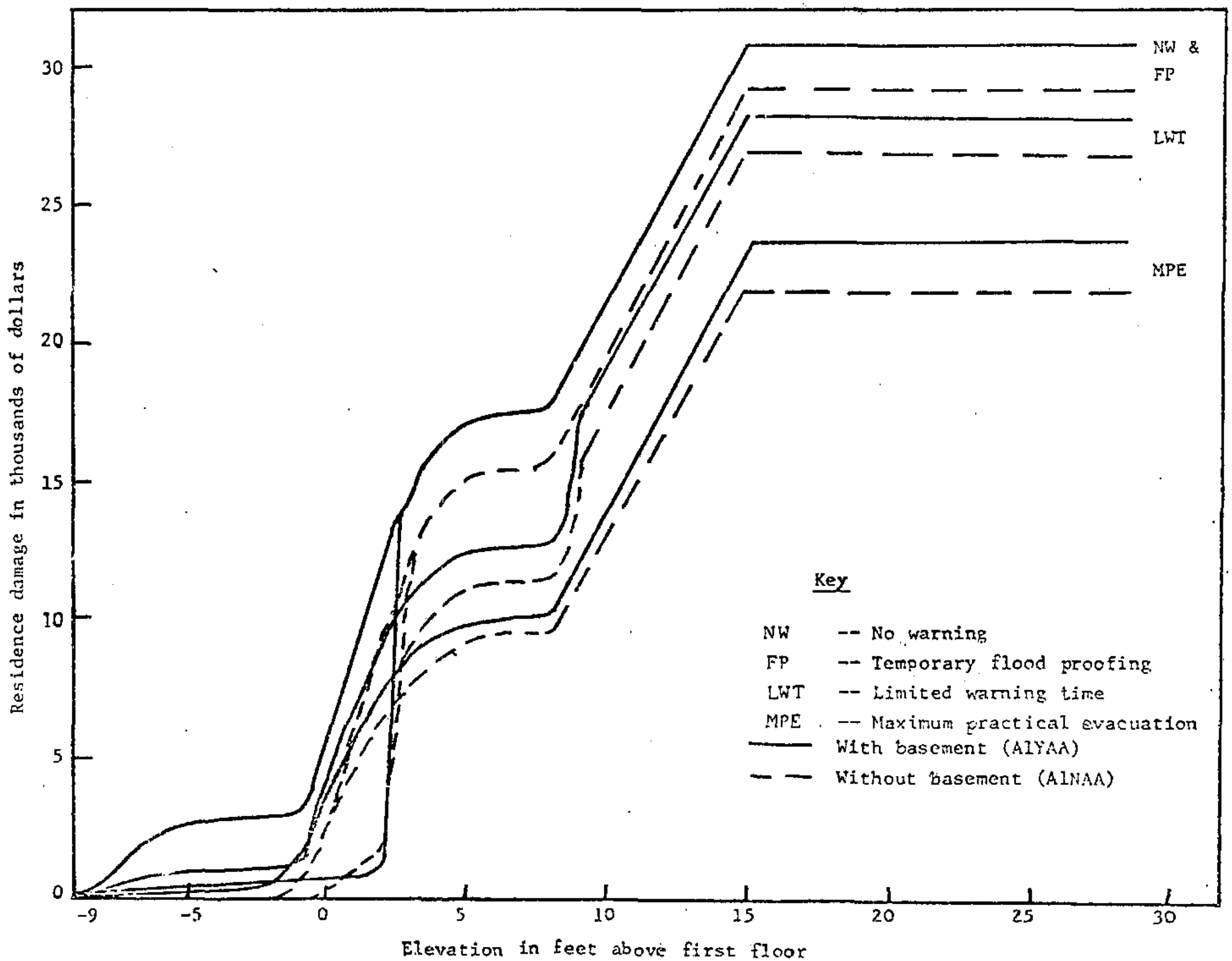

Figure 9 - Stage damage relations for selected actions by flood plain residential occupants

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 the appendix served as the primary data source for these data. Typical data developed for these various situations are presented in Figure 9. At flood levels which submerge the total structure, the loss is at a maximum; therefore the stage damage line is horizontal above the 15-foot level for one-storey homes as shown in Figure 9. Detailed discussions of damage reductions and related costs required for each case will clarify the background of each stage-damage relation.

3.2.1 Synthetic stage-damage data

3.2.1.1 Damage -- 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 per cent response to the warning, also provides an estimate of the reducible damage in a dwelling.

3.2.1.2 Damage -- Limited warning time (LWT)

The effect of a reduced warning time on residential flood damage 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 per cent response to the warning.

3.2.1.3 Damage -- Limited response to warning (LR)

A reduced response to the flood warning was modelled by combining the NW and MPE tables, using an appropriate weighting procedure. Flood-plain occupants on the lower elevations prone to frequent flooding were assumed to respond more efficiently than those at higher elevations who would suffer damage 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 per cent response by some residents and no response by others, probably does not reflect true flood-plain action accurately, 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 II.

3.2.1.4 Damage -- 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 /12/. Damage at elevations up to two feet above the first floor* were estimated at

* The American expression "first floor" corresponds to "ground floor" in many parts of the world.

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 two feet above the first floor. Thus the AFP curve shown in Figure 9 would probably tend toward the NW curve, but would not join it as indicated.

TABLE II

Limited response

Elevation of flood of record referenced to first floor* of each individual residence	Percentage of home-owners who act (MPE data used)	who do not act NW data used)
Maximum to +2 feet	75%	25%
+2 feet to -4 feet (inclusive)	50%	50%
Less than -4 feet	25%	75%

3.2.2 Synthetic stage-cost data

3.2.2.1 Costs -- Evacuation actions -- MPE, LWT, LR

An estimate of the cost required to reduce flood damage through evacuation action was made by considering the value of labour and materials required to evacuate and return appropriate movable items located in the home area to be inundated. The labour 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 flood plain. The estimates were restricted to average home size and value of furnishings; the same multiplier table used for damage was applied to these dollar values for cost estimates of other home sizes and furnishing 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 /8/, 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 10 is a graphical presentation of typical evacuation costs. Homes without basements naturally require no action until the flood crest approaches the first-floor level. Additional effort to move small kitchen utensils when the crest exceeds three feet above the first floor accounts for the slight increase in cost noted at the elevation. Inadequate warning time in the LWT case reduces the evacuation-reoccupation cost in general, but the costs related to flood crests above the eight-foot level were diminished substantially in this model.

3.2.2.2 Costs — Temporary flood-proofing (FP)

Flood-proofing costs were prepared in the same general format, but specific purchases were assumed in addition to the labour estimates. Sandbags, plywood, and polyethylene sheets were considered necessary for all homes to reduce damage below the level two 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 wash-water removal or moderate drainage problems. The assumed cost of the installed pump and motor was $ 1 000. 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 every second year on the average. 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 10. 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.

3.2.2.3 Costs — Providing the forecasts

The annual cost of providing the forecast to the entire basin is approximately $100 000. Since only a fraction of this value, perhaps one-third, is associated with residences, and since this value is approximately one per cent of the basin-wide results, it may be safely neglected. As the accuracy of such studies improves, it may be necessary to include an estimate.

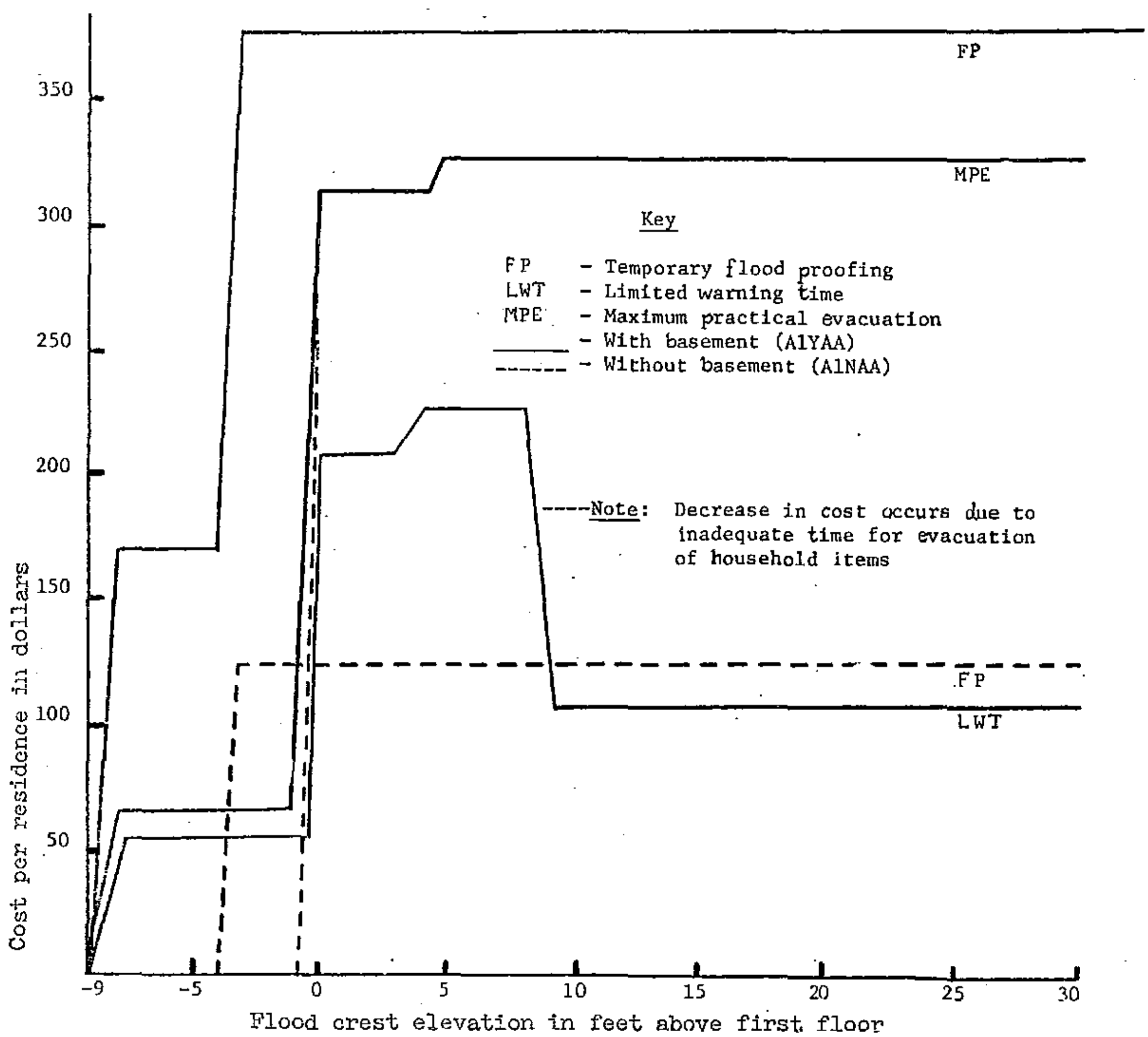

Figure 10 - Stage cost relations for selected actions by flood plain residential occupants

3.3 Simulation results

3.3.1 Presentation of results

Results from this study were presented in two categories:

(a) A detailed report of all results for four representative cities in the basin — Harrisburg, Pennsylvania; Milton, Pennsylvania; Carbondale, Pennsylvania; and Owego, New York. The cities are shown in Figure 11, a map of the basin.

(b) Summary comments on the remaining communities in the flood plain of the main stem and major tributaries.

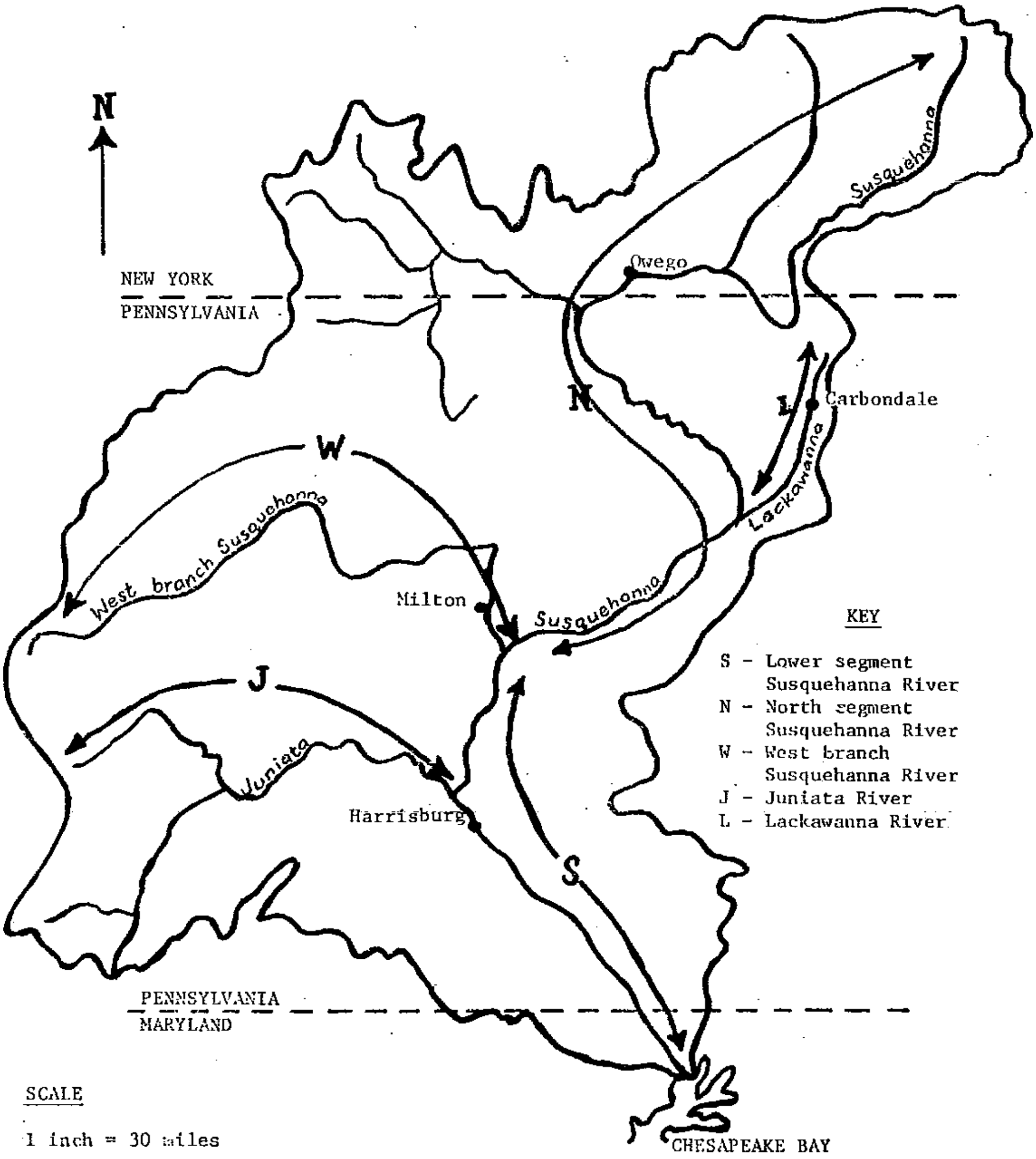

Figure 11 - Susquehanna River Basin - Major segments of river system

A sample of the community stage-damage relation obtained for one of the four cities is presented in Figure 12. Table III contains values describing the basin-wide benefit/cost relationship. Details of the results have been presented elsewhere [3].

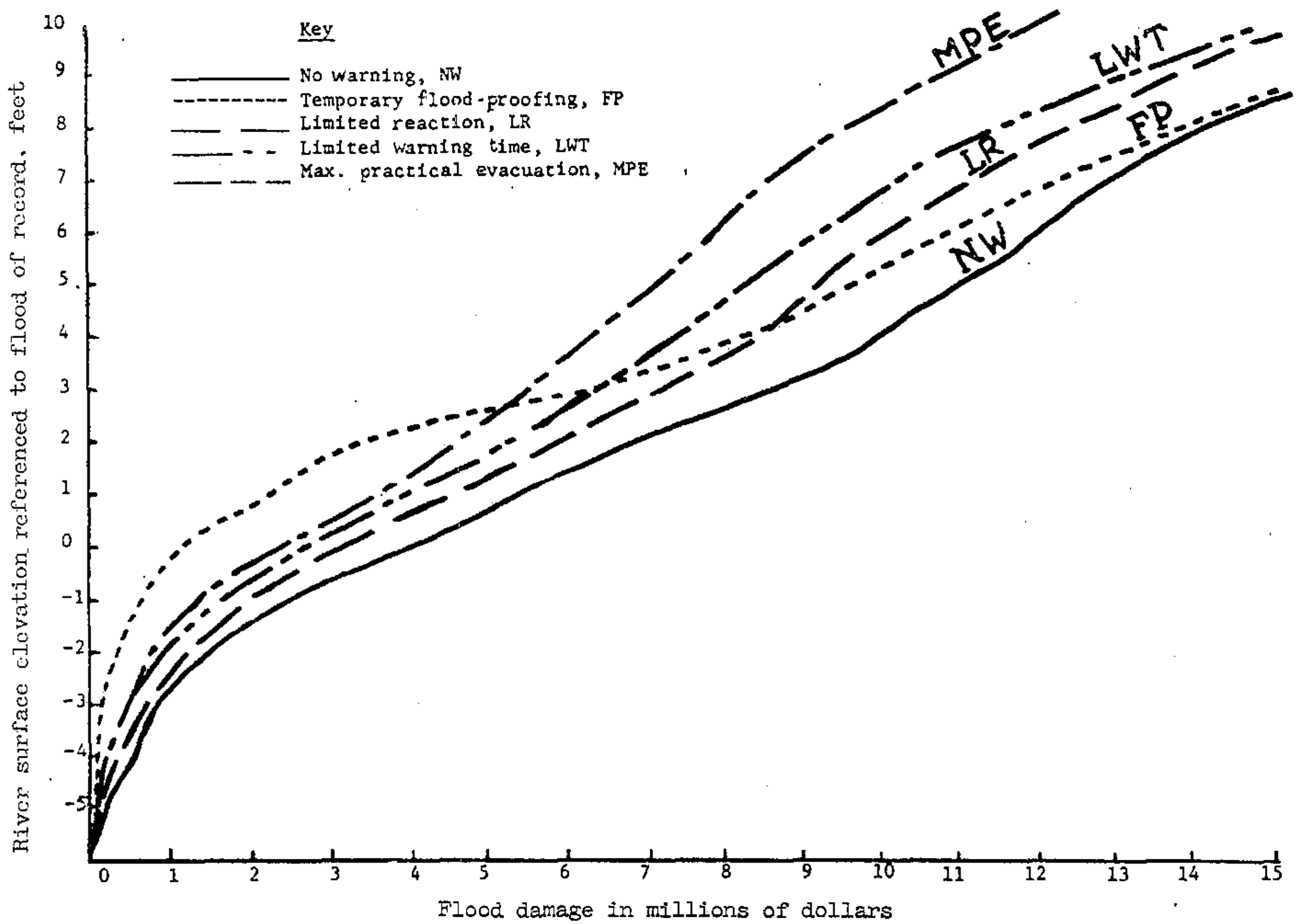

Figure 12 - Stage-damage relation for part of Harrisburg, Pa. (Reach S-5B) during various types of flood plain occupant actions

TABLE III

Summary of basin-wide simulation

Simulation results, expected annual values in thousand dollars*

River segment	No warning (NW) damage	Max. pract. evacuation (MPE) Benefits (B)	Costs (C)	B/C	%B**	Limited warning time (LWT) Benefits (B)	Costs (C)	B/C	%B	Temporary flood-proofing (FP) 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

* Response to warning is assumed to be 100%

** $\%B = \dfrac{\text{Benefits}}{\text{No warning damage}} \times 100\%$

3.3.2 Discussion of results

The ability to simulate action of flood-plain occupants was demonstrated to a limited extent by this simulation. Several conclusions may be drawn from the study.

(a) Action by urban residents throughout most of the Susquehanna River Basin to reduce flood damage, when based on receipt of a warning, will provide benefits exceeding the costs. Although the cost estimates were based on limited field information and are incomplete, it is unlikely that benefit-to-cost ratios in the vicinity of 3 to 7 as shown in Table III 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 autmobiles 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.

(b) It is apparent from a study of Table III that approximately one-fifth to one-third of urban residential flood damage may be reduced through use of a warning system (when coupled with 100 per cent response) in the Basin. The NW damage was $3 040 000 while the benefits (reduction in damage) from the three action studies range from $678 000 to $1 200 000 for LWT and FP respectively. An improved estimate of reducible damage 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 III) receive warning times of at least 24 hours; therefore, the MPE damage is appropriate. Elsewhere in the Basin the LWT values could be used to indicate reducible damage. The result of such an improved calculation would probably indicate reducible damage to be approximately one-quarter of the total.

(c) The estimated costs for evacuation and reoccupation vary widely according to the river segment and type of action. 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 vary from 1.0 to 7.5 and the FP ratio varies from 1.0 to 1.8.

(d) 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.

4. CONCLUSIONS AND RECOMMENDATIONS

The initial efforts to evaluate benefits and costs associated with hydrological forecasts have begun. Although the task seems formidable, some progress has occurred and there are many opportunities for further progress, both in the area of improved forecasting techniques and in the area of economic data collection. The digital computer has made large studies feasible, but many investigations may be conducted without one. The combination of hydrology and economics can become a powerful source of guidance in planning a national hydrological research programme. Most nations will have unique flood-plain characteristics, both natural and socio-political; therefore little opportunity for generalized studies exists. However, the basic concepts should be applicable to all nations. As the demand for allocation of a nation's limited resources increases, the need for increased objectivity in use of public money will become more apparent. Benefit/cost analysis will not, of course, be the only source of information used by a water resources manager in the decision-making process, but it can become more valuable than at present.

Several recommendations can be made:

(a) Investigate the feasibility of conducting a benefit/cost evaluation for the different types of hydrological forecast which are provided at present or may be provided in the future;

(b) Organize a forecasting service for those hydrological phenomena that represent obvious large net benefits, such as the flood-forecasting programme of the United States;

(c) Use preliminary benefit/cost results to aid in planning levels of research and development activity in different hydrological areas.

5. ACKNOWLEDGEMENTS

This report is based on earlier studies supported by the Office of Hydrology, U.S. National Weather Service. Various staff members in the Office of Hydrology have continued their assistance. Messrs. R. F. Kresge and M. Kohler provided counsel and Mr. T. J. Nordenson reviewed the draft. A literature search was also provided.

A number of hydrologists have reviewed the draft of this paper. The author has based many alterations to the manuscript on their comments. The efforts of the following are acknowledged:

<u>Working Group on Hydrological Forecasting, WMO</u>

Dr. A. I. Afanassiev, U.S.S.R., chairman

Mr. D. N. Body, Australia

Ing. J. Hladny, Czechoslovakia

Dr. C. J. E. Schuurmans, Netherlands

Mr. T. J. Nordenson, U.S.A.

<u>Others</u>

Mr. Takeo Kinosita, Public Works Research Institute, Ministry of Construction, Tokyo, Japan

Dr. H. Liebscher, Bundesanstalt für Gewässerkunde, Coblenz, Germany

Mr. M. Breinich, National Water Authority, Budapest, Hungary

Mr. P. Guillot, Eléctricité de France, Grenoble, France

Mr. B. Tanovan, Mekong Committee, Bangkok, Thailand

REFERENCES

1. Bhavnagri, V. S. and Bugliarello, G., 1965: Mathematical representation of an urban flood plain. J. Hydrol. Div., Proc. Amer. Soc. Civil Engr., 91 (HY2), 149-174.

2. Day, H. J., Bugliarello, G., Ho, P. H. P. and Houghton, V. T., 1969: Evaluation of benefits of a flood warning system. Water Resour. Res., 5(5), 937-946.

3. Day, H. J., March 1970: Flood warning benefit evaluation — Susquehanna River Basin (urban residences), ESSA Technical Memorandum WBTM HYDRO-10, Silver Spring, Maryland.

4. Hirshleifer, J., DeHaven, J. C. and Milliman, J. W., 1960: Water supply economics, technology and policy. Univ. of Chicago.

5. Kates, R. W., 1965: Industrial flood losses: Damage estimation in the Lehigh Valley. Univ. of Chicago, Dept. of Geography Research, Paper No. 98.

6. Kirsten, M., 1964: Ein neues Verfahren für die Bestimmung der wirtschaftlichen Ausbaugrösse und der Würdigkeit von Hochwasserschutzmassnahmen. Mitteilungen des Institutes für Wasserwirtschaft, Berlin.

7. Krutilla, J. V. and Eckstein, O., 1958: Multiple purpose river development. Johns Hopkins, Baltimore.

8. Maass, A. et al., 1962: Design of water resource systems. Harvard University Press.

9. McKean, R. N., 1958: Efficiency in government through system analysis. Wiley, New York.

10. Pierpont, R., 1967: Disaster service — American Red Cross. Personal communication (July).

11. Plott, R. W., 1967: Baltimore District of Corps Engineers. Personal communication (July).

12. Shaeffer, J. R., 1967: Introduction to flood proofing. Center for Urban Studies, University of Chicago, Chicago, Illinois.

13. White, G. F. (Editor), 1961: Papers on flood problems. Univ. of Chicago, Dept. of Geography Research, Paper No. 70.

14. White, G. F., 1969: Strategies of American water management. Univ. of Michigan.

APPENDIX

SAMPLE WORK SHEETS

FOR PREPARATION OF SYNTHETIC STAGE-DAMAGE TABLES

SAMPLE WORK SHEET FOR PREPARATION OF SYNTHETIC STAGE-DAMAGE TABLE

PREPARED BY BALTIMORE DISTRICT, USCE

TYPE AIYAA RESIDENCE UNDER CONDITIONS OF NO WARNING

Description	Elevation of Water in Residence -9	-8	-7	-6	-5	-4	-3	-2	-1	First Floor 0	+1	+2	+3
Furnishings: 1st Floor													
Living Room										0	300	050	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	500	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	230	1230	1230	1230	1230	1230	1230
Clean 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

(continued)

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					0	75				
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

(continued)

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	100	100	100	100	100	100	100	100	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	10270	10360	11470	12655	13840	15025	15985	17295	18385

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 within or outside the house. Hourly labour 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 which adjusts for residences of different size and furnishing 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 in Chapter 3.

Cost estimates related to the LWT case were obtained in a similar manner; however, labour 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 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. & 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
0 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 cost — 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;

Labour required for limited evacuation and reoccupation of basement and first floor.

Capital costs are assumed as a requirement only for homes with basement; 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
	$1,000

Annual capital recovery cost = 1,000 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	
Installation 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
Installation 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 three feet below the first floor.

-8 to -6 feet	-5 to -4 feet	-3 feet and higher
$225	$285	$605

(Elevations referenced to first floor)