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FLOOD DAMAGE REDUCTION POTENTIAL OF RIVER FORECAST SERVICES IN THE CONNECTICUT RIVER BASIN

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National Weather
Service
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CONTENTS

TABLES

LIST OF FIGURES

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ABSTRACT. Flood plain management has been a subject of special concern in the United States for the past two decades. A river forecasting system is an integral part of a total flood plain management program. It is particularly important in those activities associated with temporary evacuation and/or floodproofing. The flood warning system associated with a river forecast system can be one of the most cost-effective alternatives for flood plain management.

This study examines flood damage reduction in four carefully selected communities in the Connecticut River Basin. Using data from these communities a basin-wide extrapolation could proceed to other flood-prone communities in the basin. Properties on the flood plain were classified into residential, commercial, industrial and automobile categories. Stage damage assessments were made for those categories for four situations: no warning (NW), limited warning time (LWT), maximum practical evacuation (MPE), and floodproofing of one-story houses (FP(1)).

The investigation found that approximately $750,000 of reducible damages can be expected on commercial and residential elements of the flood plain. Although reducible damages associated with industrial structures were not evaluated, elsewhere in the Nation such values often are of the same order of magnitude as residential and commercial. Total basin-wide reducible damages, therefore, undoubtedly exceed $1,500,000 per year. The present annual cost to the National Weather Service of providing river forecasts throughout the basin is approximately $75,000. A total of $200,000 per year would be adequate to provide forecast services associated with reducible damages.

1. INTRODUCTION

The Supplemental Flood Management Study (SFMS) for the Connecticut River Basin, initiated during the summer of 1973 by the New England River Basins

Commission, is intended to provide an integrated analysis of both structural and nonstructural means of reducing flood damage while considering related environmental, economic, social, and institutional factors. This report has been prepared to meet the National Weather Service (NWS) related requirements of the Connecticut River Basin Program Plan of Study, Element NWS No. 2, 1E - "Assess Flood Damage Reduction Potential of Flood Forecasting, Warning, and Evacuation, Alone and in Combination with Other Nonstructural Alternatives." This Supplemental Flood Management Study is being conducted by a variety of federal and state agencies with specific responsibilities in the Connecticut River Basin. The study, coordinated by the Connecticut River Basin Program staff, located in Hanover, N.H., consists of five phases:

a. Problem definition and selection of alternatives

b. Evaluation of alternatives

c. Selection of plan

d. Formulation of plan

e. Plan review and approval

This report is intended to fulfill the NWS responsibilities in Phases b, c, d, and e.

The present investigation is a supplement to an earlier comprehensive coordinated study of the Connecticut River Basin (Connecticut River Basin Coordinating Committee, 1970). The earlier report, directed and reviewed by the Connecticut River Basin Coordinating Committee (CRBCC) composed of federal and state agencies and chaired by the New England Division of the Corps of Engineers (COE), was based on a detailed 6-year effort to inventory and analyze alternatives for managing water and related land resources of the Basin. Part of the report was a proposal for the preservation, development, and management of these resources with special emphasis on water quality, water supply, power generation, outdoor recreation, and flood control. The "early action plan" for implementing some of the recommendations by 1980 was estimated to cost $1.8 billion.

Soon after completion and publication of the 1970 document, the need to analyze more carefully both structural and nonstructural alternatives for flood plain management was emphasized.

Flood plain management may occur in a variety of activity combinations, including both structural and nonstructural programs. Some structural alternatives, such as upstream flood control reservoirs, affect flood damage reduction by lowering the flood crest. Others, such as dikes and flood walls, separate valuable low-lying portions of the flood plain from the river channel. Nonstructural alternatives include acquisition of flood plain land and buildings, relocation of existing buildings, land-use regulations such as restricting to open space on low-lying portions of the flood plain and to nonresidential structures on higher elevations of the flood plain. Both temporary and permanent floodproofing of structures in the floodway can also reduce damage. Government flood insurance provides an opportunity for residents near the waterway to recover part of the financial loss they incur during a flood.

A river forecast is an integral part of flood plain management. It is particularly important in those activities associated with temporary evacuation or floodproofing. Flood damage reduction associated with a river forecast is dependent not only on an accurate forecast, but also on the effective dissemination of the warning and a response to the warning by citizens on the flood plain. The flood warning system associated with a river forecast can be one of the most cost-effective alternatives for flood plain management (Day 1970).

2. BACKGROUND

Flood plain management has been a subject of special concern in the United States for the past two decades. White (1961a) and his colleagues at the University of Chicago, and Goddard from the Tennessee Valley Authority (White 1961b), made significant early contributions to the understanding of man's action on the flood plain during and after times of disaster, as well as an integrated basin-wide consideration of flood plain management. Bhavnagri (1965) and Day (1966) proposed a hydrologic and economic model for estimating benefits associated with a river forecast. Although early development of the model was based on a small amount of field data, the comprehensive analysis of water and related land resources in the Susquehanna River Basin conducted by federal and state agencies during the early 1960s provided the first opportunity to use extensive field data with the model. Experience gained during this investigation indicated that significant useful data on the cost effectiveness of a flood warning service can be obtained through its use (Day 1973). The model is based on an understanding of three primary characteristics of the flood plain as well as their interrelationship: (1) the topographic features, including elevations and locations of all structures, (2) river hydrology and hydraulics, including stage frequency data throughout the flood damage area, and (3) synthetically developed stage damage relationships for individual structures on the flood plain. The synthetic stage damage tables provide an economic procedure for estimating possible damage reductions (benefits) associated with a flood warning. Realization of these benefits is, of course, dependent on the receipt of and response to the warning in the affected areas. Local citizen response is probably affected by a number of factors including but not restricted to accuracy of the previous forecasts and time since the last flood. Details of the river forecast benefit model are available in the literature (Day 1966, 1973).

The Connecticut River rises a few miles north of the Canadian border and flows 400 miles southerly into Long Island Sound. The watershed covers an area of 11,250 mi^2, almost all of which is contained within the four states of Vermont, Massachusetts, New Hampshire, and Connecticut (fig. 2.1). The Basin has a maximum width of only 60 miles and ranges in elevation from sea level to 6,000 feet. The river flow averages 18,000 cubic feet per second (cfs) at Hartford, Conn., with maximum flow of 289,000 cfs and a minimum of 1,100 cfs during the period of record. Land use of the approximately 7,000,000 acres in the Basin is as follows: 79% in forest, 9% in cropland, 4% in pasture, 4% in urban built-up areas, and 4% in others (Connecticut River Basin Coordinating Committee 1970). The Basin population in 1970 was estimated to be 1,900,000, with nearly 84% living in the heavily urbanized areas of Massachusetts and Connecticut adjacent to the river and its tributaries. Most central urban areas in Massachusetts and Connecticut are on the flood plain and are protected against all but the largest flood events. Expected annual damages have been reduced substantially in these areas. Unfortunately, urban growth has occurred on the flood plain of many tributaries, and as a result the expected annual damages for the Basin have continued to increase. The need for an expanded river forecast system to include more tributaries is anticipated.

3. OBJECTIVES AND STUDY PLAN

The general objective of this investigation is to assess the flood damage reduction potential of flood warnings in combination with other nonstructural methods. Specific objectives include (1) the identification of flood damage centers throughout the watershed where a river forecast is or could be effective as a nonstructural management activity; (2) the estimation of the benefits and costs associated with providing the forecast and implementing damage reduction as a result of it; (3) the estimation of the effectiveness of a forecast when used in combination with other structural and nonstructural management methods.

The study plan prepared to achieve these objectives includes:

a. The identification of flood damage centers appropriate as sample sites representative of damage elsewhere throughout the river basin.

b. The field investigation at each of these sites to obtain adequate hydrologic, topographic, and flood plain structural information for use with the river forecast benefit evaluation model.

c. The identification and collection of adequate published and unpublished documents describing flood damage centers elsewhere throughout the Basin.

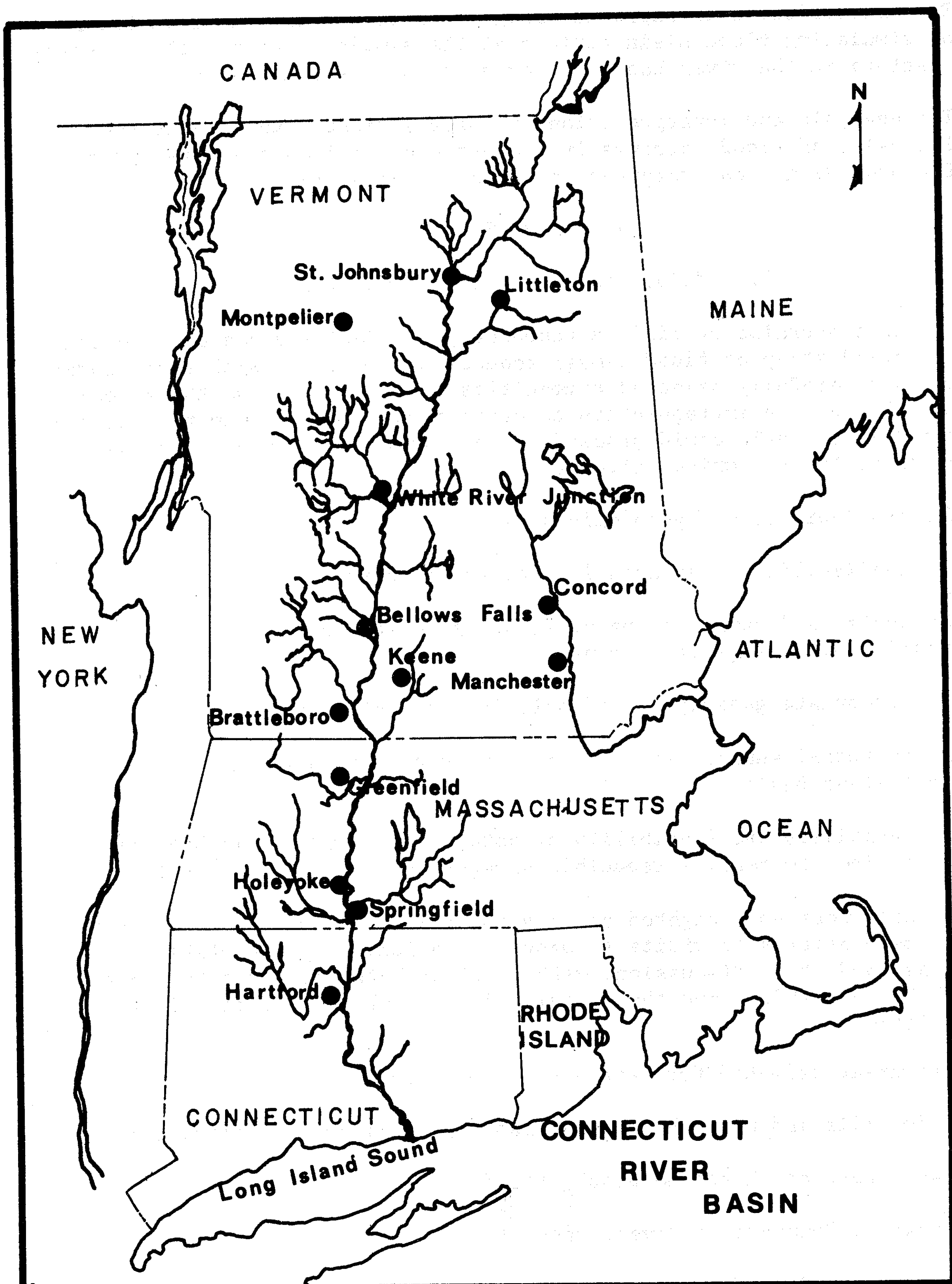


Figure 2.1 --Connecticut River Basin

d. The extrapolation of expected damage reduction estimates from the results of simulating flood plain actions at the sample sites to all remaining damage centers in the river basin, using data obtained in step c.

e. The analysis and interpretation of these estimates to predict the potential value of flood warnings in the basin as well as the developmental needs for providing these warnings in areas not presently served.

4. METHODS

4.1 Selection of Sample Communities

Due to the constraint of limited resources, the decision was made to conduct a detailed study of flood damage reduction associated with river forecasts in four carefully selected communities. Using data from these communities a basin-wide extrapolation to other flood prone communities in the Connecticut River Basin could proceed. The selection of study areas was made by use of the following criteria:

a. The availability of hydrologic data.

b. The availability of acceptable topographic maps.

c. The social and economic characteristics to ensure that each site was representative of a distinct segment.

d. An appropriate geographic and political distribution.

e. The potential enhancement of other concurrent studies in the Connecticut River Basin.

f. The capability and feasibility of both present and future NWS river forecast services to realize reducible damages due to flood forecasts.

These criteria were not weighted equally for all locations. Final selections were made after site visits to many of the initially acceptable communities, and after discussions with staff of both the River Forecast Center (RFC) in Hartford and the consulting firm, Cheney, Miller, Ellis, and Associates.

The four areas selected for detailed study were:

a. Lyndonville and St. Johnsbury at Passumpsic River, Vt. (fig. 4.1)

b. Brattleboro at Whetstone Brook, Vt. (fig. 4.2)

c. Agawam at Connecticut River, Mass. (fig. 4.3)

d. West Hartford at Trout Brook, Conn. (fig. 4.4)

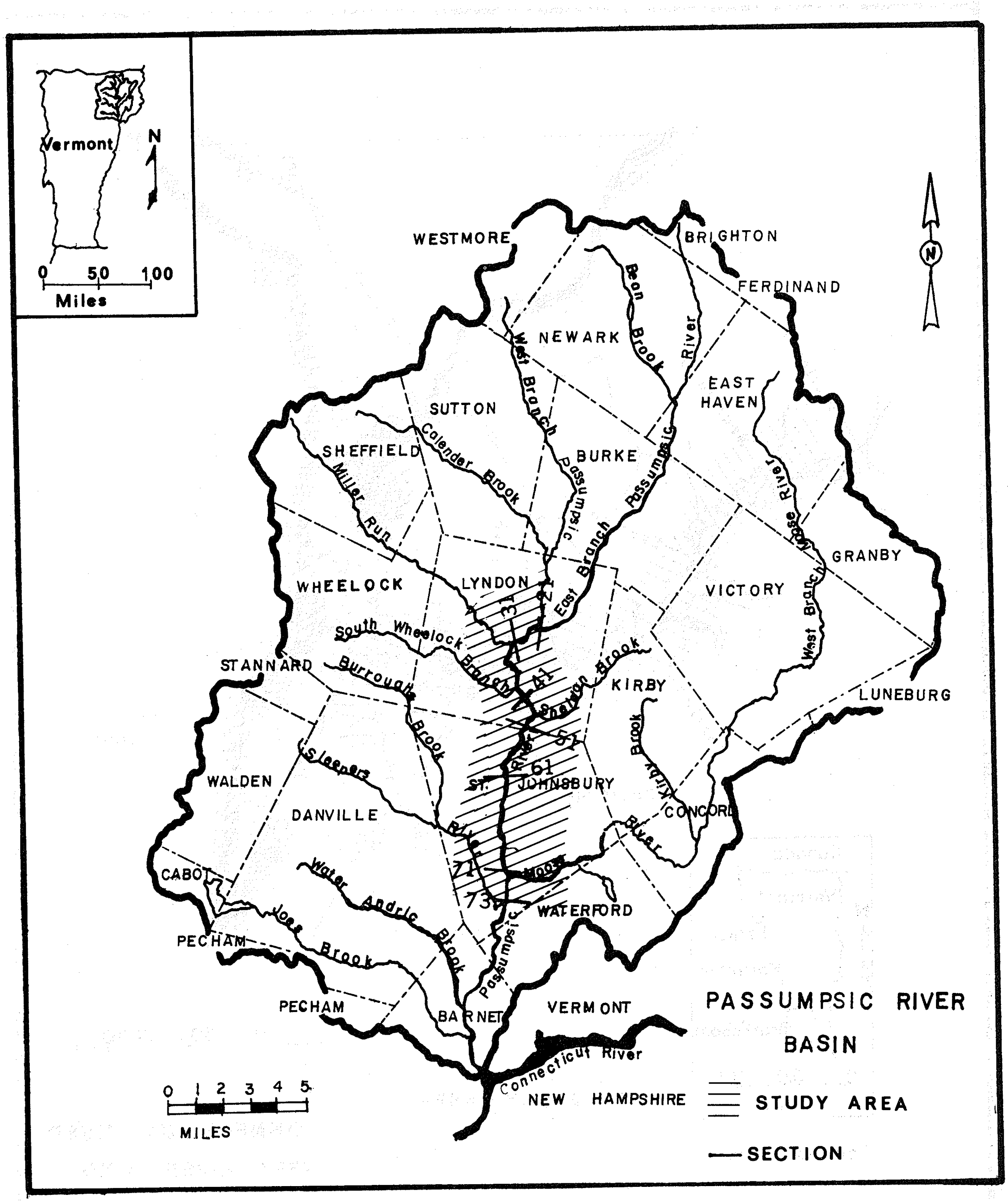


Figure 4.1--Study Area - Passumpsic River, Vt.

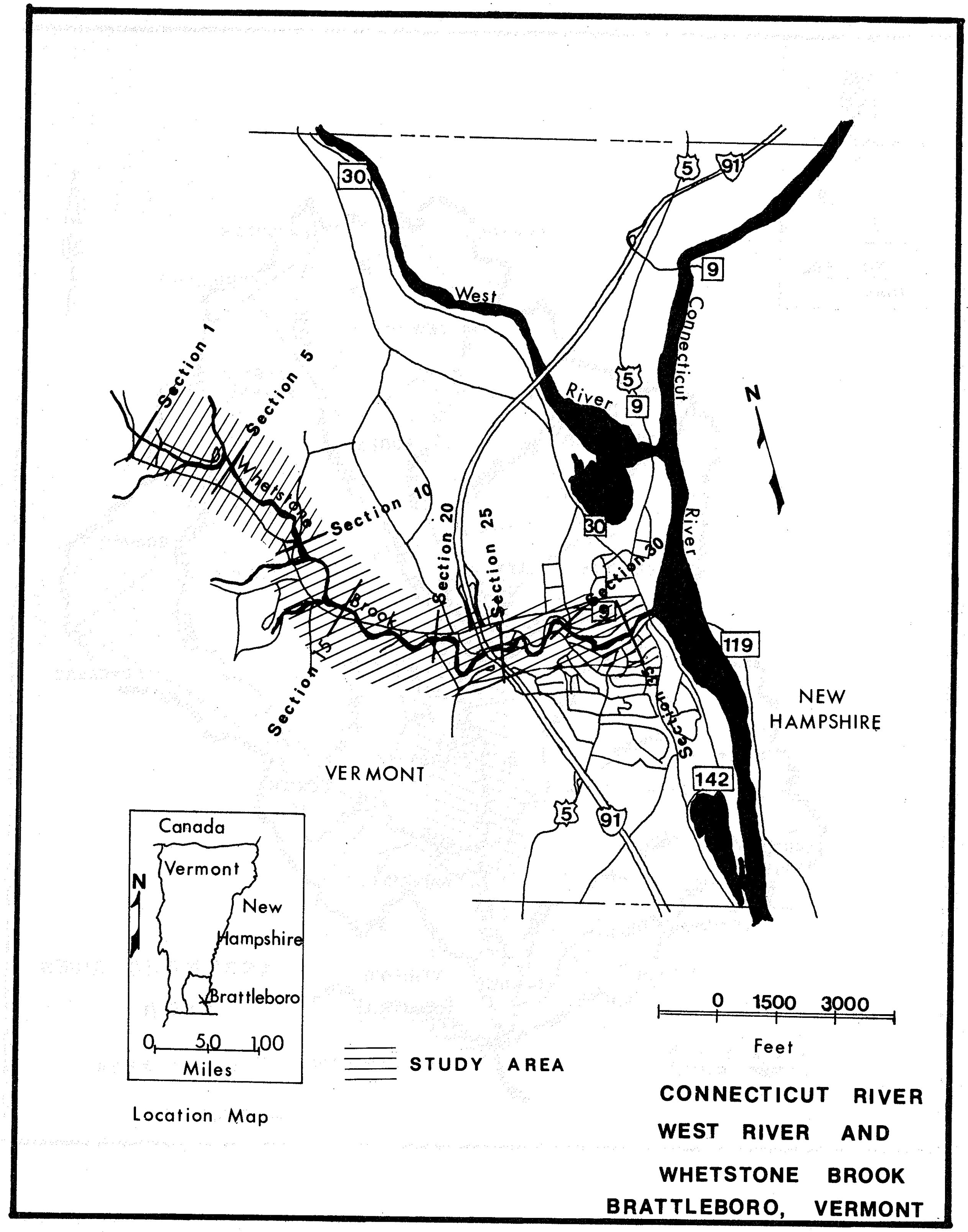


Figure 4.2--Study Area - Whetstone Brook, Vt.

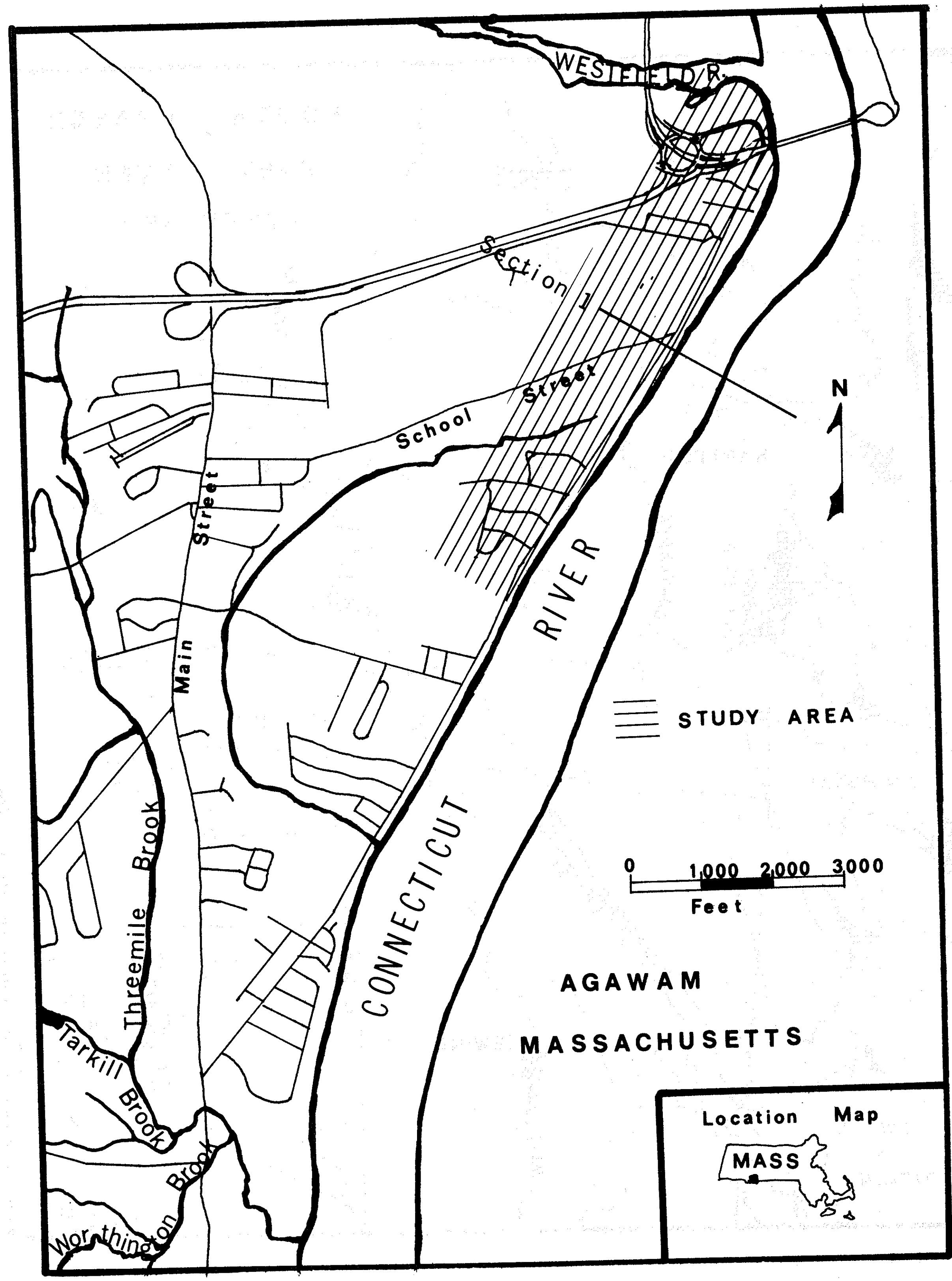


Figure 4.3--Study Area - Connecticut River at Agawam, Mass.

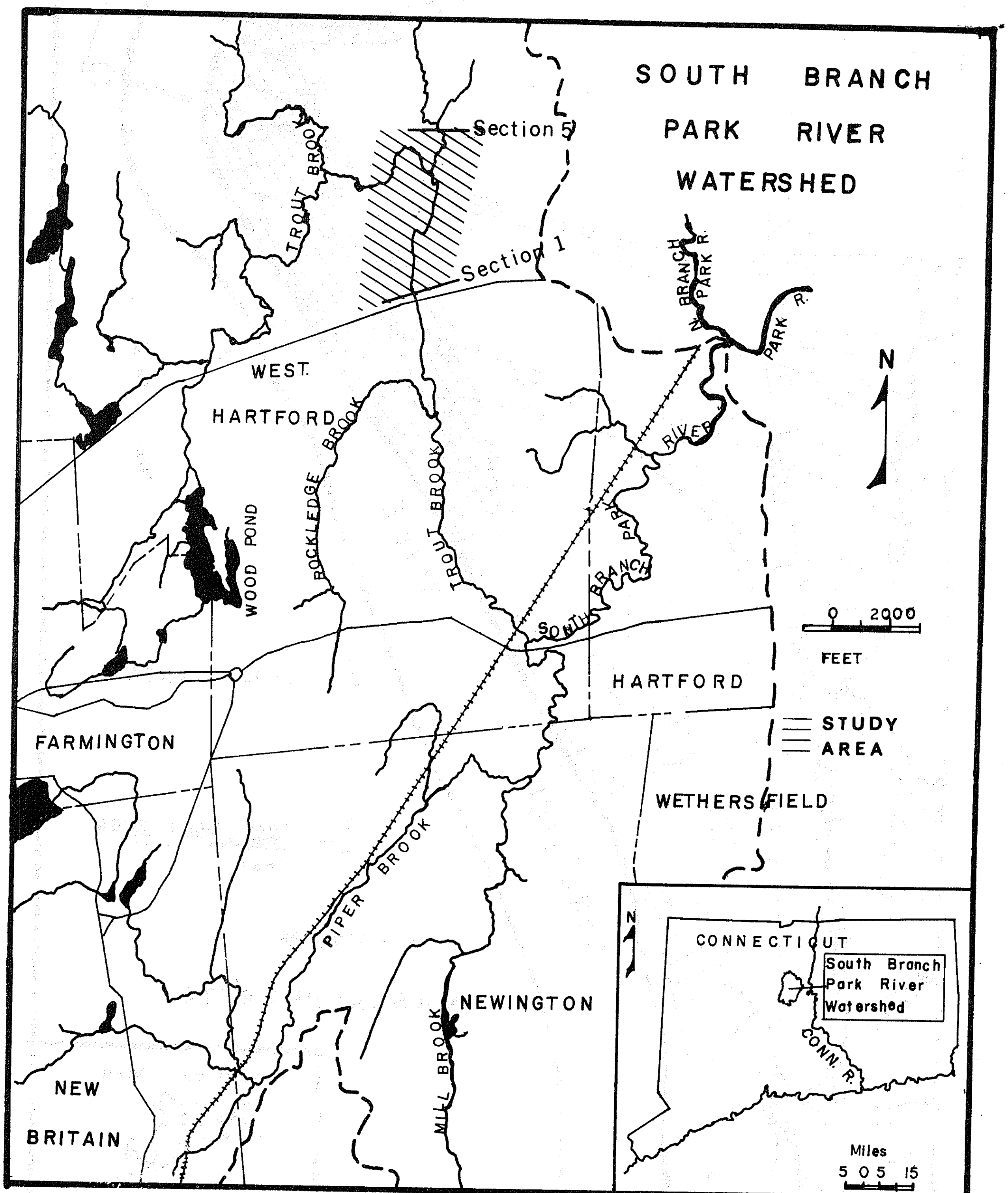


Figure 4.4--Study Area - Trout Brook, Conn.

They represent four different flood plain characteristics on either tributaries or on the river main stem. They are located in distinctively different economic compositions and in three different states. The Passumpsic River (Lyndonville and St. Johnsbury) was studied concurrently by the Soil Conservation Service (SCS) and by Cheney, Miller, Ellis, and Associates. The Whetstone Brook was also studied by the SCS. This investigation of the potential benefit due to a flood warning system has been designed to complement their investigations.

4.2 Data Collections

4.2.1 Topographic Data Collection

A detailed and accurate topographic map is essential to (1) identification of the flood plain boundaries from given hydrologic information; (2) location of structures on the flood plain; and (3) provision of guidance during the field data collection. The sources of topographic maps include: the United States Geological Survey (USGS) topographic maps; maps in the Flood Plain Information Studies by the COE; maps in the Flood Hazard Analysis studies by the SCS; and maps by either the local planning commission or by the highway department. The scale, contour line detail, timeliness, and general quality of these maps vary greatly. In order to provide higher resolution for field use, some portions of maps were enlarged with the contour lines interpolated into 1- and 2-ft intervals. Structures on the flood plain were located on these maps with newer structures added during the field survey. The sources of the maps for the four communities were:

Passumsic River:	USGS (15-min) SCS (Soil Conservation Service 1973) COE (1" = 400') (Corps of Engineers 1973)
Whetstone Brook:	USGS (15-min) COE (1" = 400') (Corps of Engineers 1972a)
Agawam, Mass. & Connecticut River:	USGS (7.5-min) COE (1" = 400') (Corps of Engineers 1972b)
West Hartford, Conn. & Whetstone Brook:	USGS (7.5-min) Metropolitan District Planning Commission Topographic Maps (1" = 200'), Hartford, Conn.

The USGS topographic maps have 10- or 20-ft contour lines; COE maps have 5-ft contours; and Hartford District Planning Commission maps have 2-ft contours. The interpolated contours were further checked in the field with a hand level.

4.2.2 Hydrologic Data Collection

The hydrologic data was based on all the existing data available for each of the four areas. The form of data and record length at different gaging stations varied. Thd data was obtained through personal communications with the USGS, the COE, and the SCS. A limited number of stream cross sections also were obtained. The sources of data are:

Passumpsic River:	SCS (discharge frequency and stream cross sections) COE (discharge, flood profile for 100-yr recurrence interval)
Whetstone Brook:	SCS (discharge frequency) COE (selected cross sections, flood profile for 100-yr recurrence interval)
Connecticut River, Agawam, Mass.:	USGS (discharge frequency and stage discharge data at Thompsonville)
Trout Brook, W. Hartford, Conn.:	USGS (discharge frequency and stage discharge data at Fern St. intersection, West Hartford)

4.2.3 Collection of Data for Properties on Flood Plain

Structures on the flood plain within the studied area were identified according to the given river, reach, section, block, and structure numbers on the field topographic maps. Field investigations were made to gather the data on each individual property. The information associated with all the properties was obtained by physically appraising each structure and its surroundings. The evaluation was done without trespassing on private properties. The following information was collected:

a. Basement (yes, no)

b. Stories (1, 1.5, 2,3)

c. Use (1, 2, 3, 4+ families, family + commercial, commercial, industrial, public)

d. Structure (frame, frame + brick, brick, stone, concrete, steel, trailer)

e. Value of furnishings (low low, low, average, high, high high)

f. General upkeep (poor, average, good, excellent)

g. First flood elevation above ground (ft)

h. Ground elevation (feet above datum)

i. For residential property
 (1) Market value (A, B or C class)
 (2) Size (large, average, small)

j. Number of gas pumps (gas stations)

k. Number of garage stalls

l. Miscellaneous: dimensions and use of commercial structures, estimate of inventories (new or used cars, equipment, other properties that have potentially reducible damages)

A movie camera was used to photograph several frames of each property for later reference. The film provided an economical and valuable record of the flood plain by (1) providing occasionally missing data; (2) assisting in the assessment of commercial reducible flood damages (especially automobiles and mobile equipment); and (3) refreshing field recollections when needed. A hand level was used in providing the elevation data on the structure.

The size of the sample at each community was:

a. Passumpsic River at Lyndonville and St. Johnsbury, Vt.: The whole community on the flood plain was included with a total of 442 structures including 284 permanent residential structures, 93 trailers, and 65 commercial structures.

b. Whetstone Brook at Brattleboro, Vt.: The whole community on the flood plain was included with a total of 409 properties including 178 permanent residential structures, 212 trailers, and 19 commercial structures.

c. Connecticut River at Agawam, Mass.: 166 properties including 158 residential and 8 commercial structures. Agawam is characterized as a homogeneous single-family residential community. This sample was judged adequate to describe the approximately 1000 homes on the flood plain.

d. Trout Brook at West Hartford, Conn.: 95 structures, all single family residential, were included. They were representative samples from the area.

4.2.4 Economic Data

The relative market value of residential or commercial structures is dependent on the local real estate market. In order to gain a relative value comparison of those structures, residential properties in particular, the real estate advertisements in local newspapers were used as an estimate. The Engineering News Record construction cost index was also used to compare values used during the 1967 Susquehanna River Study (Day 1970) with 1974 values in the sample communities. These sources and private consultation were utilized in updating the state-damage values previously constructed (Day 1970). Multipliers selected for updating the Susquehanna River market values were: 1.5 for Passumpsic River, 1.5 for Whetstone Brook, 1.75 for Agawam, Mass., and 2.0 for Trout Brook.

4.3 Data Analysis

4.3.1 Hydrologic Data Analysis

The river stage-frequency relation is an essential part of the calculation and must be determined first. The stage-frequency relation was developed for each section of the river. The sections were selected on the basis of flood plain topography, river slope, and also the distribution of structures so that damage to each structure and its contents would be estimated with reasonable accuracy. The Passumpsic River was subdivided into 74 sections (only 36 sections contain structures in the flood plain); the Whetstone Brook was subdivided into 34 sections. The Agawam area was considered as only one section due to the high concentration of structures in the area and the gentle slope of the Connecticut River at that location. The Trout Brook study area was subdivided into six sections.

The discharge frequency data, the channel cross-section data and other associated data discussed in section 4.2.1 were the sources of information used in estimating stage-frequency. The stage-discharge (rating curve) was often not available. Manning's formula was used under those conditions to compute the missing stage-discharge relation at locations where the channel cross-section area was available. Backwater effects on flood stage were not specifically calculated due to the lack of data. The stage was adjusted subjectively at appropriate sections to compensate for backwater effects. The river stage-frequency relations were estimated at 10-, 20-, 30-, 50-, 100-, 200-, and 1000-yr recurrence intervals. Since river discharge and cross-section data were available at only a limited number of sections, stage-frequency relations elsewhere were extrapolated from their adjacent river sections with respect to the channel slope and the estimated flood profile.

The stage-frequency curve at each section was digitized according to recurrence intervals. The stage-frequency relation used in the four sample communities is available from the author or from the Office of Hydrology (O/H), National Weather Service.

4.3.2 Economic Data Analysis

The properties on the flood plain were classified into residential (permanent and trailer), commercial, industrial, and automobile categories. In the residential class, each structure was further characterized into one of the 22 types according to its structure class, stories, basement or no basement, furnishings, and upkeep. Each type of residential structure was identified with a stage-damage table under the conditions of no warning (NW), limited warning time (LWT), and maximum practical evacuation (MPE). There were 22 separate tables for each of the three conditions for a specific community. The stage-damage tables previously discussed (Day 1970b) were revised and updated for each condition and for each of the four sample communities. (See section 4.2.4). Similarly, the trailers were classified into three groups according to their size and general condition. Each trailer class was described in a separate stage-damage table. A passenger automobile stage-damage table was also developed. There were 26 different stage-damage tables for each condition, NW, LWT, or MPE respectively for each sample community.

The stage-damage assessment for commercial properties was made on an individual basis by using the field data and the film. Each family was assumed to own one car but only ½ the cars on the flood plain were assumed to be evacuated as a result of the NWS river forecast. Industrial properties were omitted from this study.

The community stage-damage tables for each condition and for each of the four sample communities are available from O/H, NWS.

4.3.3 Data Analysis Techniques

Procedures used in the data analysis and computation are shown in table 4.1. The procedure involves an extensive sequence of data coding and bookkeeping routines. Flood stages vs. recurrence intervals are stored in sequence according to their section numbers. The stage-damage tables are stored simultaneously. Each property identified by its location in terms of the river, reach, section, block, and building number is read into the computer program along with all the other associated information concerning the property. The property is then categorized and coded. If it is a commercial or industrial property it will be evaluated separately. Otherwise, it will interact with the stage-recurrence interval table to initiate computation of the flood stage above the ground and above the first floor since the elevations of the ground and first floors are both shown. The specific flood stage vs. recurrence interval information is then transferred to a selected appropriate stage-damage table according to its classification. Therefore, an appropriate damage amount in dollars is chosen, associated with a given flood stage at the structure. Hence the damage vs. recurrence interval relationship for this particular structure is established. Similar relationships can also be established for all the cases of NW, LWT, and MPE. After the first structure is done the second structure will follow until all properties are included. The results are tabulated and summarized either according to river sections or watershed. The expected annual damage in all cases (NW, LWT, MPE), can be calculated respectively. The detailed computer printout is available from O/H, NWS.

The cost of evacuation and reoccupation under limited warning time and maximum possible evacuation was also computed in a similar manner. The detailed results are available from O/H, NWS.

4.3.4 Results

A series of analyses on both the flood damage and the cost of evacuation and reoccupation was made for the sample communities. In each of the cases, i.e., no warning (NW), limited warning time (LWT), maximum practical evacuation (MPE), and floodproofing of a one-story house (FP(1)), a separate set of corresponding synthetic flood stage-damage tables and flood stage-cost tables was introduced into the computation procedure. The no-warning (NW) case yields the maximum damage that can be incurred. The limited warning time (LWT) case in which a warning time of approximately 6 to 12 hours is provided yields the damage after a reduction resulting from local action due to the warning. The case of maximum practical evacuation (MPE) is that in which all moveable items are evacuated when flood warning is provided approximately 12 to 24 hours in advance. Full response by the community to the warning is assumed. Flood-proofing of one story (FP(1)) at no warning is an experimental alternative in investigating the damage and cost if the occupants in all one-story houses could build storage space in the attic to be used for storing valuables in case of flood.

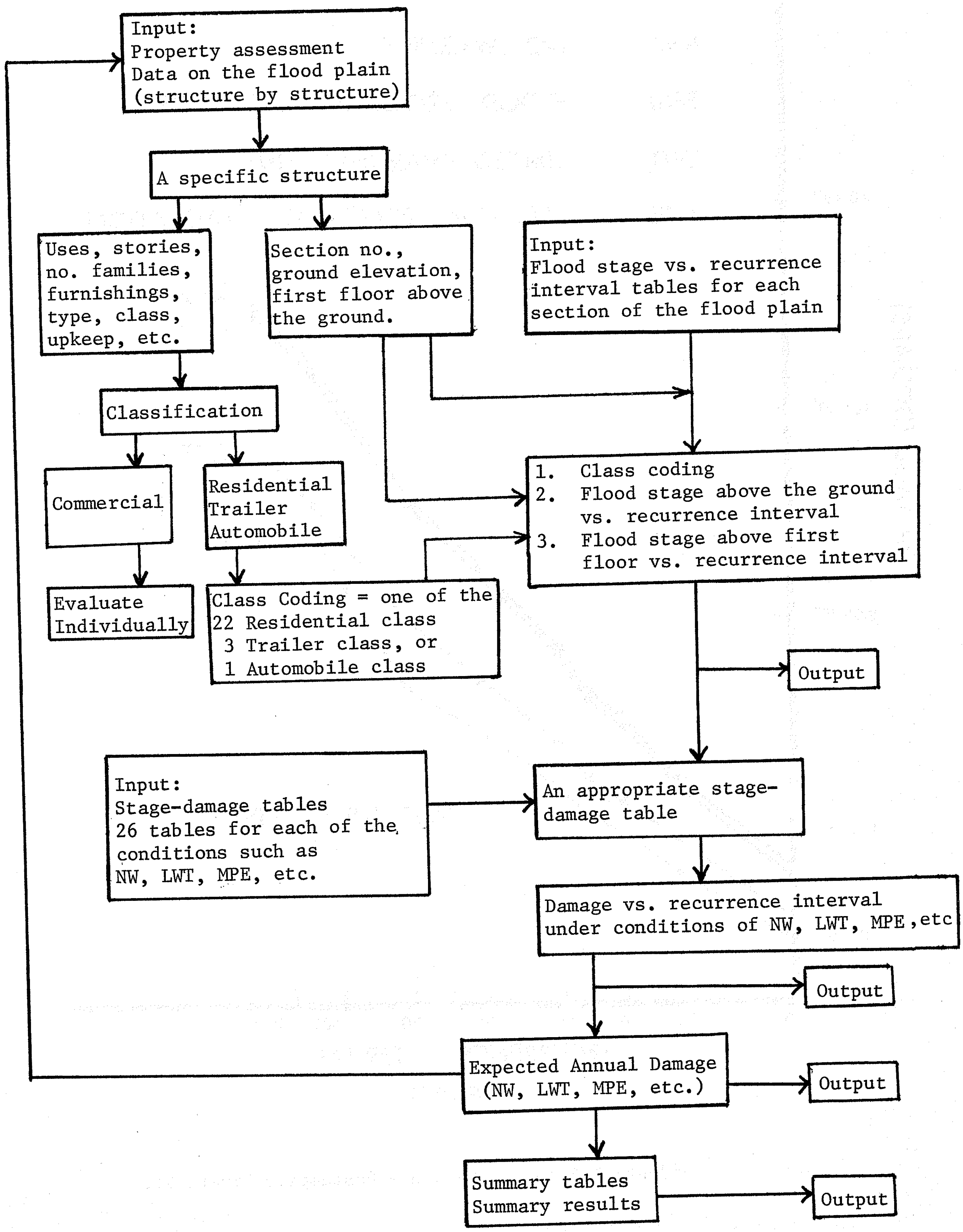
The flood damages under these four cases for Passumpsic River are presented in figure 4.5. The difference between NW and FP(1), LWT or MPE at any specific recurrence is the reducible damage under the condition when FP(1), LWT, or MPE is implemented respectively. Because of the small number of one-story houses in Lyndonville and St. Johnsbury, the reducible damage due to FP(1) is negligible. The flood damage under the condition of NW, LWT, MPE, and FP(1) for Whetstone Brook, Agawam, and Trout Brook samples are presented in figures 4.6, 4.7, and 4.8 respectively.

The cost of evacuation and reoccupation under the condition when LWT or MPE is implemented is presented in figures 4.9, 4.10, 4.11, and 4.12. The cost in all these communities under all the conditions is several orders of magnitude less than that of the corresponding reducible damage in these communities. The commercial properties in the study were evaluated individually in terms of the reducible damage in the field and by using the office data and film.

An additional flood plain management alternative, permanent evacuation of all houses and trailers where the estimated flood stage at 100-yr recurrence interval is more than 3 feet, was used in the Lyndonville and St. Johnsbury flood plains. The resultant damage and costs of evacuation and reoccupation is shown in figures 4.13 and 4.14.

The summary of sample information on the sample communities is in table 4.2. The summary of expected annual damage due to residential property,

Table 4.1--Computation Procedures



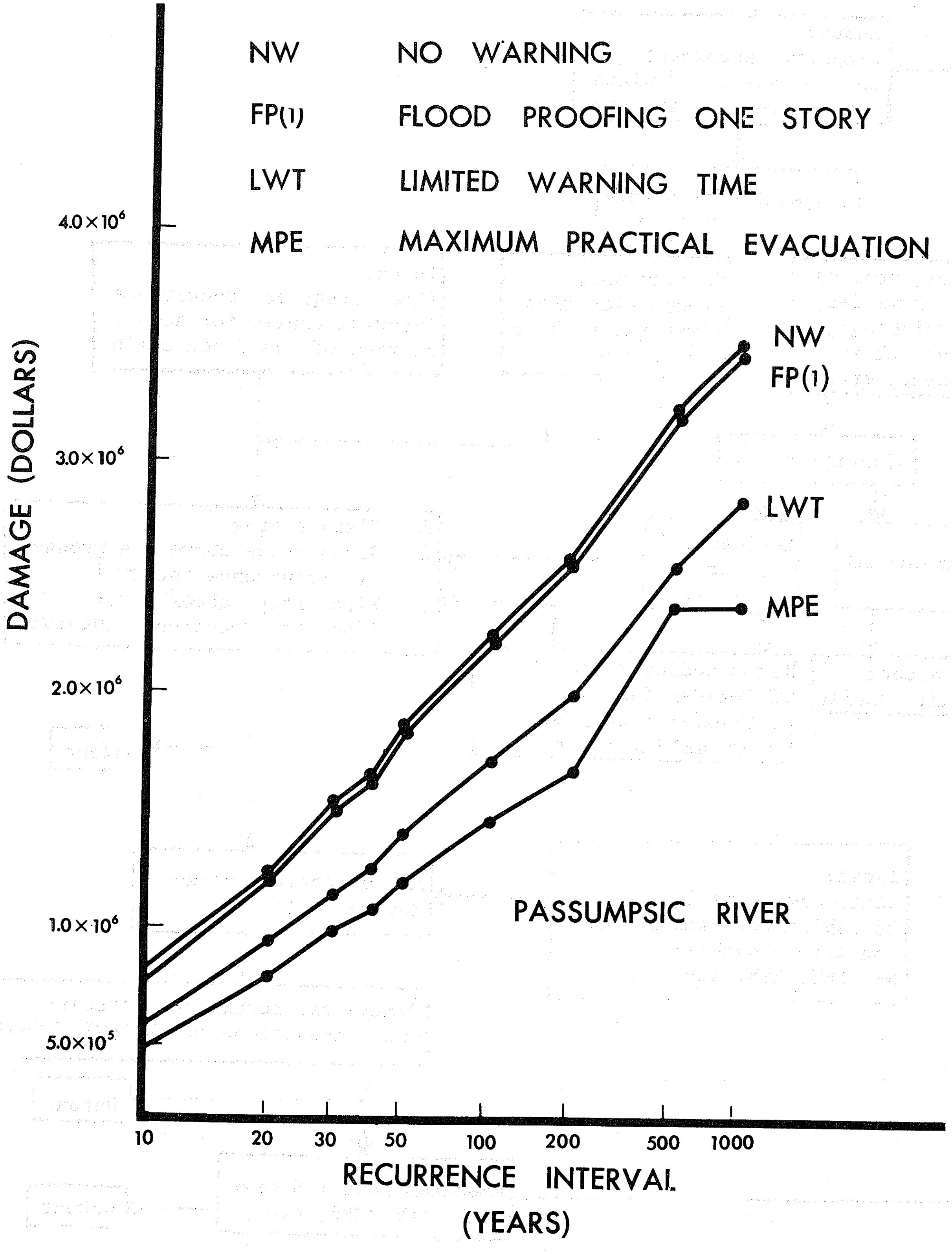


Figure 4.5--Residential Property Damage - Passumpsic River, Vt.

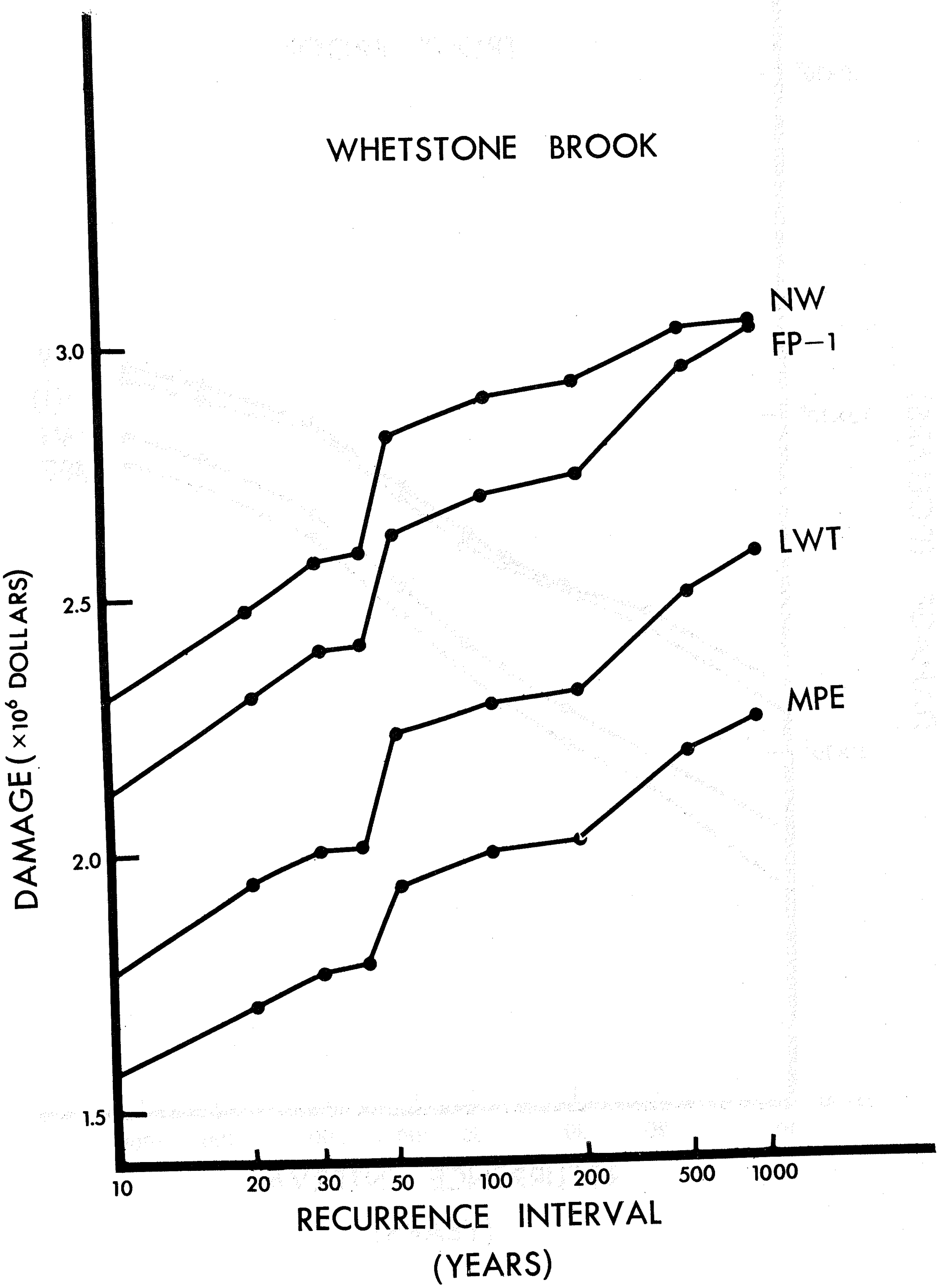


Figure 4.6--Residential Property Damage - Whetstone Brook, Vt.

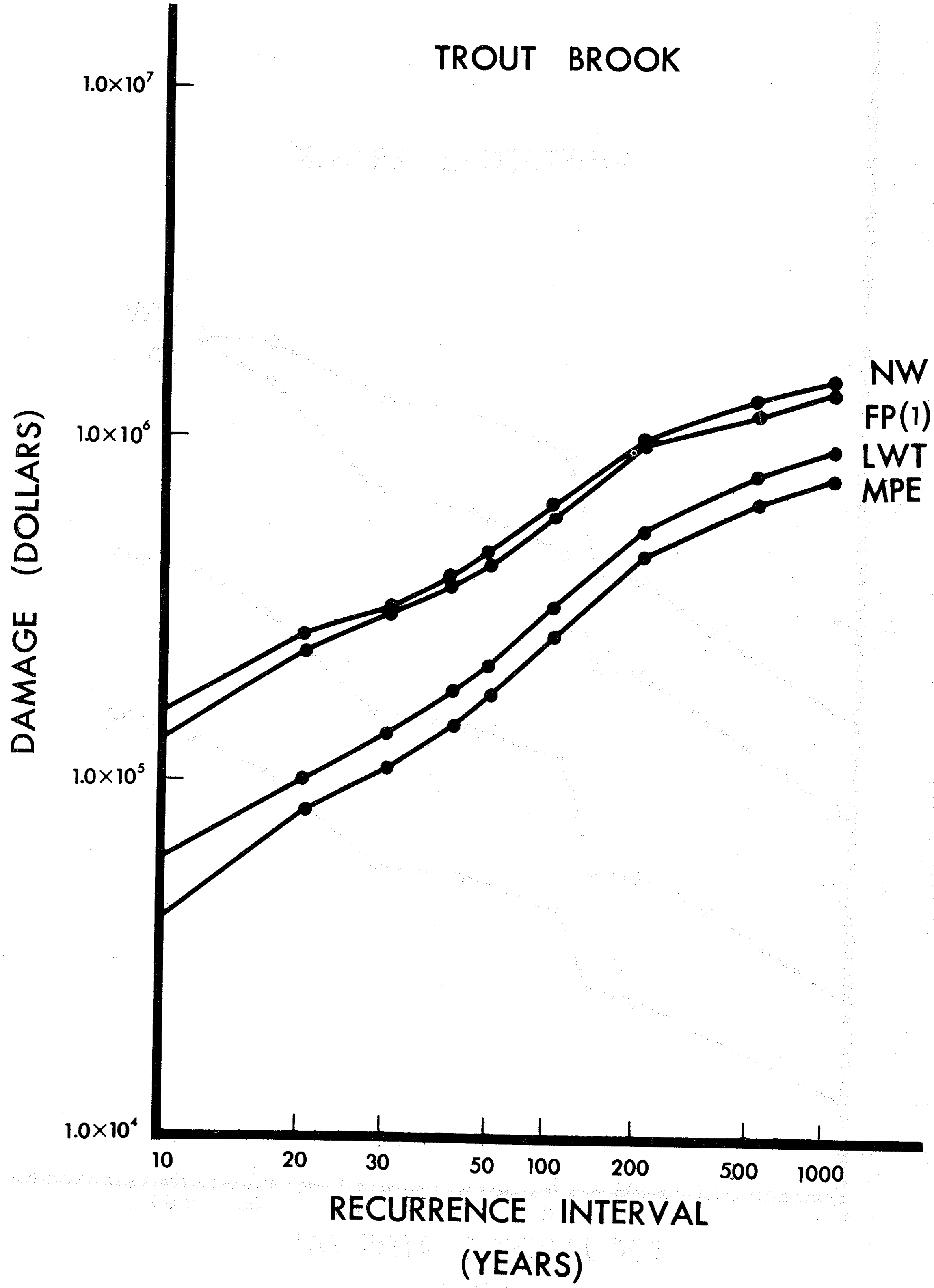


Figure 4.7--Residential Property Damage - Trout Brook, Conn.

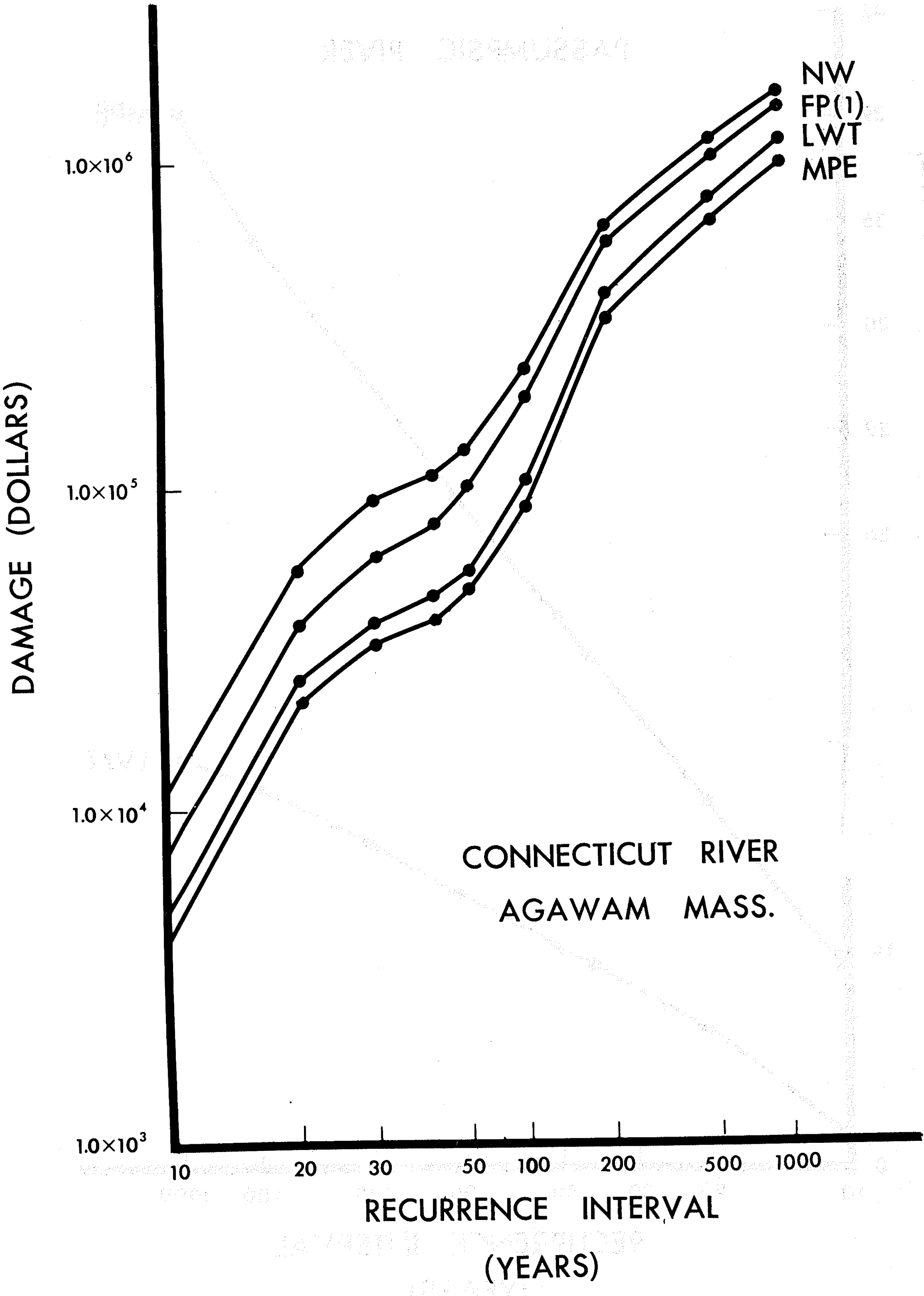


Figure 4.8--Residential Property Damage - Connecticut River at Agawam, Mass.

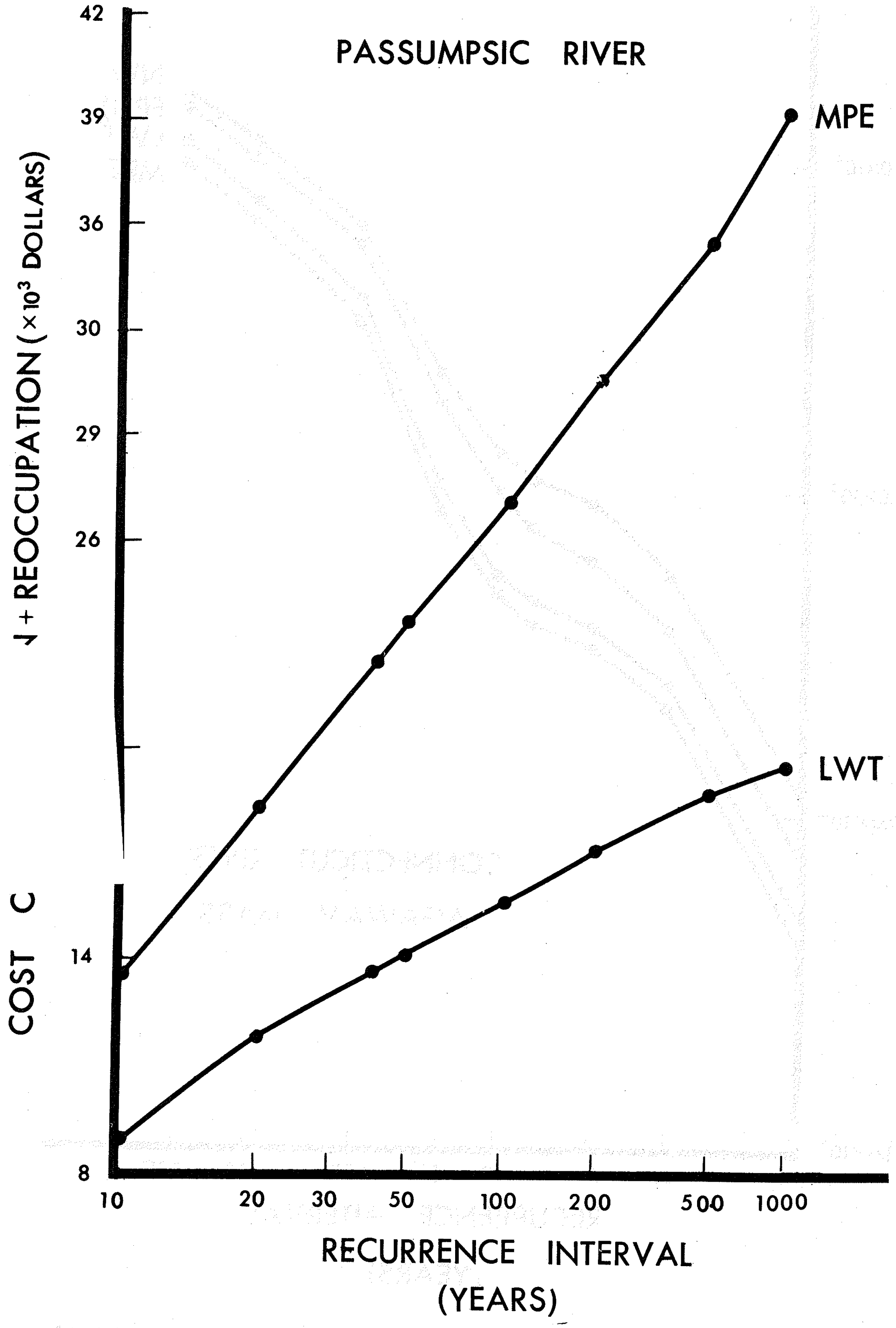


Figure 4.9--Cost of Evacuation and Reoccupation - Passumpsic River, Vt.

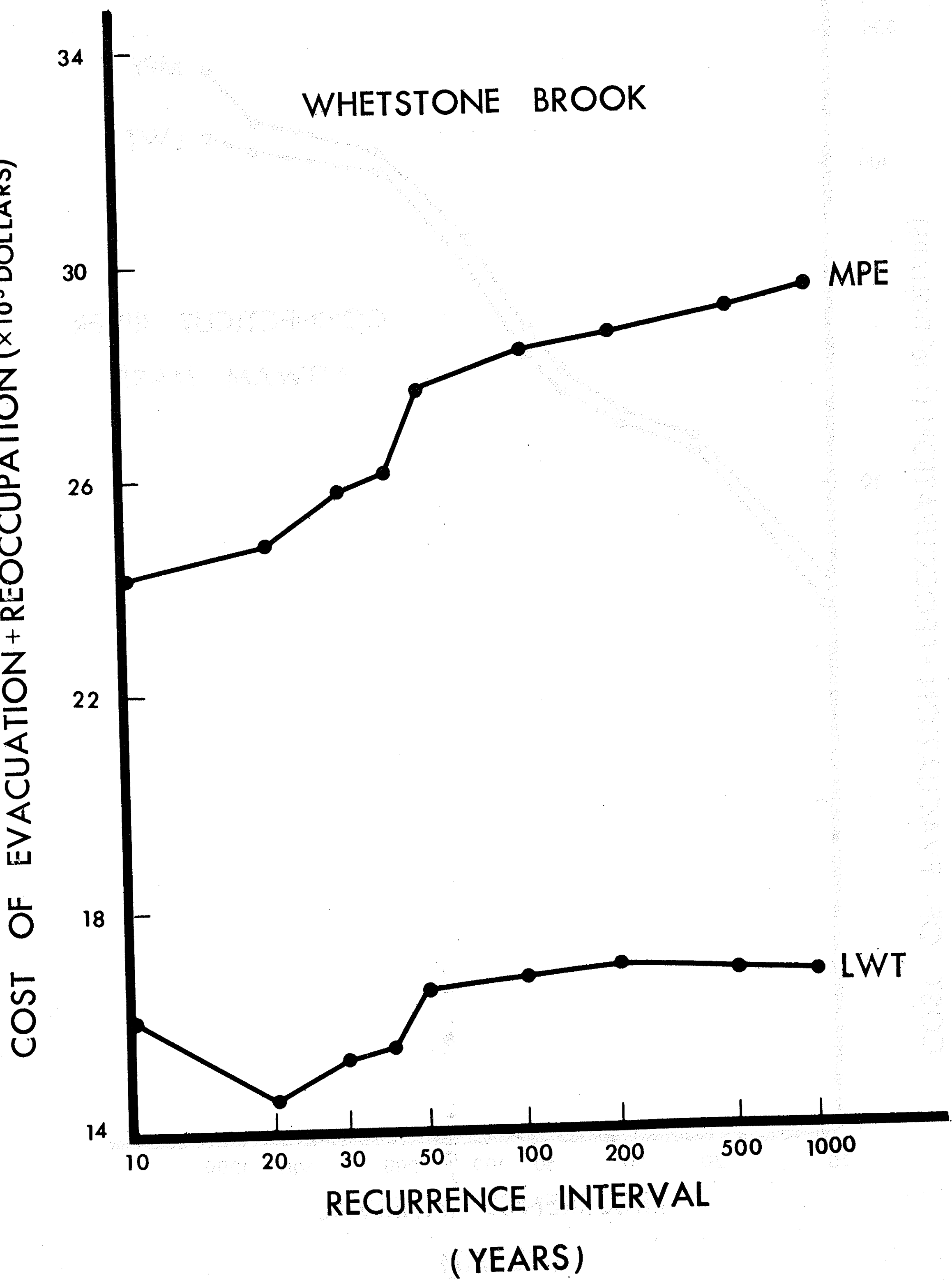


Figure 4.10--Cost of Evacuation and Reoccupation - Whetstone Brook, Vt.

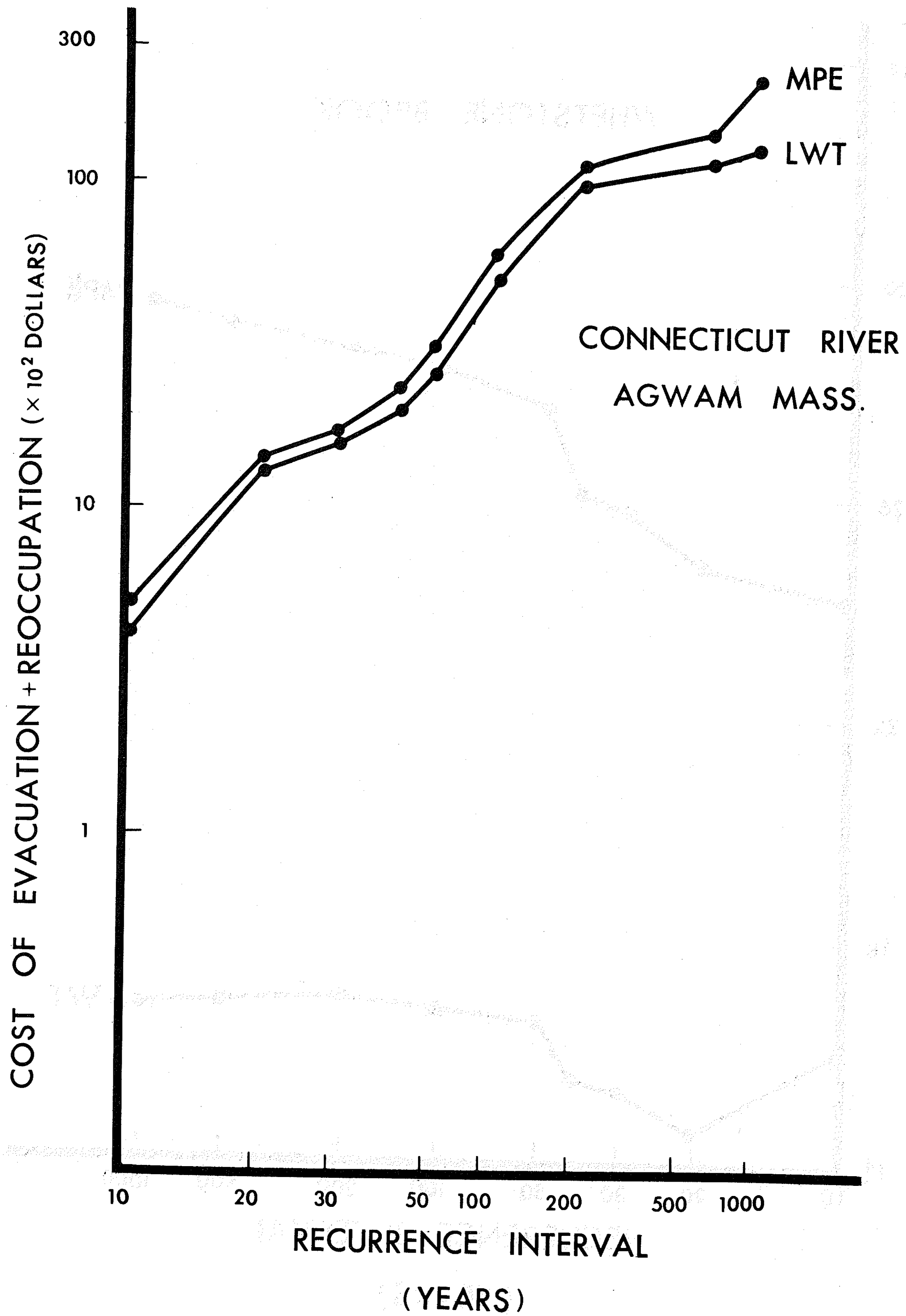


Figure 4.11--Cost of Evacuation and Reoccupation - Connecticut River at Agawam, Mass.

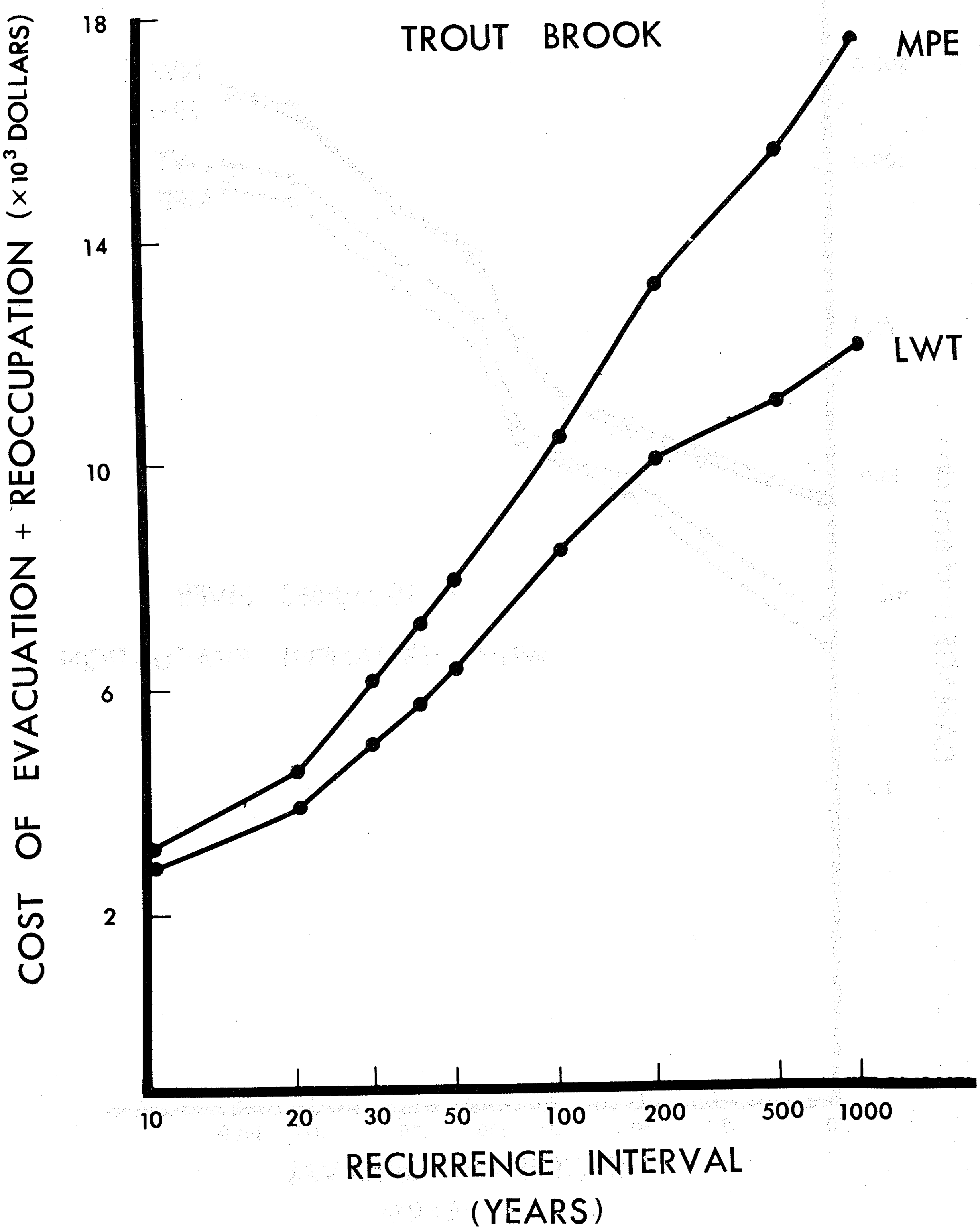


Figure 4.12--Cost of Evacuation and Reoccupation - Trout Brook, Conn.

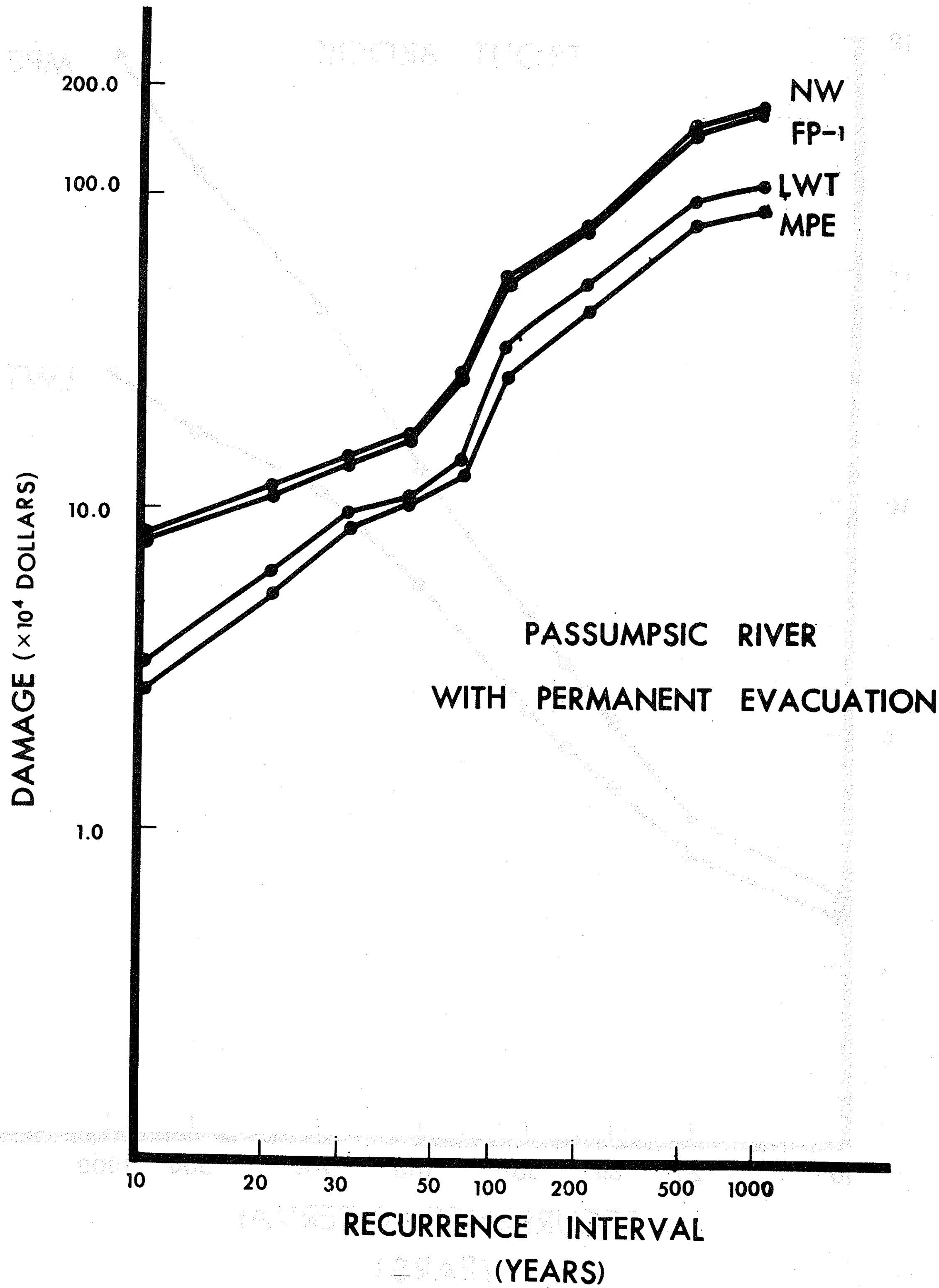


Figure 4.13--Damage Estimates with Permanent Evacuation at Passumpsic, Vt.

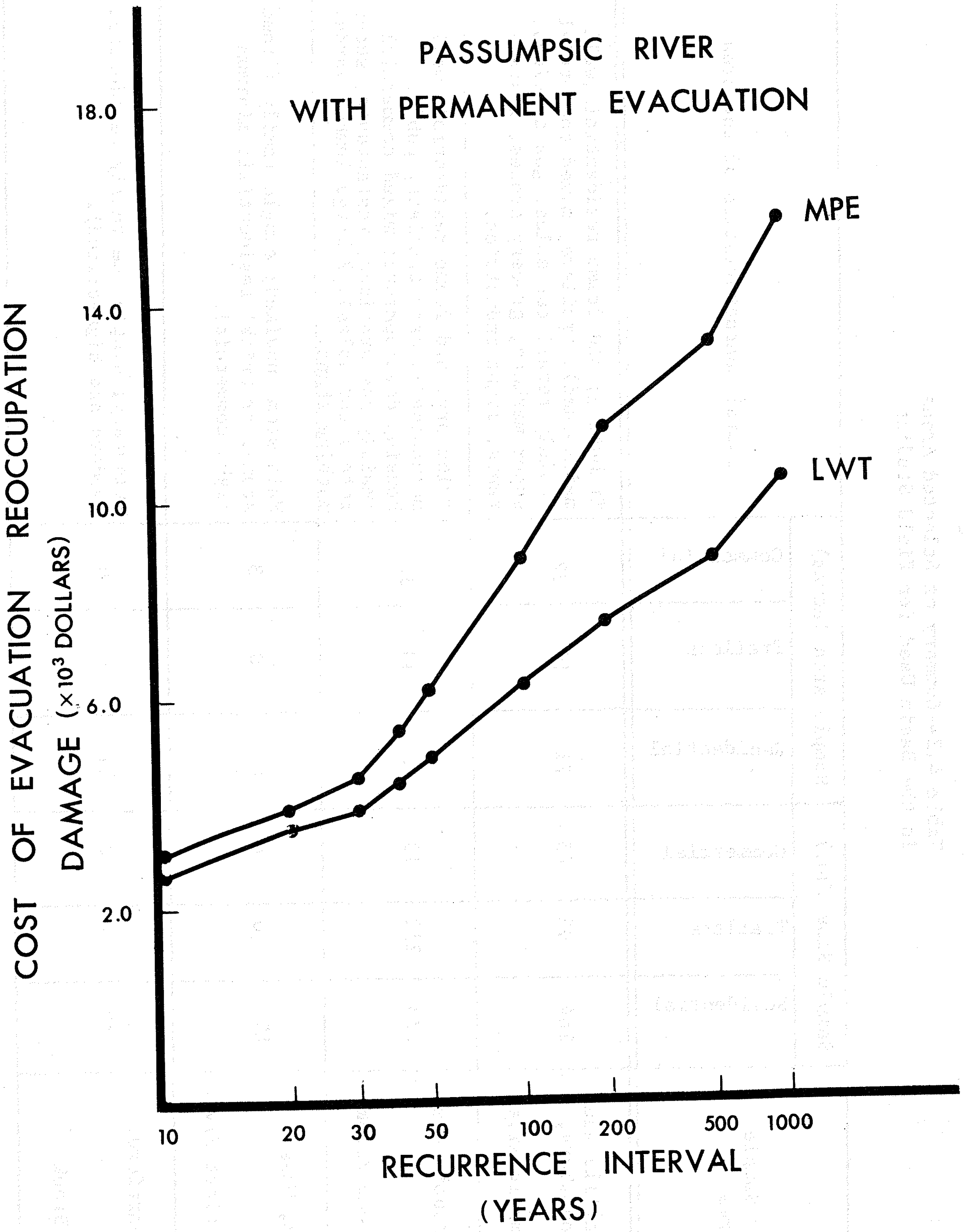


Figure 4.14--Cost of Evacuation and Reoccupation with Permanent Evacuation at Passumpsic River, Vt.

Table 4.2--Summary of Selected Areas in the Basin Used for Field Studies

Field Sample Area	Sample Size (No.)			Sample Area (Acres)			General Characteristics of the Area
	Residential	Trailers	Commercial	Residential	Trailers	Commercial	
Lyndonville and St. Johnsbury, Vt. Passumpsic River	284	93	65	71	19	32	Tributary; old frame residential (well maintained), trailers, mixed commercial (mainly retail car sales, gas stations, super markets, grocery stores, restaurants, light industries.
Brattleboro, Vt. Whetstone Brook	178	212	19	45	43	10	Tributary; old frame residential (well maintained), many trailers, public housing developments; mixed commercial (mainly gas stations, restaurants, shops, retail car sales), 2 large lumber yards, machine shops.
Agawam, Mass. Connecticut River	158	0	8	40	0	3	Main stem, undiked; single family (frame, stone, or brick) residential; minimum light commercial.
West Hartford, Conn. Trout Brook	95	0	0	24	0	0	Tributary; single one family residential (modern and high-priced).

houses, trailers, and family automobiles in the sample communities is listed in table 4.3. Based upon the previous analysis, the expected annual gross benefits and costs of evacuation and reoccupation in all four samples is summarized in table 4.4.

Furthermore, the expected annual reducible damage amount per unit area of flood plain and per unit of structure on the flood plain in all four communities is computed in table 4.5. These unit amounts may be used in providing useful quantitative estimates for other flood plains with similar characteristics.

5. BASIN-WIDE EXTRAPOLATION

An estimate of the expected annual reducible damages associated with both residential and commercial structures on flood plains throughout the Connecticut River Basin has been made. No detailed field data were collected at sites other than those described in section 4. Information on the characteristics of flood plains elsewhere in the watershed has been obtained from both published and unpublished documents, private communications, and site visits. The primary source of this information is from the New England Division, COE reports prepared as part of the Phase I, SFMS effort. Other sources included Flood Plain Information publications provided by the Corps and water resources reports published by the SCS and by the State of Vermont. Discussions with representatives of Cheney, Miller, Ellis, and Associates and NWS RFC provided additional insight. This flood plain information can be organized in two categories: (1) area characteristics; and (2) structure type characteristics. Since the results of field investigations in sample communities were calculated in both dollars per acre and dollars per structural unit, the extrapolation could proceed directly by use of either set of values. Judgment was used to determine which of the sample communities or combination of sample communities would be used for a particular extrapolation. The Agawam, Mass., results were used for all flood plains protected by a dike from floods greater than the 100-yr recurrence interval. This selection was made since Agawam is sufficiently high on the flood plain so that the damage there is representative of a diked community. The Brattleboro and St. Johnsbury-Lyndonville values were used according to perceived similarity of flood plain structures. The Trout Brook values were used for structures in the suburban areas of West Hartford and Bloomfield. The estimate for Keene, N.H., was particularly difficult to make, since the Corps of Engineers report indicated heavy development of commercial, residential and light industrial activities along a 1.6-mi stretch of the Ashuelot River in the center city of Keene. The land area was approximated to be 300 acres, even though over 4,000 acres was identified as the flood plain. Details of the extrapolation are presented in table 5.1. Based on this calculation, the expected annual reducible damage throughout the Connecticut River Basin is approximately $750,000.

Table 4.3--Summary of Expected Annual Residential Property Damage Values in the Sample Communities

	Lyndonville, St. Johnsbury, Vt. Passumpsic River (Dollars)	Lyndonville, St. Johnsbury, Vt. Passumpsic River With Permanent Evacuation * (Dollars)	Brattleboro, Vt. Whetstone Brook (Dollars)	Agawam, Mass. Connecticut River (Dollars)	W. Hartford, Conn. Trout Brook (Dollars)
NW	126,460	20,348	248,694	10,122	31,064
LWT	93,892	11,630	194,060	5,435	13,564
MPE	79,631	10,188	171,608	4,679	10,824
FP(1)	123,458	19,988	231,178	8,113	28,317
Sample Size	377	377	490	158	95

* Permanent Evacuation of all houses and trailers with ≥ 3 feet water at 100 yr recurrence.

NW: No Warning
LWT: Limited Warning Time
MPE: Maximum Practical Evacuation
FP(1): Flood Proofing in One-Story Houses

Table 4.4--Expected Gross Benefit and Cost Estimate in the Sample Communities

Expected Annual Gross Benefit and Cost Estimates (Dollars) (Residential Properties)										
	Lyndonville, St. Johnsbury, Vt. Passumpsic River		Lyndonville, St. Johnsbury, Vt. Passumpsic River With Permanent Evacuation *		Brattleboro, Vt. Whetstone Brook		Agawam, Mass. Connecticut River		W. Hartford, Conn. Trout Brook	
	Gross Benefit	Cost	Gross Benefit	Cost	Gross Benefit	Cost	Gross Benefit	Cost	Gross Benefit	Cost
NW-LWT	32,570	1,130	8,718	355	54,634	1,584	4,687	202	17,500	4,430
NW-MPE	46,820	1,806	10,160	436	77,086	2,534	5,443	241	20,240	531
NW-FP(1)	3,002		360		17,516		2,009		2,747	
Sample Size	377		377		490		158		95	
Expected Annual Gross Benefit (Commercial Properties)										
NW-LWT	20,950		—		20,702		15		0	
Sample Size	65		—		19		8		0	

* See Footnote Table 4.3

Table 4.5--Summary, Expected Annual Damages in Selected Basin Areas Used for Field Studies

Field Sample Area	Expected Annual Damage (No Warning) (Dollars)	Expected Annual Damage (Limited Warning Time) (Dollars)	Expected Annual Reducible Damage (Residential) (Dollars)	Expected Annual Reducible Damage (Commercial) (Dollars)	Expected Annual Reducible Damage Per Acre			Total Expected Annual Reducible Damage Per Acre (Dollars)	Total Expected Annual Reducible Damage/ Structure		
					Res.	Trl.	Com.		Res.	Trl.	Com.
Lyndonville and St. Johnsbury, Vt.	118,500 (Residential)	87,347 (Residential)	31,153 (Residential)	20,950	438	75	654	389	110	15	322
Passumpsic River	7,960 (Trailer)	6,545 (Trailer)	1,415 (Trailer)								
Brattleboro, Vt.	147,953 (Residential)	110,633 (Residential)	37,320 (Residential)	26,702	829	402	2670	301	209	82	1405
Whetstone Brook	100,741 (Trailer)	83,427 (Trailer)	17,313 (Trailer)								
Agawam, Mass	10,122	5,434	4,688	15	117	0	5	71	30	0	5
Connecticut River	0 (Trailer)	0 (Trailer)	0 (Trailer)								
West Hartford, Conn.	31,064	13,564	17,500	0	729	0	0	243	184	0	0
Trout Brook	0 (Trailer)	0 (Trailer)	0 (Trailer)								

Table 5.1--Basin-Wide Extrapolation - Connecticut River Basin+

Basin Segment & Community	General Characteristics	Urban Flood Plain Specific Characteristics: Area (Acres)			Number of Structures			Expected Annual Reducible Damage: Based on Field Studies (See Table 4.2): Dollars Per Acre			Dollars Per Unit			Extrapolation: Area Total $			Structure Total $			TOTAL
		Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	
I. Deerfield River Basin & Mainstream to Mouth																				
a) Hatfield	No Information							(Please see reference list - Section 10)												
b) Northampton	Main Stem; majority of urban area protected by dike, specific commercial, industrial & public facilities outside of dike include: asphalt plant, fairground, container plant & a motel.[1]	←1000[(11)]→ (primarily fairground)			NA	NA	NA	(Not Available)					1500						1500	1500
c) Holyoke	Mainstem; majority of urban area protected by dike which would be overtopped by the Std. Project Flood but not by the 100 yr. recurrence flood. If topped, 230 acres of heavy urban land would be flooded.[2]	NA	NA	NA	12	-	3[(2)]				110		320				1320		940	2260
	*(Values refer to flooding at levels higher than 100 yr. recurrence, i.e. Intermediate Regional Flood)																			
		←230→						70						←16300→						16300
d) Springfield	Mainstem and Tributary: Urban Flood Plain protected by dike to level between the 100 yr. and the Std. Project Flood.[1]	NA *	NA	NA	NA	NA	NA			5						4100				4100
		←820→																		
e) West Springfield	Mainstem; majority of flood plain protected to 100 yr. recurrence interval by dike. Approx. 1,500 acres of heavy industrial and commercial urban land would be flooded by the Std. Project Flood, including a fairground, Sears Roebuck, electric power generating station and a paper company.[3]	NA *	NA	NA	14	-	13[(3)]				110		320				1540		4160	5700
		←1500→								5						7500				7500

+ See Data Sources at end of table

Table 5.1--Cont.

Basin Segment & Community	General Characteristics	Urban Flood Plain Specific Characteristics: Area (Acres)			Number of Structures			Expected Annual Reducible Damage: Based on Field Studies (See Table 4.2): Dollars Per Acre			Dollars Per Unit			Extrapolation: Area Total $			Structure Total $			TOTAL
		Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	
f) Chicopee & Chicopee Falls	Tributary; large portion of Chicopee and Chicopee Falls flood plain protected to 100 yr. recurrence by dike. Land flooded by the Std. Proj. Flood includes approx. 65 residences and 60 commercial & industrial buildings.(4)	NA	NA	NA	15(4)	-	NA				110						1,650			1,650
					*		*													
					65		60				30		5				1,950		300	2,250
g) Westfield	Tributary; primary urban flood plain in city of Westfield. Development in flood plain estimated at approx. $20,000,000. Dike protects major development to 100 yr. recurrence event. At higher levels 423 single family residences, 500 multiple family housing units, and 55 commercial firms would be flooded (2.5) seriously. (5)		(2.5) 2000		NA	NA	NA													
					*		*													
					923		55				30		5				27,700		165	27,900
h) Agawam	Mainstem; primarily residential. No dike. High river banks. Broad, flat flood plain at high recurrence intervals.(6)	NA	NA	NA	1000	-	20				30		5				30,000		100	30,100
i) Hartford	Mainstem and Tributary; central flood plain protected against Std. Proj. Flood by dike (Conn. River) and by conduit & pumping station (Park River). Damage upstream in the Park River Basins (within Hartford) is still likely at the Std. Proj. Flood as noted. Data based on 1955 flood was 1659 residences, 237 commercial & 64 commercial & 64 industrial structures.(7)	NA	NA	NA	NA	NA	NA													
					*		*													
					1659	-	237				30		5				50,000		1,190	51,200

Table 5.1--Cont.

Basin Segment & Community	General Characteristics	Urban Flood Plain Specific Characteristics: Area (Acres) Res.	Trl.	Comm.	Number of Structures Res.	Trl.	Comm.	Expected Annual Reducible Damage: Based on Field Studies (See Table 4.2): Dollars Per Acre Res.	Trl.	Comm.	Dollars Per Unit Res.	Trl.	Comm.	Extrapolation: Area Total $ Res.	Trl.	Comm.	Structure Total $ Res.	Trl.	Comm.	TOTAL
j) East Hartford	Mainstem and Tributary; major central city flood plain protected by dike for floods less than 100 yr. recurrence. Proseven reservoirs upstream would prevent dike overtopping with Std. Proj. Flood. Structure behind dike includes 1000 residences and several hundred commercial units.[8]	NA	NA	NA	240	125	13[8]				110	15	320				26,400	1,880	4,160	32,400
					*		*[8]													
					1000	-	200				30		5				30,000		1,000	31,000
k) Rocky Hill	Main Stem; minimum flood plain. Flood plain (1000 acres) is zoned for agricultural use only.[9]	NA	NA	NA	2[9]	-	-				110						220			220
l) Glastonbury	Main Stem; agricultural use for low land. 500 single family residences are located on land higher than the 100 year recurrence interval and lower than the Std. Proj. Flood.[10]	NA	NA	NA	100	-	-				210						21,000			21,000
					*															
					500	-	-				30						15,000			15,000
m) West Hartford and Bloomfield	Tributary; north and south branches of the Park River. Local flooding of approx. 600 single family residences & 85 commercial structures with damage of $2 million occurred in the[11] North Branch during 1955 flood (recurrence interval greater than 100 yr. & less than 1000 yr)[12] Assume 1000 single family homes & 200 commercial structures would be affected by 100 yr. recurrence interval flood in both No. & So. branches in 1974 due to increased urbanization since 1955. (13)	NA	NA	NA	NA	NA	NA													
					*		*													
					1000	-	200				180		300				180,000		60,000	240,000

Table 5.1--Cont.

Basin Segment & Community	General Characteristics	Urban Flood Plain Specific Characteristics: Area (Acres)			Number of Structures			Expected Annual Reducible Damage: Based on Field Studies (See Table 4.2): Dollars Per Acre			Dollars Per Unit			Extrapolation: Area Total $			Structure Total $			TOTAL
		Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	
V. Ammonoosuc River Basin Littleton, N. H.	Tributary; commerical & light industrial use of narrow flood plain.[19]	NA	NA	NA			4						320						1,280	1,280
VI. Passumpsic River Basin St. Johnsbury & Lyndonville, Vt.	Tributary; old frame residential houses (well maintained), trailers, mixed commercial, (mainly retail car sales, gas stations, super markets, grocery store, restaurants, light industries.[20]				284	93	65				110	15	320				31,153	1,415	20,950	53,500
VII. Mill River Basin Northampton, Mass.	Tributary; broad flood plain at confluence with Connecticut River (included in III-b). Additional 140 acres of urban flood plain upstream of confluence. (Commercial, industrial, and residential use).[21]		←105→						←300→						←31,500→					31,500
VIII. Whetstone Brook Basin Brattleboro, Vt.	Tributary; old frame residential houses (well maintained), many trailers, public housing developments; mixed commercial (mainly gas stations, restaurants, shops, retail car sales); two large lumber yards, a machine shop.[20]				178	212	19				209	82	1,405				37,320	17,313	26,702	81,300
																			GRAND TOTAL	758,300

Table 5.1--Cont.

Basin Segment & Community	General Characteristics	Urban Flood Plain Specific Characteristics: Area (Acres)			Number of Structures			Expected Annual Reducible Damage: Based on Field Studies (See Table 4.2): Dollars Per Acre			Dollars Per Unit			Extrapolation: Area Total $			Structure Total $			TOTAL
		Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	Res.	Trl.	Comm.	
II. Ashuelot River Basin (Keene, N.H.)	Tributary; broad, flat urban flood plain; heavy center city industrial & commercial development.(14)	←	300[14]	→	NA	NA	NA	←	300	→				←	90,000	→				90,000
III. Sugar River Basin & Mainstream to Brattleboro																				
a) Claremont, N.H.	Tributary; broad, flat urban flood plain. No local protection exists. At the 100 yr. recurrence interval 460 acres would be flooded including 30 residences, 30 mobile homes and 15 commercial buildings.[15]	NA	NA	NA	30[15]	30	15				110	15	320				3,300	450	4,800	8,550
b) Brattleboro	Main stem; central urban area primarily retail commercial affected only by low recurrence interval floods from Connecticut River.[16]	NA	NA	NA			7[16]						300						2,100	2,100
IV. White River Basin & Mainstream to Lebanon																				
a) Hartford, Vt. White River Junction, Vt.	Main stem and tributary; small flood plain occupied by small communities which are affected by low recurrence interval floods.[17]				17[17]	-	6				110	-	320				1,870		1,920	3,790
b) Lebanon, N.H. W. Lebanon, N. H.	Mainstem and tributary; broad, flat flood plain at confluence of Mascoma & Connecticut Rivers. Approx. 6 commercial bldgs. have recently been erected there. Generally narrow flood plain along Mascoma River in Lebanon.[18]						6[18]						1,400						8,400	8,400
		←	80[18]	→				←	110	→				←	8,800	→				8,800

Table 5.1--Cont.
Data Sources

1. Corps of Engineers, "Draft Copy, Present Status of Elements for Flood Damage Reduction - Northampton, Springfield and Chicopee, Mass.; Connecticut River Supplemental Study," New England Division, Waltham, Mass.,Dec. 4, 1973, p. 5.

2. Corps of Engineers, "Draft Copy, Present Status of Elements for Flood Damage Reduction - Holyoke, West Springfield and Westfield, Mass.; Connecticut River Supplemental Study," New England Division, Waltham, Mass.,Feb. 7, 1974, p. 6.

3. Corps of Engineers, "Draft Copy, Present Status of Elements for Flood Damage Reduction - Holyoke, West Springfield and Westfield, Mass.; Connecticut River Supplemental Study," New England Division, Waltham, Mass.,Feb. 7, 1974, p. 19.

4. Corps of Engineers, "Flood Plain Information, Chicopee River," New England Division, Waltham, Mass., Sept. 1973, Plates 3, 4, 6, 7, 8 and 9.

5. Corps of Engineers, "Flood Plain Information; Westfield and Little Rivers, Westfield, Mass.," New England Division, Waltham, Mass., June 1969, p. 40.

6. Personal communication, Mr. Charles Hopkins, National Weather Service, Hartford, Conn. (Supplemented by field experience during study).

7. Corps of Engineers, "Draft Copy, Present Status of Elements for Flood Damage Reduction - Hartford, East Hartford and Rocky Hill, Conn.," New England Division, Waltham, Mass., Nov. 9, 1973, pages 5 and 8.

8. Corps of Engineers, "Draft Copy, Present Status of Elements for Flood Damage Reduction - East Hartford, Conn.," New England Division, Waltham, Mass., Nov. 9, 1973, p. 4.

9. Corps of Engineers, "Draft Copy, Present Status of Elements for Flood Damage Reduction - Rocky Hill Section, Conn.," New England Division, Waltham, Mass., Nov. 9, 1973, p. 6.

10. Corps of Engineers, "Draft Copy, Present Status of Elements for Flood Damage Reduction - Glastonbury, Conn.," New England Division, Waltham, Mass.,Jan. 7, 1974, p. 7.

11. Corps of Engineers, "Draft Copy, Present Status of Elements for Flood Damage Reduction - Northampton, Springfield and Chicopee, Mass.; Connecticut River Supplemental Study," New England Division, Waltham, Mass., Dec. 4, 1973, p. 13.

12. "Work Plan for Watershed Protection and Flood Prevention, North Branch, Park River Watershed, Hartford County, Conn.," State of Connecticut, May 1959, p. 9.

13. Personal Communication, Mr. Charles Hopkins, National Weather Service, Hartford, Conn., July 1974.

14. Corps of Engineers, "Draft Copy, Present Status of Elements for Flood Damage Reduction - Lebanon, Claremont and Keene, N.H.; Connecticut River Supplemental Study," New England Division, Waltham, Mass., Dec. 3, 1973, p. 39.

15. Corps of Engineers, "Draft Copy, Present Status of Elements for Flood Damage Reduction - Lebanon, Claremont and Keene, N.H.; Connecticut River Supplemental Study," New England Division, Waltham, Mass., Dec. 3, 1973, p. 23 and 24.

16. Corps of Engineers, "Flood Plain Information, Connecticut River, West River and Whetstone Brook; Brattleboro, Vt.," New England Division, Waltham, Mass., Jan. 1972, p. 13.

17. Corps of Engineers, "Draft Copy, Present Status of Elements for Flood Damage Reduction - St. Johnsbury, Hartford, Vt., and Littleton, N.H.," New England Division, Waltham, Mass., Nov. 19, 1973, p. 8 and 9.

18. Corps of Engineers, "Draft Copy, Present Status of Elements for Flood Damage Reduction - Lebanon, Claremont, and Keene, N.H.," New England Division, Waltham, Mass., Dec. 3, 1973, p. 7 and 8.

19. Corps of Engineers, "Draft Copy, Present Status of Elements for Flood Damage Reduction - Littleton, N.H.;" New England Division, Waltham, Mass., Nov. 19, 1973, p. 4.

20. Field Data collected during summer 1974 by H. J. Day and K. K. Lee.

21. Corps of Engineers, "Draft Copy, Present Status of Elements for Flood Damage Reduction - Northampton, Springfield and Chicopee, Mass.; Connecticut River Supplemental Study," New England Division, Waltham, Mass., Dec. 4, 1973, p. 5.

6. RESULTS

The basin-wide extrapolation has provided an estimated annual reducible flood damage of approximately $750,000 in the residential and commercial sectors of the flood plain. The majority of these reducible damages are present on tributaries to the main stem. The largest single amount, $240,000, has been identified with the upper reaches of the North and South branches of the Park River and its tributaries in West Hartford, Bloomfield, Conn., and adjacent suburban communities. The second largest amount, $190,000, was estimated for the central urban area of Keene, N.H. Reducible damages associated with a river forecast for communities along the main stem of the Connecticut River have been identified from table 5.1 and presented in summary fashion in table 6.1. The largest values have been identified with East Hartford, Conn., where several hundred structures, both residential and commercial, are on the flood plain outside the dike. In addition, the dike is not adequate at present to prevent waters of the standard project flood from inundating the central urban portion of the community. Agawam, Mass., represents the other major source of reducible damages where over 1,000 homes, many of them recently built, are on the flood plain associated with floods that have a recurrence interval greater than 100 years.

The results from this study can be compared with related studies in a minimum of situations. The 1970 Connecticut River Basin Report stated that annual losses due to floods in the Basin amounted to approximately $7,000,000. The fraction of total flood damage estimated as reducible due to forecasts in the Susquehanna study reference varied from 1/5 to 1/3. If this range applies in the Connecticut River Basin, the $750,000 estimate of reducible damages seems rather modest. Recent efforts by Dr. Phillip Cheney of Cheney, Miller, Ellis, and Associates have resulted in the identification of average annual damages approximating $141,000 along the main stem (urban structures only) from New England Division - COE data. The related value for the combination of urban and industrial damage is $272,000. If reducible damages are approximately 1/3 of those identified by Cheney's study of COE data, about $50,000 per year should be expected along the main stem, rather than $160,000 as estimated in this study. On the other hand, it is possible that some of the industrial damage was considered commercial damage in this report. It is also possible that the COE values do not reflect recent residential and commercial growth on the main stem flood plain.

A comparison of estimated values on the tributaries is available for only the Passumpsic River Basin in the vicinity of St. Johnsbury and Lyndonville, Whetstone Brook in the vicinity of Brattleboro, and the Mill River at Northampton, Mass. Table 6.2 is a summary of values for these three areas as estimated by the SCS and for this report. The values in the Passumpsic and in the Mill River seem quite comparative while those for the Whetstone Brook are larger than the SCS amounts. Special care must be exercised in making

Table 6.1--Main Stem Reducible Damages
(Based on Extrapolation from Table 5.1)

Main Stem - Expected Annual Reducible Damage in Dollars	Basin Segment
8,400	West Lebanon
2,100	Brattleboro
1,500	Northampton
18,560	Holyoke
4,100	Springfield
13,200	West Springfield
30,130	Agawam
–	Hartford
63,400	East Hartford
200	Rocky Hill
21,000	Glastonbury

Total $162,500

Table 6.2--Comparison of Expected Annual Flood Damage Estimates Along Selected Tributaries

Passumpsic River St. Johnsbury and Lyndonville, Vt.		Whetstone Brook Brattleboro, Vt.	
Soil Conservation Service	This Study *	Soil Conservation Service	This Study
286,100	147,410	183,300	269,400

* Based on the Sum of Residential ($126,460) and Commercial ($20,950) estimates values

comparisons since different assumptions have been used in the calculations, e.g., the SCS values are based on floods with recurrence intervals of 100 years and less, while floods with recurrence intervals up to 1000 years were used in this study. One reason identified for this variation is the difference in value used for trailers. The SCS used a lower dollar value, less than $5,000, while values ranging from $5,000 to $12,000, depending on the size of the trailer, were used in this report. These values are based upon the market value of reasonably new units; most trailers in the Whetstone Brook area were very modern. In addition, automobiles were considered as present on the flood plain and subject to damage in this investigation while they were not in the SCS study. Of course, not all activities motivated by a flood warning have been included in this study. For example, no attempt has been made to account for the number of lives saved during a flood due to a forecast.

The results are sufficiently comparable to place confidence in the values as long as they are used for general planning purposes.

7. NWS FORECAST SERVICES IN THE CONNECTICUT RIVER BASIN - PRESENT AND POTENTIAL

A summary is presented of the services provided by the RFC in Hartford to the Connecticut River Basin. In addition, recommendations are made for the purchase and installation of additional field and office equipment and office personnel to provide adequate forecasts throughout the Basin necessary for realizing the reducible damages identified in this report. Of course, receipt of and response to the forecasts in the flood plain communities are required for actual savings to occur.

7.1 Review of Present Services

The center for flood forecasts and the dissemination of warnings which may lead to flood plain evacuation is the NWS RFC in Hartford, Conn. The RFC, staffed by seven hydrologists, provides both flash flood guidance and formal river forecasts to much of New York State and all of New England.

Special flash flood forecasts are provided at six locations in the Connecticut River Basin: (1) Passumpsic, Vt., on the Passumpsic River; (2) Bath, N.H., on the Ammonoosuc River; (3) West Hartford, Vt., on the White River; (4) Westfield, Mass., on the Westfield River; and (5,6) Hartford, Conn., on both the North and South branches of the Park River. The primary purpose of these flash flood forecasts is to reduce loss of life; however, it also provides time for saving highly mobile property such as motor vehicles, television sets, foodstuffs, linen, and small furniture. Formal river forecasts are provided at 14 locations on the main stem of the river and on two of the slower tributaries (table 7.1). Flood-stage forecasts for each of these locations are based on weather information provided at 35 substations throughout the Basin. Values of precipitation, temperature, river

Table 7.1--Existing River Forecasts - NWS, RFC, Hartford, Conn.

City	River
Dalton, N.H.	Connecticut River
Wells River, Vt.	Connecticut River
White River Junction, Vt.	Connecticut River
North Walpole, N.H.	Connecticut River
Montague City, Mass.	Connecticut River
Northampton, Mass.	Connecticut River
Holyoke, Mass.	Connecticut River
Indian Orchard, Mass.	Chicopee River
Springfield, Mass.	Connecticut River
Thompsonville, Conn.	Connecticut River
Simsbury, Conn.	Farmington River
Rainbow, Conn.	Farmington River
Hartford, Conn.	Connecticut River
Bodkin Rock, Conn.	Connecticut River

stage, water equivalent of snow, and prevailing weather at each station are transmitted to the Hartford RFC by private citizens who receive a modest compensation for this service. Warning times associated with the forecasts based on this information vary from 12 hours to several days, depending on the forecast point location and the storm characteristics. The maintenance of a reliable and accurate cadre of citizen observers is directly related to the quality of the forecast. River forecast locations are presented in table 7.1.

The methods used in preparation of forecasts are conventional but time-tested. After collecting the precipitation information, the runoff is determined for each sub-basin using statistically based procedures that relate previous recent rainfall, time of the year, storm rainfall or snow melt, basin elevation, and latitude to the runoff. The stream discharge is computed for the individual forecast points by use of unit hydrograph and streamflow routing techniques that account for reservoir storage and release. Streamflow is converted to stage, which in turn is related to previous flood crest heights or community critical elevations when warnings are issued.

Dissemination of the forecasts throughout the Basin follows multiple paths:

a. Local weather teletype - This message is directed to wire services and to the Connecticut State Police. The State Police send the message on their intrastate police teletypewriter to police barracks throughout Connecticut, who in turn communicate with local police departments. The message is also sent by the Connecticut State Police via interstate police teletypewriter to Massachusetts, Vermont, and New Hampshire State Police. Massachusetts and New Hampshire have their own intrastate police teletypewriter systems for transmission throughout the state. Vermont has a police short-wave radio system used for such communications. State civil defense groups also connect with the teletypewriter network and disseminate the forecasts to related organizations.

b. Internal National Weather Service Teletypewriter Network - This message, identical to that sent on local teletypewriter, is directed to other NWS offices, including the O/H in Silver Spring, Maryland, which in turn alerts the Office of the Chief, COE, and national headquarters of the Red Cross and civil defense, as well as congressional interests.

c. Interstate Civil Defense Phone (National Warning System, NAWAS) - The principal use of this "hot-line" telephone system is to notify the civil defense headquarters of each State that a warning will be forthcoming. It may be used for voice dissemination to affected local communities in the event of teletypewriter failure.

The understanding of and response to the warning associated with the forecast are more difficult to achieve than providing technical improvements in the forecast service. Flood plain occupants, including local civil defense staff, police, city engineers, and elected officials, as well as the general public, have frequently demonstrated during recent floods that they do not comprehend the forecasts and warnings. Even when predictions are timely, accurate, and well understood, public response has been erratic. Local leadership and associated planning are necessary for river forecasts and warnings to be completely effective.

7.2 Recommendations for Future Services

Improvements in forecasting can be accomplished using existing technology, the effectiveness of which has been demonstrated elsewhere in the nation. An expanded and automated data collection network supplemented by cooperative substation observers is a major requirement to increase the warning time and to provide river forecasts for additional communities. Rainfall and river stage data can be obtained routinely every 6 hours or more frequently by use of an Automatic Hydrologic Observing System (AHOS). AHOS is capable of observing parameters such as temperature, precipitation and river stages. Increased coverage of the river basin with weather radar will also improve forecast services. As noted on figure 7.1, at present there is one automated rain gage adjacent to the watershed in Wallingford, Conn., and one located in the Park River Basin near Hartford, Conn. Additional AHOSs are needed throughout the Basin. Recommended locations are Bristol, Manchester, and Winsted, Conn.; Hampden and West Deerfield, Mass.; Keene, N.H.; and Whetstone Brook, Ludlow, Bethel, Westbrook, and Canaan, Vt. These automatic precipitation gages should be supplemented by two or three weather radar units appropriately located. Additional river gages are also required for improved forecast services. Recommended locations as noted on figure 7.1 are Rocky Hill, Conn., main stem; Chicopee, Chicopee River; Ware, Mass., Chicopee River system (Ware River); West Deerfield, Mass., Deerfield River; Brattleboro, Vt., main stem; Brattleboro, Vt., Whetstone Brook; West Claremont, N.H., Sugar River; North Canaan, N.H., Mascoma River; Littleton, N.H., Ammonoosuc River; Lancaster, N.H., Israel River; Groveton, N.H., Upper Ammonoosuc River; and Lyndonville, Vt., Passumpsic River.

It is evident that improved forecast services should be developed soon for several locations throughout the Basin, such as Lyndonville, Vt., Brattleboro, Vt., (Whetstone Brook), Westfield, Mass., (Westfield River) and North and South branches of the Park River in the West Hartford, Conn., area. In all these areas, perhaps with the exception of Whetstone Brook in Brattleboro, a 6-hr warning time can be provided when a continuous basin computer model is used in conjunction with the automatic river and rainfall reporting network. Special attention is directed to the Whetstone Brook of Brattleboro, and to the Passumpsic River at Lyndonville, Vt. Self-help forecasts may be particularly effective at these two locations. The procedure with a self-help forecast service is to identify and appoint a responsible person or organization in the local area who will (1) receive detailed briefing and instruction in flood forecasting from the NWS, and (2) will maintain a local precipitation gage for direct use. This self-help system, when used in

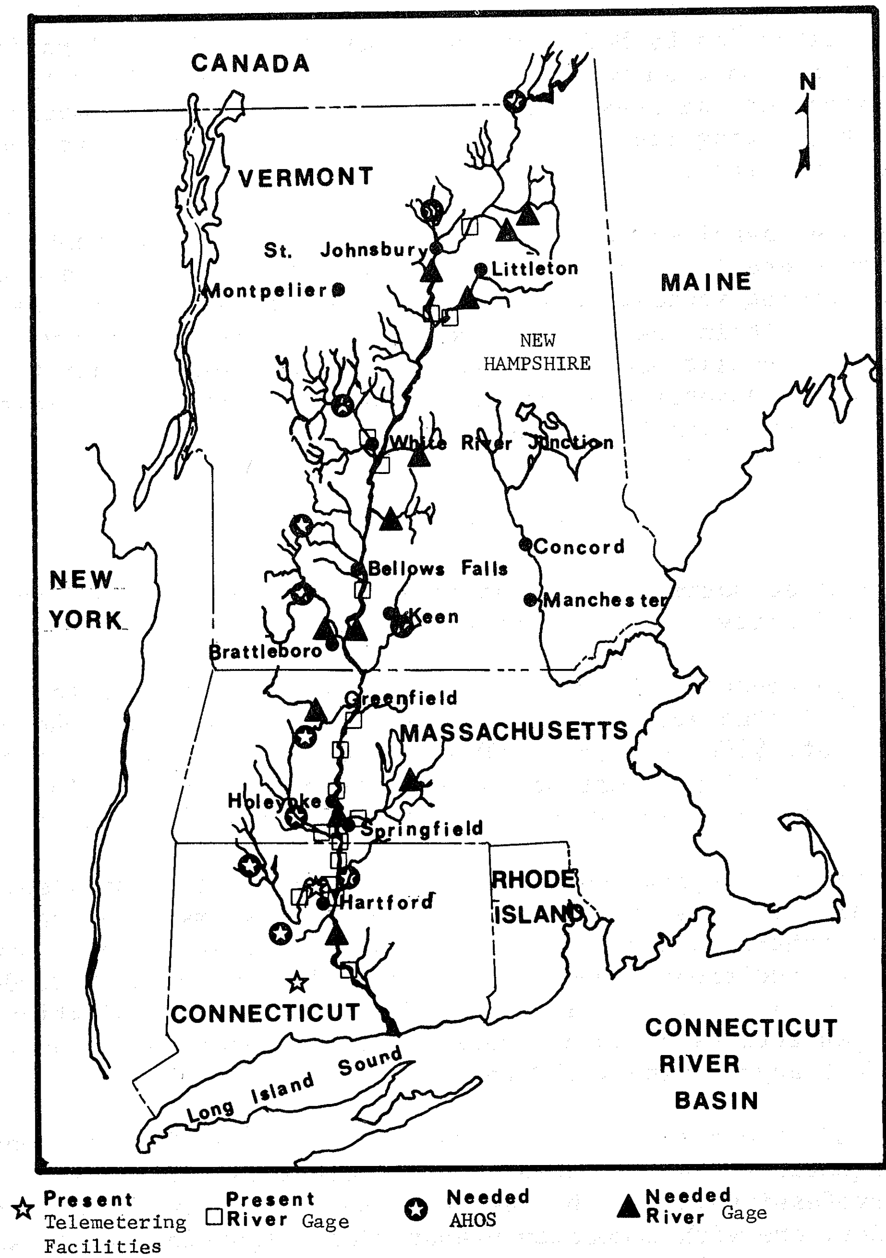


Figure 7.1--NWS Hydrologic Services - Basin Data Sources - Present and Recommended

conjunction with a watershed forecast model for the Whetstone Brook, should provide a maximum of 3 hours warning time (time from heavy precipitation to flood peak) for that critical flood plain.

Community preparedness is an equally critical area for development. The creation and maintenance of an improved system to implement local temporary evacuation based on flood warnings is required. Perhaps training programs for local citizens led by NWS personnel would be helpful. A roving local disaster information team made up of specially trained NWS staff might be created to move into an area during the early stages of an impending flood to supplement existing local personnel in the effort to understand and implement flood warnings.

These improved services could be provided by use of equipment and techniques proven operationally elsewhere in the Nation. Research activities underway at present indicate that an additional 6 to 12 hours' warning time can be expected within the next decade in most areas of the river basin through use of forecast procedures based on meteorology rather than ground-based hydrology. Quantitative precipitation forecasts, i.e., rainfall predictions before the rain is on the ground, are expected to be operational within this time period.

7.3 Cost Estimates

The following approximate cost estimates have been developed to aid in determining feasibility of justifying increased services:

a. Field Equipment: Automatic rainfall gages, DARDC, capital cost $3,000 per unit field installed. Operating cost, $25 per month telephone charge. Maintenance cost, $600 per year. (Two maintenance visits per year.) Unit life, 10 years. Cost per year per unit, (assuming straight-line depreciation),$1,200 per year. Twelve units, basin-wide cost $14,400 per year.

b. River Gages: Capital cost $10,000 per unit field installed. Maintenance $300 per year. Estimated life, 10 years. Estimated annual cost, (assuming straight-line depreciation), $1,300 per year. Twelve new units, $15,600. Total additional annual cost for field equipment, $30,000. It may be desirable to have a terminal available for direct communication with self-help organizations at some locations such as Whetstone Brook. Such a unit would cost approximately $50 per month.

c. Office Additions and Improvements: Appropriate digital computer capability is required for accelerated river forecast calculations. In addition, three more professionals will be needed on the staff, one with forecast responsibilities, one with community preparation responsibilities, and one with maintenance responsibilities. Total cost for these manpower additions is approximately $75,000 per year. Computer costs vary widely, depending upon the size of the unit. Perhaps a rental charge of $1,000 per month would be an approximate value. Total additional annual cost to provide improved services--approximately $125,000. This value does not include the increased costs of providing better local implementation procedures. The Defense Civil Preparedness Agency (DCPA), which exists in many locations throughout the river basin, would undoubtedly play a role in this effort.

8. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be reached as a result of this investigation:

a. Reducible damages potentially available as a result of a river forecast substantially exceed the costs associated with providing and implementing it. The basin-wide extrapolation indicated that approximately $750,000 reducible damages can be expected in the commercial and residential elements of the flood plain. No attempt has been made to estimate reducible damages associated with industrial structures, but elsewhere in the Nation such values often are of the same order of magnitude as residential and commercial. Total basin-wide reducible damages, therefore, undoubtedly exceed $1,500,000 per year. The present annual cost of the NWS providing forecasts throughout the Basin is approximately $75,000. A total of $200,000 per year would be adequate to provide forecast services associated with the reducible damages. Substantial sums could be used by local and State organizations with implementation responsibilities without the total cost exceeding $500,000 per year. It seems reasonable to assume, therefore, that a benefit-cost ratio of at least three exists associated with this element of a flood plain management program.

b. Technology and experience by the NWS elsewhere are both adequate to upgrade the forecast services necessary to expect the reducible damages identified.

c. Investment in NWS facilities alone without similar focus on local and regional organizations would not be desirable.

d. An estimate of reducible damages throughout a large complex river basin can be obtained through a combination of minimum field study, use of synthetic structural stage damage tables, and existing topographic and hydrographic data available.

e. Based on a rather minimum of experience, i.e., the Passumpsic River detailed study, it is apparent that an integrated analysis of both structural and nonstructural alternatives for flood plain management can be economically conducted. The analysis of river forecast effectiveness in combination with flood plain permanent evacuation up to a level equal to the structures with 3 feet or more of water at the flood associated with 100-yr recurrence interval, as well as the special flood-proofing alternative for one-story residential structures as reported in section 4, provide the basis for this statement. The inclusion of variations in stream hydrology as a result of different reservoirs can be added to the basin flood plain simulation model without any changes in program format.

Recommendations:

a. Flood warnings as provided by the NWS RFC should be included as a primary element of the several nonstructural alternatives for flood plain management in the Connecticut River Basin. Special attention should be directed to increasing the scope of services necessary to generate the reducible damages as estimated for the entire Basin. Particular attention is directed to the Park River Basin in the West Hartford area, the Whetstone Brook area of Brattleboro, Vt., and the central urban areas of both Keene, N.H., and Westfield, Mass.

b. Special attention should be directed to the development of community awareness and preparation for implementing flood forecasts when provided. A cooperative effort between local, state, and federal (particularly NWS) organizations is important.

c. Additional investigations of the reducible damages possible from various combinations of nonstructural and structural alternatives, including a river forecast, are needed in many areas of the Basin, with particular emphasis on major damage centers identified in this study, such as Keene, N.H., Westfield, Mass., East Hartford, Conn., and the Park River Basin of West Hartford, Conn.

d. The extension of these investigations focusing on the cost-effectiveness of a river forecast service elsewhere in the Nation is recommended. This study has benefited from the earlier Susquehanna River basin investigation and has gone beyond it in at least two significant ways: (1) the collection of field data directly associated with the NWS study; and (2) the inclusion of commercial reducible damages in the basin-wide investigation. The effectiveness of forecasts used for other purposes such as navigation, irrigation, and water supply, can proceed using similar fundamental concepts.

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REFERENCES

Bhavnagri, V. S. and Bugliarello, E., "Mathematical Representation of an Urban Flood Plain," Journal of Hydraulics Division, ASCE, 91 (HY2), March 1965, pp. 149-174.

Connecticut River Basin Coordinating Committee, "Comprehensive Water and Related Land Resources Investigation, Connecticut River Basin," Vol. I Main Report, Vol. II and III Appendices, June 1970.

Corps of Engineers, "Flood Plain Information, Connecticut River Basin," New England Division, Waltham, Mass., June 1970.

Corps of Engineers, "Flood Plain Information, Connecticut River, West River and Whetstone Brook, Brattleboro, Vt.," New England Division, Waltham, Mass., Jan. 1972b.

Corps of Engineers, "Flood Plain Information, Passumpsic River, St. Johnsbury, Vt.," New England Division, Waltham, Mass., Dec. 1972a.

Day, H. J., "A Study of the Benefits Due to the U.S. Weather Bureau River Forecast Service," ESSA-Weather Bureau, Office of Hydrology, June 1966.

Day, H. J., "Flood Warning Benefit Evaluation - Susquehanna River Basin (Urban Residences)," ESSA Technical Memorandum WBTM HYDRO-10, Weather Bureau, Silver Spring, Md., March 1970.

Day, H. J., "Benefit and Cost Analysis of Hydrological Forecast," World Meteorological Organization, Operational Hydrology, Report No. 3 WMO-No. 341, Oct. 1973, p. 33.

Soil Conservation Service, "Flood Hazard Analyses, Passumpsic River, Lyndon, Vt.," Jan. 1973.

White, G. F., "Human Adjustment to Floods," Department of Geography Research Paper No. 29, University of Chicago, Chicago, Ill., 1961a.

White, G. F., (editor), "Papers on Flood Problems," Department of Geography Research Paper No. 70, University of Chicago, Chicago, Ill., 1961b.