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WATER PLANNING AND MANAGEMENT BRANCH
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Flood Plain Management — Hydro-Economic Analysis

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Abstract

Economic and social studies are essential in any process of water resources planning or river bank management. This study deals with the establishment of an integrated system which would form the basis of the rational planning of flood plains and would include hydrological, hydrodynamic, physical and economic components. The application of such a system to a region of interest should lead to the establishment of a management policy for river banks, the basic objectives of which may be classified as follows:

(i) The analysis of flood/damage relations to obtain probability distribution functions for damages caused by floods.

(ii) The estimation of these damages without a post-flood investigation. This helps in the rational planning of zones already urbanized and the adequate management of zones set for future urbanization.

To reach these objectives, a digital simulation approach is taken in which the flood phenomenon and its impact on flood plains are considered as a complex system, which permits the estimation of hydrological characteristics (depth of submersion) for every economic unit in different activity sectors (permanent and secondary residential, agricultural, commercial and industrial). From this, one may correlate floods and flood damage, which can be extrapolated in time and space for various types of physical and non-physical damage. This theory is based on the use of extreme values and the sum of a random number of random variables in a stochastic process. The Richelieu River basin in Quebec, with its rural and urban sectors, has been chosen for a numerical application.

By dealing with both the economic and technical aspects of floods and their effect on flood plains, this study is significant on two levels:

(i) On the theoretical level, the use of stochastic methods to establish a flood/damage correlation effectively combines technical and economic aspects, thereby serving as a base for management studies and decision making with respect to flood plains in particular and water resources planning in general. In addition, it permits the determination of the variables involved and of the damage distribution function, the extrapolation of future damage, and the ability to transfer the parameters from an economic model of an experimental zone to another economically identical zone. Finally, damages can be assessed with very little investigation; moreover, the capability of the model to gain forecasting power can be improved as the amount of data gathered by these investigations increases.

(ii) On a practical level, the systematic approach to flood plain management of the Richelieu River drainage basin permits the estimation of various types of damage sustained by each unit of the economic sectors under consideration and the determination of the effect of seasonality on damage estimation. This approach shows that the submersion level is not the only significant variable in the stimation of agricultural damages.

The results of this study will contribute to the development of criteria for studying the value of management projects; the judicious choice of a flood control system after criteria, both technical and economic, have been determined; the determinaton of flood/damage correlation with not need for post-flood investigations; and the integration of urban and rural hydrology to obtain better watershed planning.

Résumé

La planification des ressources en eau, ainsi que l'aménagement des rives, impliquent que des études tant techniques, qu'économiques et sociales soient entreprises. La présente étude s'intéresse à la planification rationnelle des plaines inondables considérées comme un système intégré formé de composantes hydrologiques, hydrodynamiques, physiques et économiques.

L'application de ce système à une région donnée doit aboutir à la mise en place d'une méthodologie de gestion des rives dont les objectifs fondamentaux peuvent être classés comme suit:

i- l'analyse des fonctions de transfert crues-dommages afin de dériver une fonction de répartition probabiliste des dommages causés par les inondations;

ii- l'estimation de ces dommages sans passer par une enquête après crue. Cette estimation permettra une planification rationnelle des zones déjà urbanisées et un aménagement adéquat des régions en voie d'urbanisation.

L'approche utilisée pour atteindre ces objectifs est celle de la simulation digitale qui consiste à considérer le processus de crue ainsi que son impact sur les plaines inondables comme un système complexe qui permet d'estimer les caractéristiques hydrologiques (hauteur de submersion) pour chaque unité économique des différents secteurs d'activités (résidentiels permanent et secondaire, agricole, commercial et industriel). Cette considération permet d'établir des fonctions de transfert crues-dommages qui peuvent être généralisées dans le temps et dans l'espace et ceci pour différents types de dommages physiques et non physiques. Les théories de base sont celles des valeurs extrêmes et de la somme du nombre aléatoire des valeurs aléatoires en processus stochastique. Pour l'application numérique de cette théorie, le bassin versant de la rivière Richelieu au Québec a été choisi, étant donné son caractère à la fois urbain et rural.

En traitant des aspects économiques et techniques des crues et de leurs effets dans les plaines inondables, cette étude revêt une importance majeure:

i- sur le plan théorique, le traitement des fonctions de transfert crues-dommages par les méthodes stochastiques est une heureuse combinaison des deux aspects techniques et économiques. Il est une amorce des

études sur l'aménagement et de la prise de décision dans les plaines inondables en particulier et la planification des ressources en eau en général. Il permet entre autre, l'identification des variables en jeu, la dérivation de fonction de répartition des dommages, la projection future des dommages, le pouvoir de transposer les paramètres du modèle économique d'une zone expérimentale à une autre identique économiquement et finalement la possibilité de réaliser une étude sur les dommages avec une enquête très peu détaillée quoiqu'on puisse améliorer la qualité de prévision du modèle économique au fur et à mesure qu'on augmente le nombre de données recueillies par ladite enquête;

ii- sur le plan pratique, l'application de l'approche systématique à l'aménagement des plaines inondables du bassin versant de la rivière Richelieu, au Québec, permet entre autre, l'estimation des différents types de dommages encourus par chaque unité des secteurs économiques considérés, la quantification de l'effet de la considération saisonnière de l'excédance hydrologique maximale sur l'estimation des dommages. Finalement, la hauteur de submersion s'avère insuffisante, à elle seule, pour l'estimation des dommages agricoles.

Les retombées de cette étude contribueront à définir d'une façon formelle l'étude de rentabilité des projets d'aménagement; à pouvoir choisir judicieusement le système de contrôle des crues après avoir fixé les critères décisionnels, techniques et économiques; à trouver les fonctions de transfert crues-dommages sans passer par des enquêtes après crues; et à intégrer l'hydrologie urbaine à celle de l'hydrologie rurale dans la planification de l'aménagement d'un bassin versant.

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List of Symbols

a	characteristic level
A_{jw}	area of j^{th} region type w
$\bar{B}_j$	mean coefficient of characteristic damage
d	vector representing physical and non-physical damage
D(t)	total instantaneous physical and non-physical damage
E_ν^t	event representing the occurrence of ν exceedances in the time interval (0,t]
$F_t(z)$	function: distribution of the water level
$F_\nu(t)$	function: distribution of the time of occurrence of the νth exceedance $\tau(\nu)$
$F_t(x)$	function: distribution of the maximum exceedance
H(x)	function: distribution of the exceedance values
K	vector representing all the physical capital
K_w	coefficients of characteristic damage
Q_b	base flow
Q_ν	peak flow of rank ν in the time interval (0,t] such that $Q_\nu > Q_b$
t	time
T	return period in years
W_{ij}	all possible decision space solutions
Y	vector representing the hydrological characteristics of the flood
z,Z	water level
α, β	coefficients of the Gompertz total damage function
β	parameter for the function: exponential distribution of the exceedance values
$\delta(z)$	normalized damage function

$\eta(t)$	number of exceedances in the time interval (0,t]
$\theta(z)$	loss function
$\Lambda(t)$	mean number of exceedances in the time interval (0,t]
ξ_ν	exceedance of rank ν in the time interval (0,t]
$\tau(\nu)$	time of occurrence of the exceedance of rank ν
$\phi_t(y)$	damage distribution function
$\chi(t)$	maximum exceedance in time interval (0,t]

Introduction

Floods are by definition the overflow of a watercourse beyond its normal channel. They can cause great harm to man, his property, and his activities. Historically, for social and cultural reasons, man has been attracted by flood plains, on which he has developed great civilizations that are identified with the watercourses nearby.

Unfortunately, this situation has created a dilemma for man. Although traditionally all human activities have developed along river banks, populations occupying these plains are constantly exposed to dangers. We must therefore choose between the following alternatives: to leave the flood plains or occupy them and face the risks.

The fight to survive has led man to make compromises, most of the time to his advantage. Thus the control of watercourses and the regulation of their flows began in ancient times.

In contrast with the objectives of such construction, there was a continuous growth in losses and damage caused by floods. This paradox can be explained mainly as follows:

i. increased economic activity in the flood plains;
ii. a continuing increase in human use of the flood plains;
iii. overevaluation by the population of the safety provided by the protective works;
iv. lack of data on the frequency of floods and on the activities that they can affect;
v. changes in the hydrological characteristics of floods.

Quebec society cannot escape such a situation, as shown in Perrier's study (1978) on the change through time in annual flood damage (Fig. 1.1). Our present knowledge with regard to this problem offers no definitive remedy; we must limit ourselves to trying to minimize the impact of floods and their devasting effects on our well-being. The objective of this study is to help in the search for the best solution to this problem so as to minimize the losses due to flood and to maximize the use of flood plains.

It should be noted that at present Canada has no clearly defined policy for control of the damage caused by floods. Such a policy must be based on an analysis of the reliability and effectiveness of the options considered. The national flood damage reduction program instituted by the federal government assumes that "an obvious way of preventing future damages from flooding is by limiting development on the flood plain" and "to limit new investment in clearly defined flood risk areas" (Bruce, Rosenberg and Page, 1977).

The spatial and temporal characteristics of floods and their impact on flood plains require that all possible solutions be considered. The final choice will depend upon the dynamic population change and the social, cultural, economic and political behaviour of the society in question. Consequently, each situation must be studied and examined separately according to previously defined profitability criteria.

CHAPTER I - FLOOD PLAIN MANAGEMENT - ANALYSIS OF THE SYSTEM

Flood Plain Management (FPM) represents, by definition, every kind of planning and action, temporary or permanent, in areas subject to flooding to ensure proper use of natural and human resources.

This fairly broad definition of FPM can be expressed as two concepts: the minimization of human and physical losses, and the optimization of the socio-economic use of the flood plains by public and private interests (Goddard, 1969). These two concepts reflect what society expects from organizations concerned with shoreland management.

To tackle so complex a subject, it is necessary first to lay down some assumptions, then to establish an analytical and conceptual approach to the problem.

The first basic assumption in FPM is the following (BCEOM, 1976):

> ...the low flood channel of a watercourse is the natural channel through which passes its daily flow, and its high flow channel is also the usual channel, but is the temporary one for its strong flows; and the alluvial plain is just as naturally the reservoir for the accumulation of its largest floods.

The second assumption will be the limitation of the area under study to the drainage basin regarded as a geographic and economic entity. All human activities in this basin are influenced by its climatic and hydrographic characteristics. This is not to deny the existence of socio-economic and hydrological interactions between basins that would be represented by a change in the flow of the watercourse.

The FPM's conceptual approach is therefore to regard the flood plains as a single system composed of a complex set of elements: man, the watercourses and the shorelands. This flood plain system will be subject to a multitude of restraints, at times contradictory, on decisions in what is called the decision space.

1.1 FLOOD-PLAIN MANAGEMENT (FPM) DECISION SPACE

The extent of the damage caused by floods and the economic importance of the flood plains in societies have made FPM into a national problem within a decision space (Fig. 1.2) in which each component will have an influence on the others. This space represents the limit on solutions to the FPM problem. Each component j of this space can be represented by a set U_i W_i of possible solutions, in which i is a subset of j. The FPM problem is to find the best solution so that:

$$FPM = \cap_j U_i W_{ij} \quad ; \quad i = 1,2,\ldots \text{ and } j = 1,2,\ldots \qquad (1.1)$$

The role of each component is thus closely tied to the effectiveness and applicability of the set to this space. The FPM solution must therefore be to consider this set, but not necessarily to give the same weight to each of its elements. Because of the nature of the problem, the political component dominates the solution selected in most cases, and this dominance changes with the economic development of the society affected (United Nations, 1977).

1.1.1. Hydrotechnical Component

The hydrotechnical component represents the quantification of the flood phenomenon and the determination of the zones threatened as well as their flood risks. It consists, in other words, in determining first the maximum flow of the watercourse under study, and then the areas of the flooded land space at the time of this peak flow.

This component may include all management decisions concerning the sites of the structures or other works and may entail altering the physical, socio-economic and environmental aspects of the drainage basin. The hydrotechnical responsibility is generally given to the hydraulic engineer, who by his training can bring in purely technical solutions and activities, and this may generate conflicts with the decision-makers.

1.1.2. Physical Component

The physical component comprises the physical and morphological condition of the drainage basin and the nature of the occupancy and use of the land. It is through this component that floods cause loss of life and physical damage. It greatly influences the choice and type of FPM by limiting the possibilities for action because of human and physical criteria.

1.1.3. Sociological Component

The sociological component is probably the most uncertain part of the FPM. Determining the factors and descriptors of this component is a random business that depends largely on society's cultural and economic development as progress is made toward the solution. This is an enormous project for several reasons, including the growth of the society, involving a change in the physical and social environment, the lack of any principle on how to envisage and contain such growth, and the refusal to abandon philosophies that are incompatible with society's post-industrial behaviour (Degreene, 1973).

In the present state of affairs, the social descriptors can be expressed as the distribution of real income; the enjoyment of life, health and security; recreation and culture; emergency prevention and protection, and the search for comfort, the aesthetically pleasing and the common good (Grigg et al. 1976).

Decisions concerning the sociological component depend very much on society's political orientation and ideology; consequently, action in that area is closely tied to society's socio-economic, political and cultural development.

1.1.4. Environmental Component

The environmental component takes on increasing importance in industrialized societies. For FPM the losses and benefits assigned to this component are regarded as intangible factors: green spaces, unmanaged rivers and lakes; archeological, geological, aquatic and other resources; the quality of the land environment and the use of non-renewable resources (Grigg et al. 1976).

1.1.5. Political Component

It is probably the political component that dominates action decisions in FPM. On the one hand, physical damage and human losses at times take on huge proportions and often local administrations are incapable of taking the necessary action to fight floods and limit their effects. It is therefore up to the central administration to put in place the necessary devices for reducing flood risks within an overall development policy. On the other hand, the reaction at the political level to catastrophes in general and to floods in particular comes at the time of the crisis, contrary to what appears to be the rule for the management of other resources or crises. Thus, the political interest of FPM is temporary and diminishes with the subsidence of the flood (United Nations, 1977).

Finally, a decision at the political level categorically reflects society's socio-economic and cultural priorities.

1.1.6. Economic Component

The economic component of FPM is the cost incurred for any planning action and any benefits that follow the action. In addition to these two factors, the economic component includes all the economic variables on which they depend such as the rate of interest and the conditions of payment. The descriptors of the economic component are the costs and benefits, which may or may not be quantifiable.

The quantifiable costs are the cost of erecting the structures, of expropriation and of maintenance and handling during the life of the structures. To these costs must be added the related intervention administration costs. Among the costs that are not quantifiable is included the economic value of the relocation of the inhabitants of a flood region, of the social, environmental and aesthetic destruction and the like. Finally, the residual damage must be regarded as a cost in the overall evaluation of the planned action.

The first quantifiable benefits are probably the damage eliminated as a result of action in the flood plains. Other quantifiable benefits are derived from the increased value of the lands, and so on. Benefits that are not quantifiable are the reduced danger to life, the development of the rural regions, social well-being and the preservation of the environment and of aesthetic values.

In spite of a deeper understanding of floods and their effect on flood plains, the benefits, especially those regarded as intangible, are still very difficult to measure. It is desirable that the benefits that are not quantifiable be considered within the decision space.

In conclusion, the objective of the FPM is to develop the best form of planning and management of the flood plains while respecting the limits of the decision space. The weighting of each component is fairly haphazard and depends on the level of development of the community.

1.2. SYSTEMATIC FLOOD PLAIN MANAGEMENT (FPM) PROCESS

As was mentioned earlier, the conceptual approach consists in regarding the flood plains as a single, integrated system. In the following section, this question will be dealt with by developing the components of the flood-plain system.

1.2.1. Definition of a System

A system is a set of physical or abstract elements, which have their own particular structure but which are interrelated so as to produce a desired effect by the action of a given cause. Thus, any system involves a model that is a useful representation of the related parts of a reality.

Generally speaking, this system can be characterized by the extreme conditions of its elements: the inputs and outputs as well as their interaction with the systems environment and the interaction of the elements, along with the inputs and the outputs of the system and the resulting feedback (Hall and Dracup, 1970).

1.2.2. Inputs and Operators of a Flood System

A flood-plain system is the complex set of elements that it comprises: the inputs, the operators, the phenomenon itself, and the decisions and actions resulting from the interaction of the elements (BCEOM, 1976). It can be represented schematically by Figure 1.3.

The flood system inputs may be endogenous or exogenous depending on whether they come from causes internal or external to the system. They fall into three classes: natural random variables, such as climatic happenings; actions by elements having no deliberate relation to the system and decisions made and applied for the purpose of changing the reactions of the operators and the resulting phenomenon.

The flood system operators are the elements forming the drainage basin as a whole: man, water and the shorelands. These three operators represent the geographic and economic entity subject to the interaction of the decision space components. The understanding and mastery of the foregoing can give direction to the choice of actions which will change the system outputs, the floods, in the desired way. A more detailed description of various types of operators will be given later.

1.2.3. Floods

The consequences of the interaction of the operators on the system inputs may be grouped into five classes defined according to the physical factors involved (United Nations, 1977). These are snowmelt, ice jams or breakups, convection storms, cyclonic storms, and mud flows generated by rains. Of course several types of high water may work together to cause a flood and several floods can occur simultaneously. For the specific purpose of this study, that typology will be replaced by floods in rural regions and floods in urban regions.

Floods in rural regions affecting large basins are caused by low-intensity precipitation over a long period, followed by rapid melting of the snow, whereas low-frequency high-intensity rainfalls cause floods in small basins.

On the other hand, the rapid growth of urban regions has influenced the formation and existence of floods in urban basins and especially downstream from urban centres. The hydrographic effects of urbanization appear in an increase in impermeable surfaces, resulting in increased surface runoff and an acceleration in basin response time to precipitation and snowmelt.

1.2.4. Decisions and Action

Once the relationship between the inputs, operators and the resulting phenomenon are determined, we have to go on to the studies needed for correcting or improving those relationships. Generally, in planning water systems, we can use two procedures. The first is to classify the possible solutions and, by elimination, keep the solution we think is best on the basis of experience and intuition. The second, based on constraints, is to classify all the components of the system and form possible combinations which, when examined from the economic, technical, political and social points of view, will provide the optimum solution (Yevjevich, 1974).

Thus,the FPM possibilities may be grouped into four categories, each of which corresponds to an attempt to act on the flood waters or on any activities that they might threaten. The categories are as follows: alteration of the flood characteristics, action on the degree of vulnerability to floods, action on the increase of losses, and a decision to bear the losses (United Nations, 1977). Figure 1.4 shows the various possible types of management for flood control and the reduction of flood damage.

It is evident that an optimum solution will be a combination of control measures. This optimum solution depends on two criteria: the physical site or the spot where the floods appear, and the distinction between property and activities.

1.3 OBJECTIVE AND PROGRAM STRUCTURES

The complexity of the planning process varies from one region to another and depends on factors such as the incidence of the flood problem on the flood plains, the flood frequency, the distribution of the social and economic powers, and the fairly broad perspectives in which the plans and decisions have been worked out. However, the design methods, regardless of local peculiarities, consist of the following series of separate but interdependent steps (Maass et al. 1970).

i. determination and evaluation of the objectives;
ii. conversion of the objectives into design criteria;
iii. development of a system specific to the problem;
iv. empirical evaluation of the consequences of the program adopted.

1.3.1 Objectives

Two types of objectives have to be distinguished. The first is long-term and expresses social and political ends such as an efficient economy, redistribution of income, and social equality. The second objective, which is short-term and long-term, is local in nature and expressed regional planning of the flood plains having regard to social-economic criteria.

1.3.2. Design Criteria

The design criteria are subject to two limiting conditions. First, they must meet the long-term, medium-term or short-term objectives. Second, they must be determined in relation to the possibility of accomplishing the solutions selected from the legal, technical and financial points of view.

For this study, only criteria corresponding to the hydrotechnical and economic components of the decision space will be used. The hydrotechnical criterion will be that of the hydrological constraints of a set flood flow or the depth of submersion for a given return period. The economic criterion will be the economic yield of the action selected for the flood plains. Two cases may arise. In the first the benefits of several types of action are similar, and the criterion selected will then be the costs. In the second case the benefits and costs are variable and it is then necessary to conduct a combined benefit-cost analysis. Thus three methods are possible: computing the benefit-cost ratio; estimating the net benefits; and computing the internal yield rate.

1.3.3. Systematization of the Problem

Once the objective and criteria are set, we can go on to simulation of the phenomenon, its operators and its impact on the design unit: the drainage basin. Thus, the flood plain management will be analyzed through a system of computer simulation in which the physical phenomenon, the two criteria, economic and hydrotechnical, and the regional peculiarities of the area under study are considered. Figure 1.5 illustrates this.

In the first step, the flood flow or level or both are estimated at a water-level recording or stream-gauging station situated preferably at the downstream or upstream end of the river study reach. This estimate is based on a hydrological criterion such as the return period. For that, a hydrological model is applied to the historical data of the station.

The second step is to ascertain the depth of submersion at any point along the banks. A conventional hydraulic model can simulate the flood flow or level and from that, the physical flood.

The third step is the estimation of the cost of the simulated flood on the basis of an economic model and on an actual case for which an investigation was made after a flood of given return period.

Once the above three steps have been completed, the economic and technical simulation is updated. Knowing the cost of the flood, several regional studies can be compared using the decision criteria before implementation of the most desirable course of action.

1.3.4. Feedback

The effect of any flood protection intervention in the flood plains will be to decrease the probability of occurrence of a given flood and consequently, reduce flood damage. The feedback from such action must be examined in the chronological order of the passage of a flood, i.e.:

i. before the flood so that the effectiveness of the action can be measured by the reduction in the flood frequency,
ii. during the flood so that the reduction in the flood damage measures the effectiveness of the action;
iii. finally, after the floods, by adjustment of the flood risk zones.

CHAPTER II - THEORETICAL CONSIDERATIONS

In this chapter, the descriptive approach to FPM will be modelled as an integrated system of hydrologic, hydrodynamic and economic components. With this kind of approach to the study of floods, the hydrological components (depth of submersion, return period) can be estimated for each economic unit in the various activity sectors (residential, agricultural, and industrial and commercial) in flood plains.

2.1. HYDROLOGICAL MODEL

A model based on the theory of extreme values and the random number of random variables presented by Todorovic (1970) was developed at the Engineering Research Center at Colorado State University. This model will be used for developing the FPM methods.

2.1.1. Flood Analysis

Let us consider a hydrograph representing the instantaneous flow of a river at a given station for a time interval (0,t] (Fig. 2.1).

Because of the discontinuity in the time of floods, the flood hydrograph can be obtained by applying the following model (Fig. 2.2):

$$\xi_\nu = \begin{cases} 0 & ;\ Q_\nu \leq Q_b \\ Q_\nu - Q_b & ;\ Q_\nu > Q_v \end{cases} \qquad (2.1)$$

where Q_b is the base flow (with no overflowing of the bank).

If we look only at the maximum happening of the intermittent series, we can produce a discrete non-negative stochastic process of the νth exceedance in the time interval (0,t]. Let us then define ξ_ν as the νth exceedance occurring at time $\tau(\nu)$ (Fig. 2.3).

This family of the discrete stochastic process ξ_ν represents the basis of the model for evaluating the flood flow.

The intermittent series shown in Figure 2.3 has two distinct types of properties:

Dynamic property:

i) time of occurrence of the exceedances $\xi, \varepsilon(0,t]$:

$$\{\tau_\nu ;\ \nu = 0, 1, 2, \ldots\} \qquad (2.2)$$

ii) number of exceedances: (above a base flow $Q_b\ \varepsilon(0,t]$):

$$\eta(t) = \text{Sup}\ \{\nu, \tau(\nu) \leq t\} \qquad (2.3)$$

Quantitative property:

i) value of the exceedance $\xi_\nu \varepsilon (0,t]$

ii) value of the maximum exceedance defined by:

$$\chi(t) = \sup_{\tau(\nu) \leq t} \xi_\nu \tag{2.4}$$

where $\chi(t)$ is a non-decreasing stochastic process.

2.1.2. Dynamic Properties

Let us look at E_ν^t, the occurrence of ν exceedances in the time interval $(0,t]$:

$$E_\nu^t = \{\eta(t) = \nu\} = \{\tau(\nu) \leq t < \tau(\nu + 1)\} \tag{2.5}$$

If we assume that in certain conditions, $P(E_\nu^t)$ follows a Poisson process with the following parameter:

$$\Lambda(t) = E[\eta(t)] \tag{2.6}$$

where $\Lambda(t)$ is a non-decreasing function that represents the density of the events ξ_ν produced per unit of time. This function varies with the seasonal or annual climatic change; thus $P(E_\nu^t)$ may be expressed as:

$$P(E_\nu^{t=T_n}) = \frac{[\Lambda(T_n) - \Lambda(T_{n-1})]^\nu}{\nu!} \exp\{-[\Lambda(T_n) - \Lambda(T_{n-1})]\} \tag{2.7}$$

where $\Lambda(T_n) - \Lambda(T_{n-1})$ is the average number of exceedances in the time interval $(T_{n-1}, T_n]$.

2.1.3. Quantitative Properties

Let the function of distribution of the maximum exceedance be:

$$F_t(x) = P\{\chi(t) \leq x\} \tag{2.8}$$

If we consider an independent and identically distributed distribution of the exceedances in a time interval $(T_{k-1}, T_k]$, express $F_t(x)$ as:

$$F_t(x) = \exp\{-\sum_{n-1}^{k-1} [\Lambda(T_n) - \Lambda(T_{n-1})][1 - H_n(x)]$$

$$- [\Lambda(t) - \Lambda(T_{k-1})][1 - H_k(x)]\} \quad (2.9)$$

for every $k = 1,2,...$ and $t \in (T_{k-1}, T_k]$

with

$$H(x) = P\{\xi_\nu \leq x\} \quad (2.10)$$

This function H(x) represents the distribution of the values of the exceedances and can be represented by any laws, such as normal, log-normal, or gamma, depending on the river or region. Rousselle (1972) found that an exponential distribution function can apply satisfactorily for describing the distribution of the exceedances in most flood cases:

$$H(x) = 1 - e^{-\beta x} \qquad \beta > 0 \quad (2.11)$$

with

$$\beta = E\{\xi_\nu\}^{-1} \quad (2.12)$$

Thus, there are two cases to consider:

i) the exceedances ξ_ν are independent and identically distributed over a one-year interval (Zelenhasic, 1970):

$$F_t(x) = \exp\{-\Lambda(t)e^{-\beta x}\} \quad (2.13)$$

ii) the exceedances ξ_ω are independent and identically distributed over a one-season interval (Rousselle, 1972):

$$F_{t_4}(x) = \exp\{-\Lambda(T_1)e^{-\beta_1 x} - [\Lambda(T_2) - \Lambda(T_1)]e^{-\beta_2 x}$$

$$- [\Lambda(T_3) - \Lambda(T_2)]e^{-\beta_3 x} - [\Lambda(T_4) - \Lambda(T_3)]e^{-\beta_4 x} \quad (2.14)$$

with $\Lambda(T_1)$, $[\Lambda(T_2) - \Lambda(T_1)]$, $[\Lambda(T_3) - \Lambda(T_2)]$ and $[\Lambda(T_4) - \Lambda(T_3)]$ representing the average number of exceedances for each season and β_1, β_2, β_3, and β_4 the parameters of the exponential function for each season.

2.2. HYDRODYNAMIC MODEL

The hydrodynamic model tries to express the aspect of propagation of a flood of any probability through the river channel, in relation to the geometric and hydrographic characteristics of the natural stream and flood-plain channels of the watercourse and the nature of the flood plains. The parameters that can influence such a hydrodynamic model are those that define the flood order: the initial conditions (stage, discharge), the shape of the cross section, the slope, the roughness coefficient, and the lateral and subsurface runoffs. The flood wave models for a one-dimensional flow in which the vertical acceleration is regarded as nil are of the following flow regimes: steady and unsteady.

2.2.1. Steady Flow

A flow is said to be steady when the local acceleration is nil. In a natural river, the flow can be regarded as steady and gradually varied, i.e., the parameters vary continually, progressively and slowly so that:

i. the shape and size of the river's cross section and the slope of the bottom vary regularly and slowly, the curvature of the channel cross-section being small;
ii. water depth varies slowly, the slope and curvature of the water surface being very slight.

Furthermore, for a flow to be considered as steady and gradually varied the following hypotheses must apply.

i. The flow lines are practically parallel, which implies a hydrostatic distribution of pressure in all flow sections;
ii. The rate of energy dissipation in each section is the same as if the flow were uniform. The rate can therefore be evaluated by the uniform flow equation. This assumption is satisfied if the flow is accelerated or convergent, but it can be somewhat erroneous if the flow is delayed or divergent.

2.2.2. Unsteady Flow

A flow is said to be unsteady when the local acceleration is not nil. This is reflected by flow conditions (such as the flow rate) that are changing in time and space. Several models have been developed to resolve this type of problem using, among others, the Saint-Venant equations: the kinematic wave equations and the continuity equation.

When the flood flow begins, it is probably unsteady; theoretically, this necessitates the use of the Saint-Venant equations. In some flow cases, however, a steady-regime model can satisfactorily represent the flood. We can conclude, as did Priessmann (1971), that choosing the most accurate approach does not necessarily bring more precision than the use of a simpler method. The choice of the most appropriate model must be based on the aim, the degree of accuracy desired and the cost of the simulation as well as on the data and the type of computer available.

2.3. ECONOMIC MODEL

The economic component is probably one of the most important components of the decision space. It embraces both determining factors in the classification of the FPM solutions: the benefits and the costs associated with any given project.

The cost factor can be divided into two parts, the cost of the project and the residual damage. In what follows we will concern ourselves with the damage component and present a model relating it to other hydrological and physical variables.

2.3.1. Definitions

Before giving an outline of the forecasting of flood plain damage, it is useful to differentiate the types of damage which occur. After a flood, the flood plains are subjected to direct, indirect, secondary, intangible and uncertain damage (Breaden, 1973).

This broad classification of damages presents difficulties in estimation and consequently, forecasts of total damage are inaccurate. We will therefore use for this study the classification of the International Champlain-Richelieu Committee (CICR, 1977) by grouping the damage into physical damage and primary and secondary non-physical damage.

The physical damage is the physical losses caused by the flooding of buildings and their contents, crops and lands (affecting their productivity), transportation facilities (like bridges, roads and watermains), soils, docks and retaining walls, and public utilities. This damage represents the cost of restoring the property to its pre-flood state by replacement or repair (CRAR, 1977).

Non-physical damage consists of: losses caused by the interruption, in the flood plains, of normal economic activities, such as limited or no access to properties; the cost of fighting floods and of other temporary waterproofing measures; the increase in the cost of living due to temporary evacuation; cost of the subsequent cleanup; loss of use of private docks and beaches; loss of business income; reduction in the value of crops depending on the duration of the flood; and shortening of the economic life of developments or an increase in the cost of maintenance.

Non-physical damage is divided in this study into primary and secondary for the following reasons.

i. Data for the upper Richelieu basin in Quebec were derived from site surveys of damages incurred at the time of the 1976 flood. These non-physical damages were subdivided into primary and secondary damages.

ii. The advantage of having an estimate of the secondary non-physical damage for the study and the implementation of a flood warning system.

The primary non-physical damage represents the losses due to an interruption of normal activities or regular service or both for which no compensation could be obtained from a source outside the flooded area. Secondary non-physical damage, on the other hand, represents the losses due to the preventive measures taken to limit flood damage (CRAR, 1977).

2.3.2. Factors Affecting the Damage

A flood is a complex event. It will be difficult to understand all the endogenous and exogenous factors as well as all the components of the flood - flood-plain system. Most systems are in general agreement on the main factors that affect flood plain damage. We can class them in three groups: hydrological factors; human adjustment factors, and land use factors (McCrory *et al*. 1976).

Hydrological Factors

These factors are directly linked to the occurrence of a flood and the flood's hydrological characteristics, which are, among others: depth of submersion; water velocity; duration of submersion; sediment load; duration of the flood; time elapsed between consecutive floods; and the presence of ice.

Human Adjustment Factors

The warning time before the flood can play an important role for emergency prevention and the evacuation of goods from the flood zone. Also, the preventive action taken in the flood plains will reduce damage and decrease the severity of emergency measures during the flood (Rousselle and El-Jabi, 1977).

Land Use Factor

This factor concerns the type and value of the property affected. It also includes the value and the location of damaged equipment.

It is virtually impossible to consider all such factors in a mathematical model for estimating damage. Consequently, we must make a judicious choice of a few factors only. Also, we must not forget that any model must be verified by means of empirical data.

2.3.3. Damage Estimation Methods

Most, if not all, of the damage estimation methods for a particular river basin are based on monetary losses calculated from a flood of known return period. In the studies analyzed, there were basically three methods of conceptualizing the flood-damage relationship: empirical, simulation and correlation.

Empirical Method

This method consists in establishing a relationship between the hydrological characteristics of floods, generally the depth of submersion, and the damages resulting from floods of different return periods.

This is the oldest method. It is reliable within the limits set by the quality of the information gathered and if it is used in the same area in which the survey was made. The results cannot be generalized in space, nor can the information be projected for higher recurrence intervals. This kind of curve can, however, be produced and used for each economic activity sector, but within the space-time limits mentioned.

Simulation Method

This method consists in simulating the flood process in flood plains, which provides hydrological characteristics such as depth of submersion and return period for each unit of the economic sectors (residential, industrial, agricultural, and so on) in the flood plains. Flood-damage transfer functions, generalized in time and space, can thus be established.

This method has the advantage of being adjustable to the economic changes in the flood plains and hydrological changes, in addition to offering possibilities of regionalization.

Correlation Method

Some authors have developed, from experimental data, relations that give directly the damage caused to a property as a function of the depth of submersion or other factors. This type of relation, called "aggregate", is obtained by an analysis of the correlation between the damage estimated from a survey and the hydrological and economic characteristics of the flood plains. Its prime advantage lies in the estimation of the annual damage for the area in question.

Since the damage is completely dependent on locality, it is difficult to generalize a method of estimation. Several factors have to be taken into consideration. These factors include: the importance and application of the study, which dictate the desired degree of precision; the activity sector analyzed as well as the level of economic development of the banks; and the quality and quantity of the collected historical data.

However, one point common to all damage studies is the quality and reliability of the surveys since, as stated above, the application of any damage estimation method is based on the data for known floods on which the model is based.

2.3.4. Model for Evaluating Flood Plain Damage

The evaluation of losses in urban regions subject to annual or seasonal floods depends on two types of variables: natural random variables (flood occurrences) and non-natural deterministic random variables (economic development of the area). Thus, a loss evaluation model must contain the largest amount of regional information possible so as to accurately represent the nature of the losses in urban and rural areas. An adequate model must:

i. give a simple representation of the physical aspect of the problem;
ii. be capable of simple execution with due regard to the information available;
iii. give a sufficient, acceptable idea of the possible losses and damage for any given flood;
iv. be general and dynamic so that it can be applied to any area.

Thus, to define the damage function, we use the following symbols:

d, a vector the elements of which describe various possible types of physical and non-physical damage; d_i is the state of a vector in geographical unit i;

K, a vector the elements of which describe all the physical capital such as residences, commercial and industrial buildings, and stocks, and associated activities such as production flow and domestic services; K_i is the state of this vector before the flood in geographic unit i;

Y, a vector the elements of which describe the flood characteristics such as water depth and velocity, duration, and water quality; Y_i is the state of this vector in geographic unit i.

The damage function can therefore be written generally as follows:

$$d = f(K,Y) \tag{2.15}$$

In view of the typology of d, K and Y we can, for any operational geographic unit for which we have a base of reliable data, calibrate this function with all the regional data, use it for the planning of each geographic unit i (such as evacuation plans, flood warnings, dikes and canals) and the management of the activities in this unit (such as the elevation of risks and insurance, or location). All we need do is restrict ourselves to the values of K_i, Y_i, i.e.:

$$d_i - f(K_i, Y_i) \tag{2.16}$$

These applications can easily be referred to the whole area. If we describe the area as a collection I_R of geographic units, we of course have:

$$d_R = \sum_{i \varepsilon i_R} f(K_i, Y_i) \tag{2.17}$$

In view of the nature of the flood damage, the function d_R is a monotonic continuous, non-decreasing function such as:

$$d_R = \begin{cases} 0 & ; Y_i \leq Y_{ib} \\ d_R & ; Y_i > Y_{ib} \end{cases} \tag{2.18}$$

where Y_{ib} is the hydrological vector in the geographic unit corresponding to the base flow.

Damage Distribution Function (DDF)

In the development of the DDF, the following hypotheses have been made:

i. There is only one given geographic unit for development of the DDF, i.e., i=1.

ii. Of the hydrological vectors Y_i, only the water level Z is taken into account, since the existing damage data include only this hydrological variable. Thus, in the method, Y is simply replaced by Z. Thus the damage function becomes:

$$d = f(K, Z) \tag{2.19}$$

River Water Level Distribution Function

For any gauging station, we can write:

$$z = g(x) \tag{2.20}$$

Equation 2.20 represents a relation between the water level and the flow of a river. This equation is established empirically and is continually improved through the accumulation of hydrometric data. Because of the nature of the flow of rivers and streams, equation 2.20 is a monotonic, continuous, non-decreasing function:

$$x = g^{-1}(z) \tag{2.21}$$

Let us define Z(t) as being the level for an exceedance $\chi(t)$; in this case

$$\begin{aligned} P[Z(t) \leq z] &= P[g[\chi(t)] \leq z] \\ &= P[\chi(t) \leq g^{-1}(z)] \end{aligned} \tag{2.22}$$

but equation 2.22 is none other than the distribution function of the maximum exceedance, i.e.:

$$P[Z(t) \leq z] = F_t[g^{-1}(z)] \tag{2.23}$$

Depth of Submersion - Damage Relation

Given the occurrence of an exceedance $\chi(t)$, the loss suffered by the area will be

$$D(t) = \theta[K, Z(t)] \tag{2.24}$$

where K is the stock of physical capital in the area. By virtue of equation 2.21, equation 2.24 becomes

$$D(t) = \theta\{K, g[\chi(t)]\} \tag{2.25}$$

The DDF $\phi_t(d)$ for a time interval (O,t] will be given by

$$\phi(d) = P[D(t) \leq d] \tag{2.26}$$

$$= P\{\theta[K, g(\chi(t))] \leq d\}$$

$$= P\{g[\chi(t)] \leq \theta^{-1}(K, d)\} \tag{2.27}$$

On the basis of equation 2.22, equation 2.27 can be written as follows:

$$\phi_t(d) = P\{\chi(t) \leq g^{-1}[\theta^{-1}(K,d]\} \tag{2.28}$$

but equation 2.28 is none other than the distribution function of the maximum exceedance $F_t(x)$ given by equation 2.9. In that case the DDF will be given by

$$\phi_t(d) = F_t\{g^{-1}[\theta^{-1}(K,d)]\} \tag{2.29}$$

This distribution function is valid for maximum exceedances identically distributed over a year or over a season.

Damage Function $\theta(k,Z(t))$

To derive equation 2.29 it is necessary to know $g(z)$ and $\theta(k,Z(t))$. The stage-discharge relationship is generally known for a given gauging station. There remains the losses function to derive before developing the DDF$\phi_t(d)$.

The losses function $\theta(K,z(t))$ is a non-decreasing function that uses information on the economic development of the flood area for a better estimation of the losses incurred in that area. A function can be estimated at random and verified on the basis of historical data, or else the function can be derived on the basis of the economic, topographical or other properties of the area. It is suggested that the second choice be preferred for the following reasons.

i. The existing data in urbanized areas may be incomplete because of a lack of geographic details or of annual data or other such information.
ii. Information may be totally lacking in areas in the process of urbanization.
iii. There may be a sudden change in the economic development of the flood plains.
iv. There may be a change in flood frequency resulting from the installation of a flood control system.

Let us take any area subject to floods (Fig. 2.4). The losses suffered by any structure A because of rising water may be estimated (Bhavnagri and Bugliarello, 1965) at

$$d_A(z) = K_A \, \delta(z) \qquad (2.30)$$

where $d_A(z)$ is the financial losses suffered for structure A,
K_A is the coefficient of characteristic damage which is a function of structure A, and
$\delta(z)$ is the non-dimensional normalized damage function.

Since equation 2.30 is linear, the losses suffered for two identical structures A and B are

$$d_{A+B}(z) = (K_A + K_B) \, \delta(z) \qquad (2.31)$$

For a flood plain level j, bounded by real or hypothetical contours, the losses will be given by:

$$d_j(z) = B_j \, \delta(z) \qquad (2.32)$$

where

$$B_j = \Sigma_r \, K_{j\,r} \qquad (2.33)$$

with $K_{j\,r}$ being the coefficient of characteristic damage of the r^{th} structure in the j^{th} section. In practice, estimating B_j appears to be an enormously laborious task compared to the accuracy obtained in the computation of flood losses. For that purpose, let us define B_j, the mean coefficient of characteristic damage, as follows:

$$\bar{B}_j = \sum_w K_w \, A_{jw} \qquad (2.34)$$

where K_w is the coefficient of characteristic damage for region w (residential, commercial, and so on) in monetary units per unit area for a maximum flood stage a, and
A_{jw} is the area occupied by region w.

The loss suffered at level j will therefore be

$$d_j(z) = \bar{B}_j \, \delta(z) \qquad (2.35)$$

The estimation of losses for all flood plains, for a given flood occurrence $\chi(t)$, becomes (Fig. 2.5):

$$D[Z(t)] = \sum_{j=1}^{i} \bar{B}_j \, \delta[Z(t) - Z_{j-1}] \text{ for } i = 1,2,\ldots \qquad (2.36)$$

Equation 2.36 enables us to find the losses suffered by the region under study for various return periods T and for a water level Z, from which we can estimate the damage function $\Theta(k,z)$, since

$$D[Z(t)] \equiv \Theta[k, Z(t)] \qquad (2.37)$$

Normalized Damage Function

The basic assumption in estimating $\theta(k,z)$ is represented by the normalized damage function $\delta(z)$. This non-dimensional function summarizes the process or manner in which floods cause losses and damage to any structure. It is a function of the topography of the banks, the intensity of economic development of the flood plains, and the characteristic flood stage "a" or maximum flood stage beyond which the losses will be independent of the water level. It is a non-decreasing function defined as follows:

$$\left[\begin{array}{c} \delta(z) = 0 \;\forall\; z < 0 \\ 0 \leqslant \delta(z) < 1 \;\forall\; 0 < z < a \\ \delta(z) = 1 \;\forall\; z > a \end{array}\right] \qquad (2.38)$$

It can be computed from the historical data or estimated from the intensity of the economic development of the region in question.

This normalized damage function and the coefficients of characteristic damage markedly influence the derivation of the damage distribution function (DDF). In an urbanized area, in establishing this function and the coefficients we encounter practical problems and replace the DDF with a total damage function, whereas in an area in the process of urbanization, with a master plan of controlled development, it is possible to estimate these two variants. We will now present an integrated application of the methods previously shown (Rousselle and El-Jabi, 1977).

Total Damage Function (TDF)

In urbanized areas like the Richelieu River basin in Quebec, the TDF must be estimated in the following way.

i. Draw up a typology of damage, physical capital, activities and descriptive parameters which describe previous floods.
ii. Specify the analytical forms of the TDF.
iii. Calibrate these functions with existing data.

Thus, as a first step, the typology of the damage and of the physical capital has been defined as a function of the availability of data, which changes from one case to the next. This typology is made very clear in the chapter on computer application.

In specifying the analytical form of the TDF, a dearth of equivalent studies in the scientific literature is encountered. The results of after-flood surveys have always shown a wide dispersion of data, and thus prevented the development of satisfactory analytical representation.

To overcome this difficulty, the damage, the types of physical capital and the types of activities are correlated. It is not easy, however, to pick out and evaluate such correlations. For example, the damage could be assumed to be a fixed proportion of the capital and of the activities. This would result in a classic economic problem. The activities and the capital are linked in a more complex way than simple proportionality. Factors which bring about the damage (water level, for example) must also be considered in establishing such relations. This is important if the damage functions are to be used for evaluating possible substitutions among the "factors of production" K and Y, in the economic computations.

This relation is therefore not linear, but takes the form of an S curve (Dantzig, 1956). It keeps the same characteristic as the damage function, i.e., monotonic, continuous and non-decreasing with, of course, non-negative values.

Generally, factor K in equation 2.15 refers to the physical capital in the flood zone, and the function can be written in the form

$$d = \alpha(K,Y)K \qquad (2.39)$$

Also, we shall distinguish the water surface elevation, z, from the other elements Y* of the hydrological vector Y, i.e.:

$$d - \alpha(K,Y^*,z)K \qquad (2.40)$$

The Gompertz distribution also answers these characteristics. It is an S curve that can explain certain kinds of growth in economics (Jantsch, 1977 and Ayres, 1972). In our case, the Gompertz distribution is expressed by:

$$d = kg(k)\,\frac{1}{e^{e^{-\alpha(Y^*)}}-1}\left[e^{e^{-\alpha(Y^*)[1-e^{-\beta(Y^*)z}]}} - 1\right] \qquad (2.41)$$

Let us take as a first approximation

$$\alpha(Y^*) = \alpha = Cte$$

$$\beta(Y^*) = \alpha = Cte$$

Equation 2.41 thus becomes

$$d = kg(k)\,\frac{1}{e^{e^{-\alpha}}-1}\left[e^{e^{-\alpha[1-e^{-\beta z}]}} - 1\right] \qquad (2.42)$$

This function has the following properties:

i. for a given physical capital $K = \bar{K}$ and the damage depending on the level z, i.e.:

$$d = \bar{k}g(\bar{k}) \frac{1}{e^{e^{-\alpha}} - 1} [e^{e^{-\alpha[1-e^{-\beta z}]}} - 1] \quad (2.43)$$

The limits of equation 2.43 are $d = 0$ for $z = 0$ and $d = \bar{K}g(\bar{k})$ when $z \to \infty$ and the trend of the function is as follows (Fig. 2.6).

It should be explained that Gompertz's distribution is a monotonic, continuous, non-decreasing, non-symmetrical function about its inflection point. Among others, it depends only on the flood level z through the two parameters α and β.

ii. For a level $z = \bar{z}$, the damage depends on the physical capital, according to the relation

$$d = kg(k) \frac{1}{e^{e^{-\alpha}} - 1} [e^{e^{-\alpha[1-e^{-\beta \bar{z}}]}} - 1] \quad (2.44)$$

$$d = kg(k) \text{ [constant]} \quad (2.45)$$

whence the prime advantage of this function which is probably the flexibility in the choice of the productivity function g(k) which may be established as a function of each region without any change in the exponential damage process. Thus, it is fairly simple to calibrate such a function in the present survey conditions.

Finally, this total damage function $d(K,Z(t))$ is the equivalent of the loss function $\theta(K,Z(t))$, i.e.:

$$d(K,Z(t)) \equiv \theta(k,Z(t)) \quad (2.46)$$

and it will be possible to derive the damage distribution function from this relation (equation 2.46).

CHAPTER III - NUMERICAL APPLICATION

The Flood Plains Management (FPM) methodology is applied to the drainage basin of the Richelieu River in Quebec, Canada. The reasons for the choice are the following.

i. The economic activity in this basin is diversified and mainly residential and agricultural.
ii. Data on flood damage are available because of a study conducted after the 1976 flood by the regional development research centre of the University of Sherbrooke (CRAR, 1977).
iii. There exists a projection of future flood damage up to the year 2030; this makes possible a comparison with other projection methods.
iv. The feasibility study of the flood-plain management describes several types of intervention projects of the Richelieu River (CICR, 1977). This choice thus provides a comparison with other methods of intervention.
v. Because the Richelieu River lies in both Canadian and American territory, there have been a number of studies under the aegis of the Canada-United States International Joint Commission. The Richelieu River basin was among the priorities of the government agencies concerned and documents on that basin are therefore abundant.

3.1. CHARACTERISTICS OF THE RICHELIEU RIVER BASIN

The Lake Champlain-Richelieu River basin takes up the northwestern part of the State of New York and the western part of the State of Vermont in the United States, and part of the southern part of Quebec Province in Canada (Fig. 3.1). The drainage basin has a total area of 9220 square miles of which 1460 square miles lie in Quebec. It extends north over a distance of 200 miles, and has a maximum width of 105 miles.

The Richelieu River flows north from its Lake Champlain outlet at Rouses Point in the United States, to the point where it discharges into the St. Lawrence at Sorel, Quebec. From the international border to Saint-Jean, a distance of about 22 miles, the Richelieu drains a strip of low-relief land with a maximum width of 15.5 miles. It has a very gentle water surface slope of about one foot for average flow.

The region under study is limited to the Canadian part of the Richelieu River basin which, excluding the Missisquoi lands, extends from the international border to the Fryer's Island dam (Fig. 3.1).

3.2. HYDROLOGY OF THE RICHELIEU RIVER BASIN

Analysis of the hydrological behaviour of drainage basins requires reliable homogeneous data on the random variable "rate of flow" or on the "water level" at a selected water-level recording station. Stream-gauging station 02ØJ007 was used for the following reasons.

i. Its site is adequate, being just downstream from the area under study; this facilitates the application of the hydraulic model because of the steady state nature of the flood discharge passing through the study area.

ii. There are data from 1938 to the present, including data for 1976, regarded as a record year and a year for which a survey of flood damage was carried out.

iii. The stage-discharge relationship is available for the complete record of levels.

iv. There is a relationship between the flow rate at station 02ØJ007 and the level of Lake Champlain at Rouses Point in the United States (Fisheries and Environment Canada, 1977). The data recorded at that point are the most reliable for explaining the hydrological behaviour of the Richelieu and cover the longest period of record (1878-1977); the results of this research can be compared with those of other studies that used the Rouses Point data.

The flow at gauging station 02ØJ007 was measured continually in winter as well as in summer (Kirk, 1976). The base flow (flow without any overflowing of the banks) was set at 25 000 cfs (708 m^3/s). This flow is the maximum beyond which damage may arise and this physical meaning of base flow does not contradict the mathematical criteria of the hydrological model (CRAR, 1977). The series of annual extremes contains 62 exceedances with an average exceedance per year of 1.550, as shown in Table 3.1. The floods in the Richelieu occur mainly in the spring, after an intense snowmelt in a fairly short time. The floods are attenuated by Lake Champlain, which regulates the high inflows to the lake over a period of many weeks. For computation purposes, the dates of the exceedances have been replaced by numbers beginning with October 1 = 1, and ending with 30 September = 365.

3.2.1 Dynamic Properties

The basic parameter of Poisson's distribution that governs the dynamic properties of the exceedances is $\Lambda(t) = E\,[n(t)]$, or the density of events ξ_ν per unit of time. Time intervals of 20, 40, 60,...360 and 365 days were used for estimating the function $\Lambda(t)$ (Fig. 3.2). The annual distribution of the number of exceedances will be given for the interval (O,t] = 365 days and (t) was estimated at $\hat{\Lambda}(t) = 1.550$, whence the annual distribution function of the number of exceedances.

$$P(E_\nu^t) = \frac{(1.550)^\nu}{\nu!} \exp(-1.550)$$

The parameters $\Lambda(t)$ of the seasonal distribution of the number of exceedances was computed from the theoretical distribution of $\Lambda(T)$ and the results obtained are shown in Table 3.2.

The adjustment between the observed distribution and the corresponding theoretical distribution of the number of exceedances was verified at a confidence level of five per cent by the use of the chi-squared test. Figure 3.3 shows the theoretical and observed frequencies of the exceedances for various time intervals (0,t].

3.2.2. Quantitative Properties

Analysis of the quantitative properties of the maximum exceedance requires knowledge of the function H(x). This function may take any form of distribution such as normal, log-normal, or gamma according to the river being studied. Assuming an exponential distribution of H(x) and using the Kolmogorov-Smirnov test, the adjustment of the observed values to the exponential distribution was accepted at a five per cent confidence level. For an annual distribution of exceedances, parameter β is equal to 1.604×10^{-4} and function H(x) will therefore be

$$H(x) = 1 - \exp\{-1.604 \times 10^{-4}x\}$$

For a seasonal distribution of exceedances, the β parameters of the exponential distribution are given in Table 3.3.

Knowing the parameters of the Poisson distribution $\Lambda(t)$ and the exponential function β, the exponential function of the maximum exceedance for an annual distribution of exceedances is given by:

$$F_t(x) = \exp\{-1.550 \exp[-1.604 \times 10^{-4}x]\}$$

For different seasonal combinations, this function will be obtained by the use of appropriate values $\Lambda(t)$ and β (Tables 3.2 and 3.3).

Adjustment of the observed distribution of the maximum exceedance to a double exponential function was verified at the five per cent confidence level by use of the Kolmogorov-Smirnov test and the results are shown in Figure 3.4.

A study of several return periods T varying from 10 to 10 000 as a function of the flow is shown in Figure 3.5. If the stage-discharge relationship of gauging station 02ØJ007 is used, a development similar to the one shown before yields the relation between the return period and the water level. Figure 3.6 illustrates this application.

3.3. HYDRAULICS OF THE RICHELIEU RIVER BASIN

Flood discharges for various return periods were estimated from the results of the hydrological analysis at a gauging station just downstream from the area under study. The flood stage, at the gauge, for each discharge was obtained by means of the stage-discharge relationship. The next step was to compute the corresponding stages in the flood plain under study for each discharge of a given return period. These stages were computed by using the HEC-2 steady state hydraulic model of the U.S. Army Corps of Engineers. The use of a steady-state model for these computations is valid for the following reasons:

i. Lake Champlain at the source of the Richelieu River has a predominant regulation effect on Richelieu River discharges.

ii. The flows of the small tributaries of the Richelieu between Lake Champlain and Saint-Jean are very small compared to the river's average flow; therefore, all lateral flows may be disregarded (Poulin, 1973).

iii. Richelieu River floods are spring floods and are due mainly to the snowmelt. The flow variation over time is therefore fairly small. The level of Lake Champlain remains high and stable during the period from April to June when 94 per cent of the floods are observed. This flow can thus be regarded as quasi-steady and it is possible to resolve it by equations for gradually varied flow.

The theory for this type of flow is well established for canals and natural watercourses and can produce very good results when properly applied. The major source of error in this case is probably the data representing flow conditions. Such data can be grouped into two classes, according to the flow characteristics.

3.3.1. Geometric Characteristics of the Low-flow and High-flow Channels

The topographic data for the natural stream and the flood plain of the Richelieu were provided by the Quebec Department of the Environment and the federal Department of the Environment. These data are as follows.

i. There is a representation of the longitudinal profile and the natural stream channel from cross section surveys. The area under study was divided into two sectors. The first extends from the Fryer's Island dam to the Gouin bridge and includes the Saint-Jean rapids; 21 sections 1700 ft apart on average were considered. These sections were surveyed by the federal Department of Public Works in 1937 and a number of them were checked in 1972 by the Quebec Department of Natural Resources. The second sector extends from the Gouin bridge to the U.S. border, where 59 cross sections 2000 ft apart on average were checked. These sections were surveyed by the federal Department of the Environment.

ii. There is the topographic representation of the flood plains from two series of maps extending from the Chambly region to the international border. The first series, to the scale of 1:4800, is from the Quebec Department of the Environment. The other series, to the scale of 1:12 000 with 10-ft contour intervals, is from the federal Department of the Environment. With these maps the cross sections in the river's flood plain channel were determined, permitting delineation of areas subject to flooding on both sides of the river.

3.3.2. Flow Characteristics

The flow characteristics can be grouped into two categories. The first provides information necessary for commencing the computation of the water surface whether it be a level or a flood stage. This starting level is downstream from the area under study and it can be obtained from the stage-discharge relationship. The second category gives the information concerning the flow behaviour in relation to the physical and topographical nature of the river. This behaviour can be represented by the roughness of the bottom or friction effect. This friction effect is represented by Manning's roughness coefficient (n) for each cross section. The coefficients are estimated by the reconstitution of a water line already observed. During the spring flood of 1972, the Quebec Natural Resources Department made instantaneous surveys between the Fryer's Island dam and the Canada-U.S. border. These surveys were made at 12 water-level recording stations for a flow of 30 000 cfs. The information was used for calibrating the hydraulic steady-state model and the results are shown in Figure 3.7.

The Manning coefficients thus estimated are representative of the river's natural stream channel. The roughness in the flood plain channel was regarded as equivalent to that of the natural stream channel with a constant increase of 0.005 (Chow, 1959). This increase was considered identical for both banks of the river.

3.3.3. Flows for Different Return Periods

When the characteristics of the natural stream and flood plain channels and the roughness coefficients have been defined, it is possible to reconstitute the water profiles or the backwater curves for flows corresponding to different return periods. The U.S. Army Corps of Engineers steady-state water surface profile (HEC-2) was used for this purpose. HEC-2 uses the method of successive approximation by section with the help of the energy equation in which the total energy is applied to the cross sections of the river. The Manning equation is used for computing the head loss due to the friction between cross sections. Other local hydraulic losses such as the effects of piers or channel transition were taken into account indirectly in the estimation of the Manning coefficient.

The program shows considerable flexibility, since the data for the cross sections can be interpolated to add to the accuracy of the water profile computations. The critical stage is also determined for each cross section to check on the flow regime. By applying the model to the study area and using the results of the hydrological models, the backwater curves for return periods of 10, 20, 50, 100, 200 and 500 years were reconstructed for the following two cases.

i. The exceedances are independent and identically distributed over an interval of one year (Fig. 3.8).
ii. The exceedances are independent and identically distributed over an interval of one season (Fig. 3.9).

By reconstituting the backwater curves in this way, flood stage can be determined at any point on the flood plain for various return periods.

3.4. ECONOMY OF THE RICHELIEU RIVER BASIN

Application of the methods for flood-plain management in the study area in the Richelieu River drainage basin requires the use of the results of the hydrological and hydraulic models as well as those of the economic model. To calibrate the latter a historical case is used. With this combination the flood-damage transfer functions are derived and then flood costs are estimated as a function of the return periods by assuming that the exceedances are independent and identically distributed over the time intervals of one year and one season.

3.4.1. 1976 Survey

In 1976, rising water generated mainly by an early, long-lasting snowmelt overflowed the banks of the Richelieu, thus causing the biggest flood since 1903. As a result of this flood, which caused damage estimated at $3 117 000 (for 1976), an on-the-site survey (CRAR, 1977) was conducted:

i. to find the stage-damage relationship for the various types of damage for various economic sectors;
ii. to establish a flood damage projection for the period 1976-2030.

Before presenting the results of this survey, which will be used for calibrating the economic model, certain things must be made clear:

(a) The economic activity in the study area will be divided into five categories representing the basic land use: permanent residential sector (PRS); secondary residential sector (SRS); commercial and industrial sector (CIS); agricultural sector (AS) and public utility sector

(PUS). The last sector (PUS) will be excluded from this study because of the lack of any inventory or evaluation details.

(b) The flood damage will be defined according to the following types: physical damage (D010); non-physical damage (D020); primary non-physical damage (D021); secondary non-physical damage (D022); and total damage (DTOT). These types of damage were described in 2.3.1.

(c) The municipal administrative division of the area under study is respected and consequently each municipality is regarded as an autonomous entity for which it is assumed that the water level is uniform for a given return period and that the value of the physical capital is uniformily distributed for the various economic sectors. This administrative division is composed of nine municipalities (Fig. 3.10): Saint-Jean (RØ1); Saint-Blaise (RØ2); Saint-Paul-de-l'Ile-aux-Noix (RØ3); Notre-Dame de Mont-Carmel (RØ4); Iberville (RE1); Saint-Athanase (RE2); Saint-Anne de Sabrevois (RE3); Henryville (RE4); and Saint-Thomas (RE5).

The survey of the flooded area of the Richelieu, which consisted of a series of questions, attempted to determine the dollar damage in 1976 on the basis of the water level derived from aerial photographs of the flood. In the survey an attempt was made not only to determine this reference level (RL), but also to estimate the damage that could occur from a theoretical flood one foot higher than the reference level (RL+1). In addition, the survey made it possible to establish the zero-damage water level which corresponded to a base flow of 25 000 cfs.

The sampling varies with the economic sector. For the two residential sectors, permanent and secondary, the sample represents 10 per cent of all the units affected; the sample represents 25 per cent of the agricultural sector and 100 per cent of the commercial and industrial sector. The results are grouped in Tables 3.4 to 3.7, which give the various types of damage for each municipality in the study area for the appropriate economic sectors. The damage is given for the actual flood (RL) and for the hypothetical flood (RL+1) in 1976 dollars.

3.4.2. Estimate of Total Damage Functions

The total damage function, in the form of a Gompertz curve, is calibrated from the submersion depth, the value of the physical capital and the total productivity function with the following assumptions being made (CICR, 1977).

i. The physical and non-physical damage does not vary with the date or duration of the extreme flood stages for the permanent and secondary residential and the commercial and industrial sectors.

ii. The agricultural damage observed during the 1976 flood is regarded as typical and consequently the date and duration are implicitly considered in the estimation of the total damage function, keeping in mind that 94 per cent of the floods are concentrated in the period from April to May, the time of the reference flood.

Furthermore, the total productivity function g(K) is taken as equal to unity due to lack of information for a more precise qualification. The Gompertz total damage function thus becomes

$$\frac{d}{K} = \frac{1}{e^{e^{-\alpha}} - 1} \{e^{e^{-\alpha[1 - e^{-\beta z}]}} - 1\}$$

Calibration of this function consists of estimating the parameters α and β, knowing the economic variable K, and the hydrological variable Z for the economic sectors and the various types of damage. The units of the variable d are regarded as unitary for the economic sectors: permanent residential: \$/unit; secondary residential: \$/unit; commercial and industrial: \$/unit; and agricultural: \$/acre.

The least squares method for non-linear functions (Draper and Smith, 1966) made it possible to choose the best theoretical curve for the unit damage values by use of the Levenberg-Marquardt smoothing algorithm (Brown and Dennis, 1972).

The smoothing of the values observed for the various types of damage is shown in Figures 3.11 to 3.15 for the secondary residential sector. Figures A-1 to A-15 in Appendix A illustrate the total damage functions obtained for the permanent residential, the commercial and industrial, and the agricultural economic sectors, for various types of damage.

With these total damage functions, and employing the results shown in Figures 3.8 and 3.9 in the two models, hydrological and hydraulic, the damage per unit of physical capital caused by floods of any given return period can be estimated. Tables 3.8 to 3.12 summarize for each municipality, the unit damage for return periods of 10, 20, 50, 100, 200 and 500 years subject to the assumption that the exceedances are independent and identically distributed over one year or one season. The tables show the secondary residential sector as an economic activity, whereas Tables B-1 to B-15 in Appendix B give the results for the permanent residential, the commercial and industrial, and the agricultural sectors.

3.4.3 Case Study

The implementation of corrective measures in the flood plains requires a projection of the damage likely to appear before and after the action taken. This projection must take the following into consideration:

i. increase in economic activity and income;
ii. increase in the rate of economic development and in the change over time of the discount rate;
iii. increased harvests because of the putting into production of new lands and increased average productivity per unit area;
iv. alteration of the geomorphologic and hydrographic characteristics of the drainage basins resulting from changing economic activities and land use;
v. physical alteration of the natural stream and flood plain channels through erosion and sedimentation;
vi. change in the flow as a result of human intervention such as the building of structures.

Some points may be considered on the basis of regional development and management plans, and others are more implicit, such as hydrographic or geomorphologic change in the drainage basins.

It is possible for the following reasons to apply these flood-plain management methods to a ten-year flood if the exceedances are regarded as independent and identically distributed over one year.

i. The corresponding discharge is almost equal to that of the 1976 flood; this entails maintaining the economic, hydrological and hydrodynamic characteristics of the area under study.
ii. The observed and the computed values for the 1976 flood can be compared.

Table 3.13 groups the various types of damage by municipality for the secondary residential sector. The results are given in 1976 dollars. For the other sectors, permanent residential, commercial and industrial, and agricultural, results are given, always for a ten-year flood, in Tables C-1 to C-3 in Appendix C.

3.5. DISCUSSION

The application of the flood-plain management methods to the Richelieu basin area under study, permits estimation of the various types of unit damages for different kinds of economic activities if exceedances are assumed as independent and identically distributed over one year and one season.

This flood damage estimate obviously depends on a number of hydrological, hydrodynamic and economic factors covered in the preceding chapters. Two are preponderant in a computer application:

i. the depth of submersion as the single hydrological variable used in developing the total damage functions;
ii. a unit total productivity function required because of the lack of information from the survey conducted after the 1976 flood.

The analysis of the results obtained from the computer application of this method has three distinct aspects:

i. Comparison of the figures for the observed damage and those computed for a flood with characteristics similar to those of the 1976 flood (T = 10 years, IID) make it possible to ascertain the uniform dispersion of these values about the line of equal damage in a non-diverging zone (Fig. 3.16), for damage and economic activities combined.
ii. An estimate of the total damage is sometimes all the information that is needed for some forms of corrective action in the flood plains. A comparison of this general estimate of the total damage with the sum of the components shows strong consistency with the equal damage line for all economic sectors except the agricultural sector where the total damage is clearly underestimated (Fig. 3.17). This deviation can be attributed to the fact that the depth of submersion cannot by itself represent the hydrological component in the estimation of agricultural damage. The flood duration, for example is an important factor. Therefore, the consideration of only one hydrological parameter for the agricultural sector does not appear to be valid.

iii. A comparison, by the same analysis as before, of the non-physical damage and its two components, primary and secondary, shows a very great deviation from the equal damage line (Fig. 3.18) for all economic sectors. The reason for this deviation is that the two non-physical classes of damage, primary and secondary, are in linear relation to the depth of submersion, but deviate from the equal damage line, so that their sum and the depth of submersion do not correspond. This becomes clear when the definitions for each class of non-physical damage are examined.

Thus a suitable estimate of the flood damage can be obtained by the use of a limited number of hydrological, hydraulic and economic factors. A forecast of such damage requires a prediction of the rate of increase and future values for each economic sector. Damage estimation accuracy could be greatly improved by taking into account the spatial distribution of physical capital and the corresponding indemnification.

CHAPTER IV - CONCLUSIONS

It would be unrealistic to state that the fight against floods has been won since, even if all the means of attenuating floods provide some protection, they have in no case completely eliminated the danger of floods (Harvey, 1979). To find a model and methods that will bring a definitive solution to the problem is therefore out of the question for the present state of the art.

The object of this study was to present an approach that consists in systematizing the use of available hydrological, hydrodynamic and economic information so as to institute rational flood-plain management. Such management requires consistent integration of the variables, be they deterministic or random, for comparison of the various possible corrective measures. To do this, the cost of the measures (composed of the installation cost and the residual flood damage cost) and the benefits procured from the measures (mainly the elimination of damage with these measures) are computed. The basic element of this study is the estimation of the damage linked to the physical and economic characteristics of the flood zones. This paper therefore systematizes the flood problem and presents the results of these methods applied to the Richelieu River case.

4.1 RESULTS OF A TECHNICAL AND ECONOMIC ANALYSIS OF FLOOD-PLAIN MANAGEMENT

Methods for rational flood-plain planning and management in urbanized areas, areas in the process of urbanization, and rural areas have been developed in this study. The main conclusions are:

i. Determination of the variables and the improvement of knowledge about the complexity of their relations gives a completely general character to the studies of floods, which have to be analyzed by sequential methods adaptable to local conditions.

ii. Analysis of flood-damage transfer functions permits derivation of a probabilistic distribution function for flood damage.

iii. Damage over time can be projected using extrapolations of hydrotechnical flood characteristics and economic flood plain characteristics without having to project the results of a post-flood survey.

iv. It is possible to transfer the parameters of the economic model from one experimental area to another economically identical area.

v. It is desirable to keep the discharge variable as a hydrologic variable.

4.2 RESULTS OF THE NUMERICAL APPLICATION

The application of the systematic approach of flood plain management to the Richelieu River drainage basin in Quebec illustrates the following:

i. It is possible to estimate the various types of damage incurred by each unit of the economic sectors under study, for return periods varying from 10 to 500 years, by assuming that the exceedances are independent and identically distributed over one year or one season.

ii. The assumption of seasonal distribution of the maximum hydrological exceedance has only a minor influence in the estimation of the damage in any activity sector (Tables 3.8 to 3.11 and B.1 to B.15). In the case of the Richelieu basin, the spring period (21 March to 20 June) is fully sufficient for estimating flood damage.

iii. The theoretical evaluation of damage gives values very close to those obtained by the after-flood survey (Fig. 3.16). Only a part of the survey data was needed for developing the method. In future, more modest surveys than that of 1976 will suffice for achieving the same level of accuracy.

iv. The total damage can be estimated directly without any need to evaluate its components (Fig. 3.17). This does not apply to non-physical damage (Fig. 3.18).

v. Agricultural damage cannot be estimated with only the depth of submersion hydrological variable (Fig. 3.18). Other hydrological variables such as the flood duration or volume have to be taken into consideration in an after-flood survey.

The flood-plain management method is a general procedure for analyzing problems caused by floods and for choosing measures which maximize the benefits derived from riverside areas. Supplementary research on floods and on the interdependence of their components with the physical and economic environments is required for increased understanding of floods and of their impact on flood plains.

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Tables

TABLE 3.1 - PEAK AND EXCEEDANCE DISCHARGES FOR THE RICHELIEU RIVER, HYDROMETRIC GAUGING STATION 02OJ007 AT FRYERS RAPID, BASE FLOW = 25 000 CFS

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R

HYDROMETRIC STATION 02OJ007........BASE FLOW = 25000 CFS

NO.	YEAR	DAY NO.	DISCHARGES (CFS)	EXCEEDANCES (CFS)	******	NO.	YEAR	DAY NO.	DISCHARGES (CFS)	EXCEEDANCES (CFS)
1	1938	182	25800.	800.	******	32	1953	217	32500.	7500.
2	1938	186	25500.	500.	******	33	1954	212	36800.	11800.
3	1938	192	25300.	300.	******	34	1955	199	40700.	15700.
4	1938	200	29200.	4200.	******	35	1956	224	32500.	7500.
5	1938	202	26300.	1300.	******	36	1958	211	39400.	14400.
6	1939	212	42600.	17600.	******	37	1959	211	34200.	9200.
7	1940	219	37100.	12100.	******	38	1960	213	36800.	11800.
8	1940	268	25500.	500.	******	39	1961	216	25900.	900.
9	1942	210	32500.	7500.	******	40	1961	218	25400.	400.
10	1943	183	25300.	300.	******	41	1961	228	26800.	1800.
11	1943	229	38100.	13100.	******	42	1962	214	30100.	5100.
12	1944	203	25600.	600.	******	43	1963	212	37600.	12600.
13	1944	215	34300.	9300.	******	44	1968	186	29900.	4900.
14	1944	233	26400.	1400.	******	45	1969	192	25700.	700.
15	1945	187	35100.	10100.	******	46	1969	212	39200.	14200.
16	1945	207	25200.	200.	******	47	1970	213	39100.	14100.
17	1945	235	34700.	9700.	******	48	1971	224	40300.	15300.
18	1946	173	26300.	1300.	******	49	1972	223	42300.	17300.
19	1946	175	25800.	800.	******	50	1972	255	26100.	1100.
20	1947	249	43700.	18700.	******	51	1972	258	25600.	600.
21	1948	187	29500.	4500.	******	52	1973	188	36600.	11600.
22	1948	198	26800.	1800.	******	53	1973	240	30100.	5100.
23	1948	201	25800.	800.	******	54	1973	276	25800.	800.
24	1950	194	26500.	1500.	******	55	1974	94	26900.	1900.
25	1950	199	26000.	1000.	******	56	1974	105	25500.	500.
26	1950	208	28800.	3800.	******	57	1974	189	26900.	1900.
27	1950	222	30100.	5100.	******	58	1974	227	35600.	10600.
28	1951	201	38700.	13700.	******	59	1975	215	27000.	2000.
29	1952	204	33600.	8600.	******	60	1976	188	41900.	16900.
30	1952	225	26300.	1300.	******	61	1977	185	35600.	10600.
31	1953	193	29600.	4600.	******	62	1977	223	25800.	800.

TABLE 3.2. SEASONAL VALUES OF $\Lambda(t)$

SEASON	PERIOD	INTERVAL	$\Lambda(t)$
Autumn	21 Sept. - 20 Dec.	$(0, T_1]$	$\Lambda(T_1) = 0.000$
Winter	21 Dec. - 20 March	$(T_1, T_2]$	$\Lambda(T_2) - \Lambda(T_1) = 0.075$
Spring	21 March - 20 June	$(T_2, T_3]$	$\Lambda(T_3) - \Lambda(T_2) = 1.435$
Summer	21 June - 20 Sept.	$(T_3, T_4]$	$\Lambda(T_4) - \Lambda(T_3) = 0.040$

TABLE 3.3. SEASONAL VALUES OF β

SEASON	AVERAGE OF EXCEEDANCES $E[\xi]$ in cfs	$\beta = \{E[\xi]\}^{-1}$
Autumn	2250	4.444×10^{-4}
Winter	750	13.333×10^{-4}
Spring	6595	1.516×10^{-4}
Summer	750	13.333×10^{-4}

TABLE 3.4 - AFTER-FLOOD SURVEY, 1976, FOR PERMANENT RESIDENTIAL SECTOR

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R

DAMAGE IN 1976 DOLLARS
SECTOR:PERMANENT RESIDENTIAL   SURVEY AFTER THE FLOOD OF 1976

MUNICI- PALITY	SAMPLE (UNIT)		POPULATION (UNIT)		PHYSICAL		NON-PHYSICAL DAMAGE: PRIMARY		NON-PHYSICAL DAMAGE: SECONDARY		NON-PHYSICAL DAMAGE: TOTAL		TOTAL	
	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1
R01	24	24	115	149	116304.	357694.	20054.	49314.	73540.	100910.	93594.	150224.	209898.	507918.
R02	9	9	90	119	122540.	231030.	9073.	42220.	54764.	93883.	63837.	136103.	136377.	367133.
R03	5	5	30	32	11476.	56584.	4695.	19631.	84325.	88007.	89020.	107638.	100496.	164222.
R04	4	4	10	30	25.	470.	287.	700.	2517.	9097.	2804.	9797.	2829.	10267.
RE1	2	2	20	50	0.	11000.	4950.	13770.	19392.	33672.	24342.	47442.	24342.	58442.
RE2	13	13	130	158	50740.	98250.	21668.	34335.	88757.	122640.	110425.	156975.	161165.	255225.
RE3	8	8	52	74	50537.	144031.	34934.	58512.	47294.	57965.	82228.	116477.	132765.	260508.
RE4	2	2	10	22	4350.	6850.	803.	1629.	7155.	9899.	7958.	11528.	12308.	18378.
RE5	3	3	20	20	5966.	9940.	19707.	26040.	11069.	14149.	30776.	40189.	36742.	50129.

REMARK:RF =REFERENCE LEVEL OF 1976 FLOOD (101.51 FT USGS AT ROUSES POINT, N.Y.)
RF+1=REFERENCE LEVEL OF 1976 FLOOD PLUS ONE FOOT (102.51 AT USGS AT ROUSES POINT, N.Y.)

TABLE 3.5 - AFTER-FLOOD SURVEY, 1976, FOR SECONDARY RESIDENTIAL SECTOR

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R

DAMAGE IN 1976 DOLLARS
SECTOR: SECONDARY RESIDENTIAL   SURVEY AFTER THE FLOOD OF 1976

MUNICI-PALITY	SAMPLE (UNIT)		POPULATION (UNIT)		PHYSICAL		NON-PHYSICAL DAMAGE PRIMARY		NON-PHYSICAL DAMAGE SECONDARY		NON-PHYSICAL DAMAGE TOTAL		TOTAL	
	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1
R01	17	17	176	176	28204.	115144.	18291.	25887.	13606.	13606.	31897.	39493.	60101.	154637.
R02	26	26	260	279	82430.	347830.	18360.	31395.	13522.	131522.	149882.	162917.	232312.	510747.
R03	53	53	534	535	168997.	637643.	75688.	94889.	137660.	137660.	213348.	232549.	382345.	870192.
R04	9	9	40	50	2664.	57778.	3052.	5164.	3673.	3673.	6725.	8837.	9389.	66615.
RE1	1	1	10	10	0.	0.	46.	92.	370.	370.	416.	462.	416.	462.
RE2	10	10	100	124	8900.	41700.	12852.	18158.	11850.	11850.	24702.	30008.	33602.	71708.
RE3	27	27	292	292	117450.	355378.	33254.	33254.	89291.	89291.	122545.	122545.	239995.	477923.
RE4	18	18	180	180	134156.	248760.	17671.	18130.	127549.	127549.	145220.	145679.	279370.	394439.
RE5	7	7	80	101	25563.	56923.	12072.	18153.	47305.	47305.	59377.	65458.	84940.	122381.

REMARK: RF =REFERENCE LEVEL OF 1976 FLOOD (101.51 FT USGS AT ROUSES POINT, N.Y.)
RF+1=REFERENCE LEVEL OF 1976 FLOOD PLUS ONE FOOT (102.51 FT USGS AT ROUSES POINT, N.Y.)

TABLE 3.6 - AFTER-FLOOD SURVEY, 1976, FOR COMMERCIAL AND INDUSTRIAL FACTOR

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R

DAMAGE IN 1976 DOLLARS
SECTOR:COMMERCIAL AND INDUSTRIAL   SURVEY AFTER THE FLOOD OF 1976

MUNICIPALITY	SAMPLE (UNIT)		POPULATION (UNIT)		PHYSICAL		NON-PHYSICAL DAMAGE: PRIMARY		NON-PHYSICAL DAMAGE: SECONDARY		NON-PHYSICAL DAMAGE: TOTAL		TOTAL	
	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1
R01	3	3	3	3	50.	350.	1198.	1273.	425.	425.	1623.	1698.	1673.	2040.
R02	2	2	2	2	7350.	8350.	3400.	3400.	2500.	2500.	5900.	5900.	13250.	14250.
R03	4	4	4	4	8550.	11600.	19044.	21444.	50265.	50295.	69309.	71739.	77859.	83339.
R04	1	1	1	2	100.	100.	9789.	9789.	0.	0.	9789.	9789.	9689.	9889.
RE1	0	0	0	1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
RE2	0	0	0	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
RE3	3	3	3	3	8200.	10200.	9030.	9030.	125.	125.	9155.	9155.	17355.	19355.
RE4	1	1	1	2	2000.	2000.	0.	0.	0.	0.	0.	0.	2000.	2000.
RE5	3	3	3	3	3000.	3000.	500.	500.	0.	0.	500.	500.	3500.	3500.

REMARK:RF =REFERENCE LEVEL OF 1976 FLOOD (101.51 FT USGS AT ROUSES POINT, N.Y.)
RF+1=REFERENCE LEVEL OF 1976 FLOOD PLUS ONE FOOT (102.51 FT USGS AT ROUSES POINT, N.Y.)

TABLE 3.7 - AFTER-FLOOD SURVEY, 1976, FOR AGRICULTURAL SECTOR

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R

DAMAGE IN 1976 DOLLARS
SECTOR:AGRICULTURAL   SURVEY AFTER THE FLOOD OF 1976

MUNICI-PALITY	SAMPLE (ACRES)		POPULATION (ACRES)		PHYSICAL		NON-PHYSICAL DAMAGE PRIMARY		NON-PHYSICAL DAMAGE SECONDARY		NON-PHYSICAL DAMAGE TOTAL		TOTAL	
	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1	RL	RL+1
RO1	12	24	105	204	33714.	60742.	437.	855.	0.	0.	437.	855.	34151.	61597.
RO2	76	123	105	154	28307.	38081.	1176.	1755.	435.	435.	1611.	2190.	29918.	40271.
RO3	79	99	884	1058	254995.	308440.	8706.	12451.	725.	1414.	9431.	13865.	264426.	322305.
RO4	263	344	529	831	64407.	78030.	4942.	7447.	363.	520.	5305.	7967.	69712.	85997.
RE1	0	0	0	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
RE2	0	0	0	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
RE3	140	211	487	919	97415.	146323.	77739.	140290.	725.	725.	78464.	14015.	175879.	287339.
RE4	311	392	1450	2325	591351.	947437.	25736.	39333.	750.	750.	26486.	40083.	617837.	987520.
RE5	66	92	100	344	56879.	188047.	20349.	70445.	0.	0.	20349.	70445.	77228.	258492.

REMARK:RF =REFERENCE LEVEL OF 1976 FLOOD (101.51 FT USGS AT ROUSES POINT, N.Y.)
RF+1=REFERENCE LEVEL OF 1976 FLOOD PLUS ONE FOOT (102.51 FT USGS AT ROUSES POINT, N.Y.)

TABLE 3.8 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, SRS*D010

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
S R S ** D 0 1 0

DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL

MUNICIPALITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION						SEASONAL DISTRIBUTION					
		RETURN PERIOD											
		10	20	50	100	200	500	10	20	50	100	200	500
RO1	2086.	229.	323.	452.	553.	651.	776.	239.	339.	477.	582.	684.	815.
		10.98	15.47	21.66	26.52	31.21	37.19	11.44	16.24	22.88	27.89	32.79	39.06
RO2	4810.	503.	748.	1001.	1220.	1434.	1703.	525.	748.	1054.	1285.	1506.	1784.
		10.45	15.55	20.81	25.35	29.82	35.41	10.91	15.55	21.92	26.71	31.30	37.09
RO3	5681.	631.	892.	1250.	1517.	1784.	2113.	658.	936.	1339.	1600.	1874.	2219.
		11.11	15.70	22.01	26.71	31.39	37.19	11.58	16.48	23.58	28.16	32.98	39.06
RO4	13894.	1609.	2267.	3178.	3850.	4517.	5349.	1675.	2377.	3337.	4053.	4751.	5608.
		11.58	16.32	22.88	27.71	32.51	38.50	12.05	17.11	24.02	29.17	34.19	40.36
RE1	3000.	232.	321.	448.	544.	645.	774.	241.	337.	471.	574.	678.	816.
		7.74	10.71	14.94	18.15	21.49	25.80	8.02	11.24	15.70	19.13	22.61	27.25
RE2	2572.	189.	269.	392.	492.	593.	729.	193.	282.	416.	522.	629.	779.
		7.35	10.45	15.24	19.13	23.05	28.35	7.52	10.98	16.16	20.30	24.46	30.28
RE3	3084.	309.	438.	616.	752.	886.	1055.	322.	461.	650.	793.	934.	1106.
		10.01	14.19	19.96	24.37	28.71	34.19	10.45	14.94	21.06	25.71	30.28	35.88
RE4	3984.	437.	616.	866.	1053.	1236.	1463.	456.	647.	911.	1107.	1299.	1537.
		10.98	15.47	21.75	26.43	31.02	36.72	11.44	16.24	22.88	27.80	32.61	38.59
RE5	4843.	551.	775.	1087.	1320.	1547.	1833.	574.	813.	1142.	1391.	1629.	1923.
		11.38	16.01	22.44	27.25	31.95	37.84	11.85	16.79	23.58	28.71	33.63	39.71

TABLE 3.9 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, SRS*D020

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
S R S ** D 0 2 0

........................DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL...........

MUNICIPA-LITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION — RETURN PERIOD 10	20	50	100	200	500	SEASONAL DISTRIBUTION — RETURN PERIOD 10	20	50	100	200	500
R01	2086.	172.	210.	255.	287.	316.	352.	176.	216.	263.	295.	325.	363.
		8.23	10.05	12.21	13.74	15.14	16.86	8.43	10.34	12.60	14.15	15.60	17.39
R02	4810.	385.	485.	574.	644.	708.	787.	394.	485.	591.	663.	729.	810.
		7.99	10.08	11.93	13.38	14.73	16.35	8.20	10.08	12.29	13.79	15.16	16.83
R03	5681.	471.	576.	700.	784.	863.	958.	482.	592.	728.	809.	889.	988.
		8.29	10.14	12.32	13.79	15.19	16.86	8.49	10.42	12.82	14.23	15.65	17.39
R04	13894.	1180.	1440.	1751.	1959.	2156.	2395.	1208.	1480.	1801.	2020.	2223.	2468.
		8.49	10.37	12.60	14.10	15.52	17.23	8.69	10.65	12.96	14.54	16.00	17.76
RE1	3000.	200.	243.	296.	331.	365.	406.	205.	250.	304.	341.	375.	419.
		6.67	8.11	9.85	11.02	12.15	13.52	6.82	8.35	10.14	11.36	12.52	13.96
RE2	2572.	166.	206.	256.	292.	326.	368.	168.	212.	265.	302.	337.	382.
		6.46	7.99	9.97	11.36	12.66	14.29	6.55	8.23	10.31	11.76	13.10	14.86
RE3	3084.	240.	295.	359.	403.	444.	494.	247.	304.	370.	416.	458.	508.
		7.79	9.56	11.65	13.07	14.40	16.00	7.99	9.85	12.01	13.49	14.86	16.49
RE4	3984.	328.	400.	487.	546.	601.	666.	336.	412.	502.	563.	619.	688.
		8.23	10.05	12.24	13.71	15.08	16.73	8.43	10.34	12.60	14.12	15.54	17.26
RE5	4843.	407.	497.	603.	676.	744.	826.	417.	510.	621.	697.	767.	851.
		8.40	10.25	12.46	13.96	15.35	17.05	8.61	10.54	12.82	14.40	15.84	17.58

TABLE 3.10 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, SRS*D021

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
S R S ** D 0 2 1

MUNICIPA-LITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION						SEASONAL DISTRIBUTION					
		RETURN PERIOD											
		10	20	50	100	200	500	10	20	50	100	200	500
RO1	2086.	48.	59.	72.	81.	90.	101.	49.	60.	74.	84.	93.	104.
		2.29	2.81	3.44	3.89	4.31	4.83	2.34	2.89	3.55	4.02	4.45	5.00
RO2	4810.	107.	136.	161.	182.	201.	225.	110.	136.	167.	188.	208.	232.
		2.22	2.82	3.36	3.79	4.19	4.68	2.28	2.82	3.46	3.91	4.32	4.82
RO3	5681.	131.	161.	197.	222.	246.	275.	134.	166.	206.	229.	254.	284.
		2.30	2.83	3.47	3.91	4.33	4.83	2.36	2.92	3.62	4.04	4.47	5.00
RO4	13894.	328.	403.	494.	556.	615.	687.	336.	415.	509.	574.	635.	710.
		2.36	2.90	3.55	4.00	4.42	4.95	2.42	2.98	3.66	4.13	4.57	5.11
RE1	3000.	55.	68.	83.	93.	103.	115.	57.	70.	85.	96.	106.	119.
		1.84	2.25	2.75	3.09	3.42	3.83	1.88	2.32	2.83	3.19	3.53	3.96
RE2	2572.	46.	57.	72.	82.	92.	104.	47.	59.	74.	85.	95.	109.
		1.78	2.22	2.79	3.19	3.57	4.06	1.81	2.29	2.88	3.31	3.70	4.23
RE3	3084.	67.	82.	101.	114.	126.	141.	68.	85.	104.	118.	130.	146.
		2.16	2.67	3.27	3.69	4.09	4.57	2.22	2.75	3.38	3.82	4.23	4.72
RE4	3984.	91.	112.	137.	155.	171.	191.	93.	115.	142.	160.	177.	197.
		2.29	2.81	3.45	3.88	4.29	4.79	2.34	2.89	3.55	4.01	4.43	4.95
RE5	4843.	113.	139.	170.	192.	212.	237.	116.	143.	175.	198.	219.	245.
		2.34	2.87	3.51	3.96	4.38	4.89	2.39	2.95	3.62	4.09	4.52	5.05

DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL

TABLE 3.11 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, SRS*D022

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
S R S ** D 0 2 2

..............................DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL..........

MUNICIPALITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION — RETURN PERIOD 10	20	50	100	200	500	SEASONAL DISTRIBUTION — RETURN PERIOD 10	20	50	100	200	500
RO1	2086.	123.	150.	183.	207.	228.	255.	126.	155.	189.	213.	235.	263.
		5.89	7.21	8.78	9.90	10.93	12.20	6.04	7.42	9.07	10.21	11.27	12.60
RO2	4810.	275.	348.	413.	464.	511.	569.	282.	348.	426.	476.	527.	586.
		5.72	7.23	8.58	9.64	10.63	11.83	5.87	7.23	8.85	9.94	10.95	12.18
RO3	5681.	337.	413.	504.	565.	623.	693.	346.	425.	525.	583.	643.	716.
		5.94	7.28	8.87	9.94	10.97	12.20	6.08	7.48	9.23	10.27	11.31	12.60
RO4	13894.	845.	1034.	1260.	1413.	1558.	1734.	865.	1063.	1297.	1457.	1608.	1789.
		6.08	7.44	9.07	10.17	11.21	12.48	6.23	7.65	9.34	10.49	11.57	12.87
RE1	3000.	143.	174.	212.	238.	262.	292.	146.	179.	218.	245.	270.	302.
		4.77	5.81	7.07	7.92	8.74	9.74	4.87	5.98	7.28	8.17	9.01	10.07
RE2	2572.	119.	147.	184.	210.	234.	265.	120.	152.	190.	217.	243.	276.
		4.62	5.72	7.15	8.17	9.11	10.31	4.68	5.89	7.40	8.46	9.44	10.73
RE3	3084.	172.	212.	258.	290.	320.	357.	177.	218.	266.	300.	331.	368.
		5.58	6.86	8.37	9.42	10.39	11.57	5.72	7.07	8.64	9.72	10.73	11.93
RE4	3984.	235.	287.	351.	394.	434.	482.	241.	296.	361.	406.	447.	498.
		5.89	7.21	8.80	9.88	10.89	12.11	6.04	7.42	9.07	10.19	11.23	12.50
RE5	4843.	291.	356.	434.	488.	537.	598.	299.	366.	447.	503.	555.	617.
		6.02	7.36	8.97	10.07	11.09	12.34	6.17	7.57	9.23	10.39	11.45	12.74

TABLE 3.12 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, SRS*DTOT

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U R I V E R
S R S ** D T O T

DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL

MUNICIPALITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION						SEASONAL DISTRIBUTION					
		RETURN PERIOD											
		10	20	50	100	200	500	10	20	50	100	200	500
RO1	2086.	456. 21.85	559. 26.81	680. 32.62	765. 36.67	841. 40.31	932. 44.69	467. 22.41	575. 27.59	702. 33.66	788. 37.75	866. 41.49	960. 46.02
RO2	4810.	1021. 21.22	1293. 26.89	1533. 31.86	1718. 35.72	1888. 39.25	2088. 43.41	1047. 21.77	1293. 26.89	1580. 32.84	1771. 36.82	1942. 40.38	2146. 44.62
RO3	5681.	1251. 22.01	1536. 27.04	1870. 32.91	2092. 36.82	2298. 40.45	2539. 44.69	1282. 22.57	1580. 27.82	1946. 34.25	2157. 37.97	2365. 41.63	2614. 46.02
RO4	13894.	3136. 22.57	3844. 27.66	4677. 33.66	5226. 37.61	5736. 41.28	6339. 45.62	3213. 23.12	3951. 28.44	4811. 34.62	5385. 38.75	5909. 42.53	6521. 46.93
RE1	3000.	528. 17.61	646. 21.54	788. 26.27	883. 29.43	974. 32.47	1083. 36.09	540. 18.01	665. 22.17	811. 27.04	910. 30.35	1003. 33.44	1117. 37.25
RE2	2572.	438. 17.04	546. 21.22	684. 26.58	781. 30.35	870. 33.81	980. 38.11	445. 17.29	562. 21.85	708. 27.51	808. 31.41	900. 34.99	1019. 39.61
RE3	3084.	637. 20.66	786. 25.48	959. 31.11	1077. 34.92	1184. 38.40	1311. 42.53	654. 21.22	810. 26.27	990. 32.09	1111. 36.02	1221. 39.61	1349. 43.75
RE4	3984.	871. 21.85	1068. 26.81	1302. 32.69	1458. 36.60	1600. 40.17	1767. 44.36	893. 22.41	1099. 27.59	1341. 33.66	1501. 37.68	1648. 41.35	1820. 45.69
RE5	4843.	1081. 22.33	1325. 27.35	1612. 33.29	1804. 37.25	1979. 40.87	2187. 45.16	1108. 22.89	1362. 28.13	1659. 34.25	1860. 38.40	2040. 42.11	2251. 46.48

TABLE 3.13 - ESTIMATED DAMAGE FOR A TEN-YEAR FLOOD (IID), SECONDARY RESIDENTIAL SECTOR

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
SRS ** IID * T=10 YEARS

MUNICIPALITY	PHYSICAL CAPITAL ($/UNIT)	PHYSICAL CAPITAL NO. OF UNITS	DAMAGE IN 1976 DOLLARS: PHYSICAL	NON-PHYSICAL: PRIMARY	NON-PHYSICAL: SECONDARY	NON-PHYSICAL: TOTAL	TOTAL
R01	2086.	176.	40298.	30210.	8390.	21633.	80232.
R02	4810.	260.	130739.	99978.	27745.	71579.	265333.
R03	5681.	534.	336994.	251397.	69846.	180048.	667784.
R04	13894.	40.	64342.	47190.	13119.	33802.	125425.
RE1	3000.	10.	2322.	2001.	553.	1430.	5283.
RE2	2572.	100.	18907.	16617.	4587.	11874.	43837.
RE3	3084.	292.	90114.	70145.	19455.	50207.	186030.
RE4	3984.	180.	78712.	59008.	16388.	42256.	156716.
RE5	4843.	80.	44072.	32559.	9048.	23320.	86516.
TOTAL DAMAGE IN 1976 DOLLARS :			806499.	609104.	169130.	436149.	1617154.

Illustrations

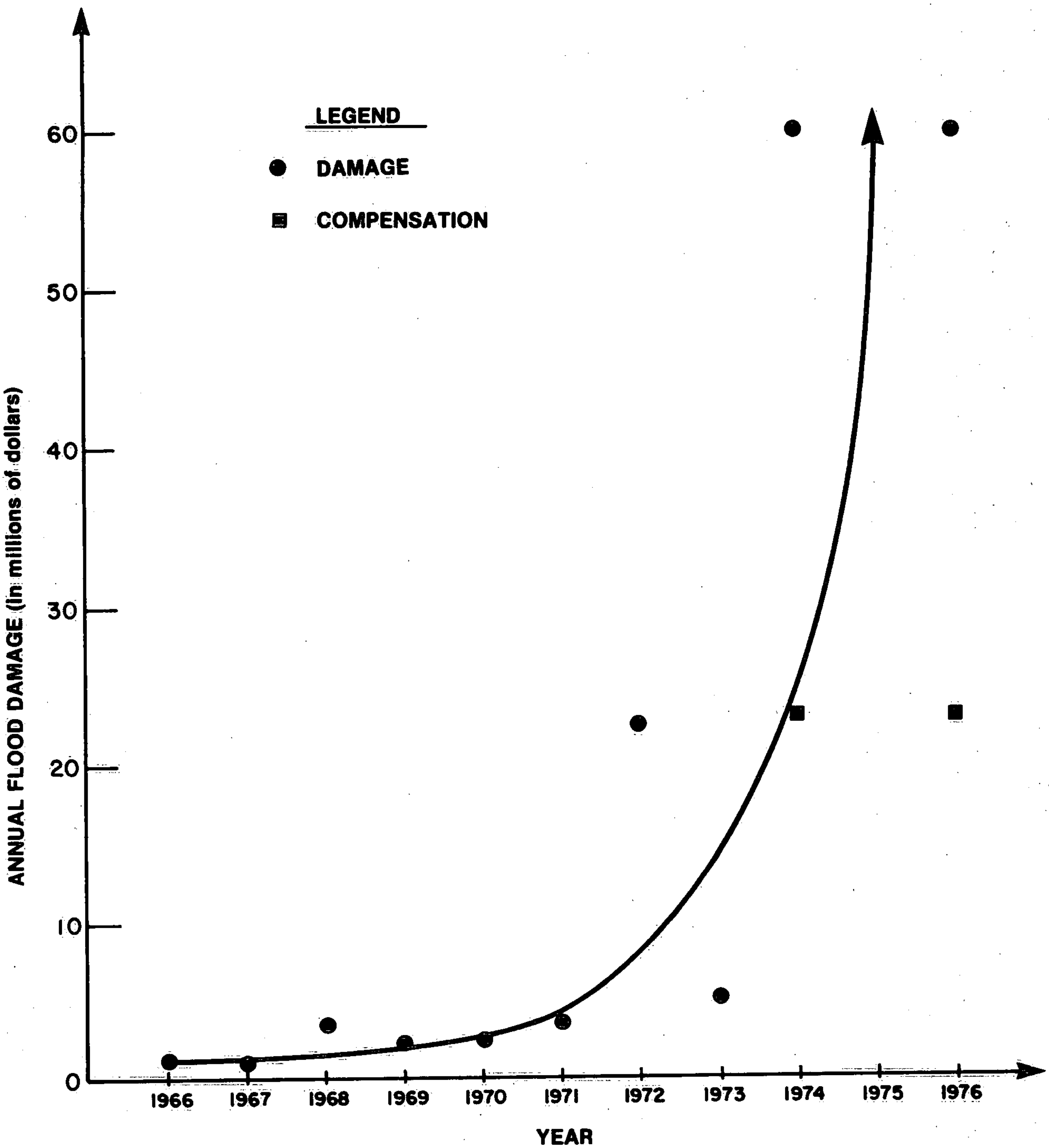

Figure 1.1. General trend of annual flood damage in Quebec.

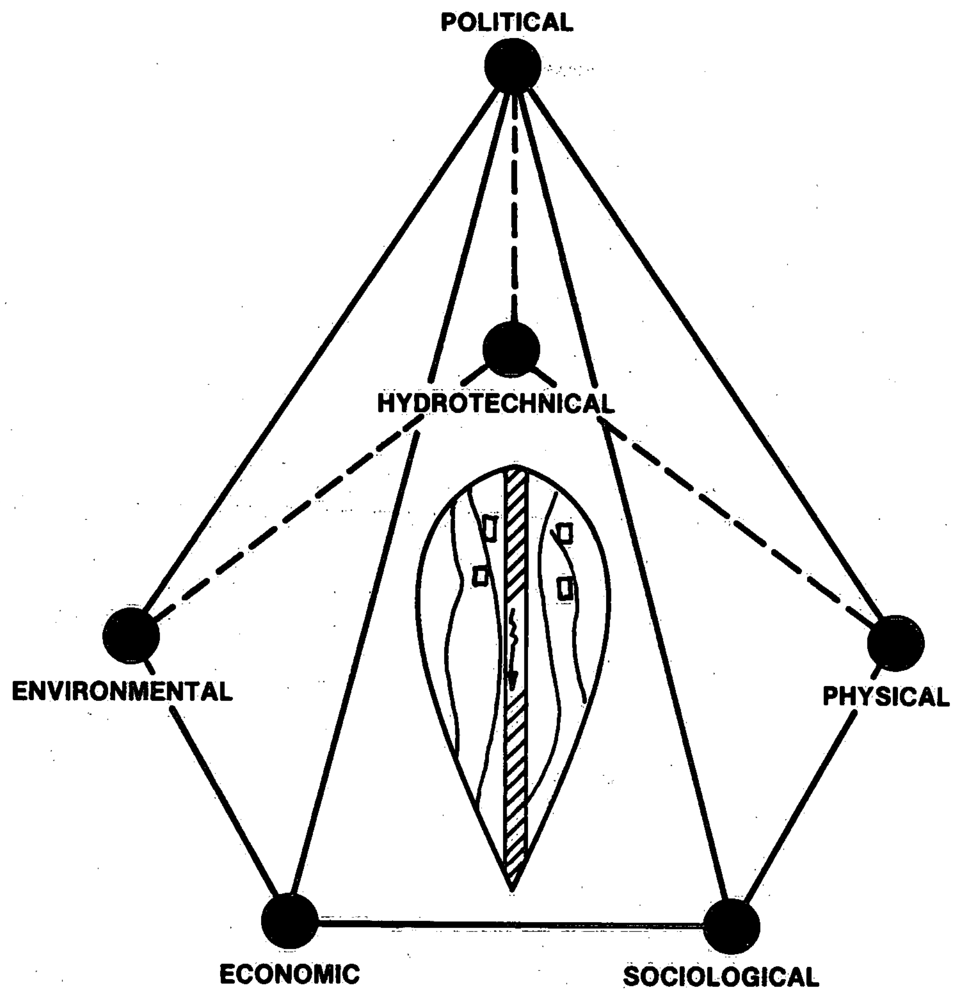

Figure 1.2. Decision space in flood plain management.

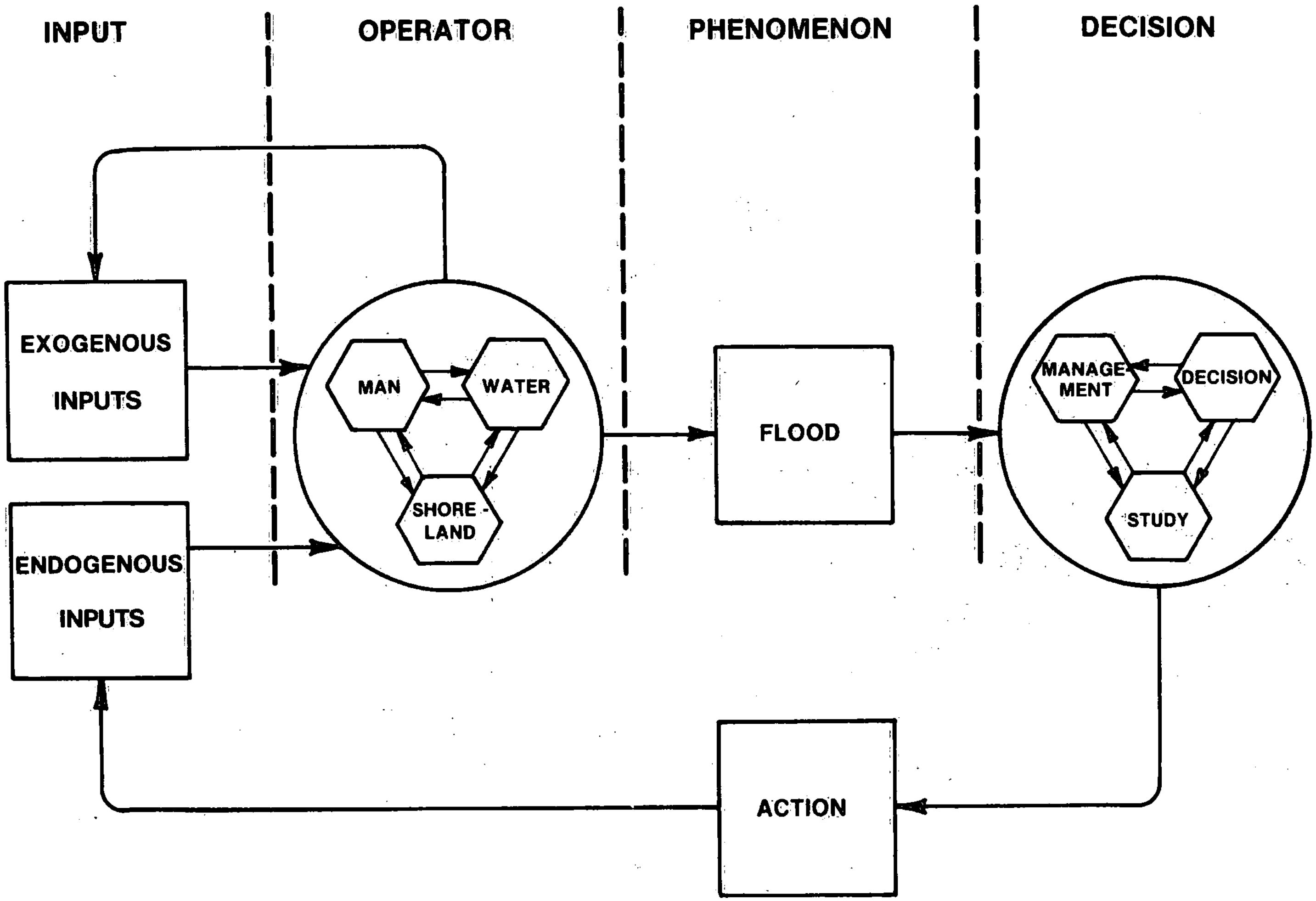

Figure 1.3. Simplified flood scheme.

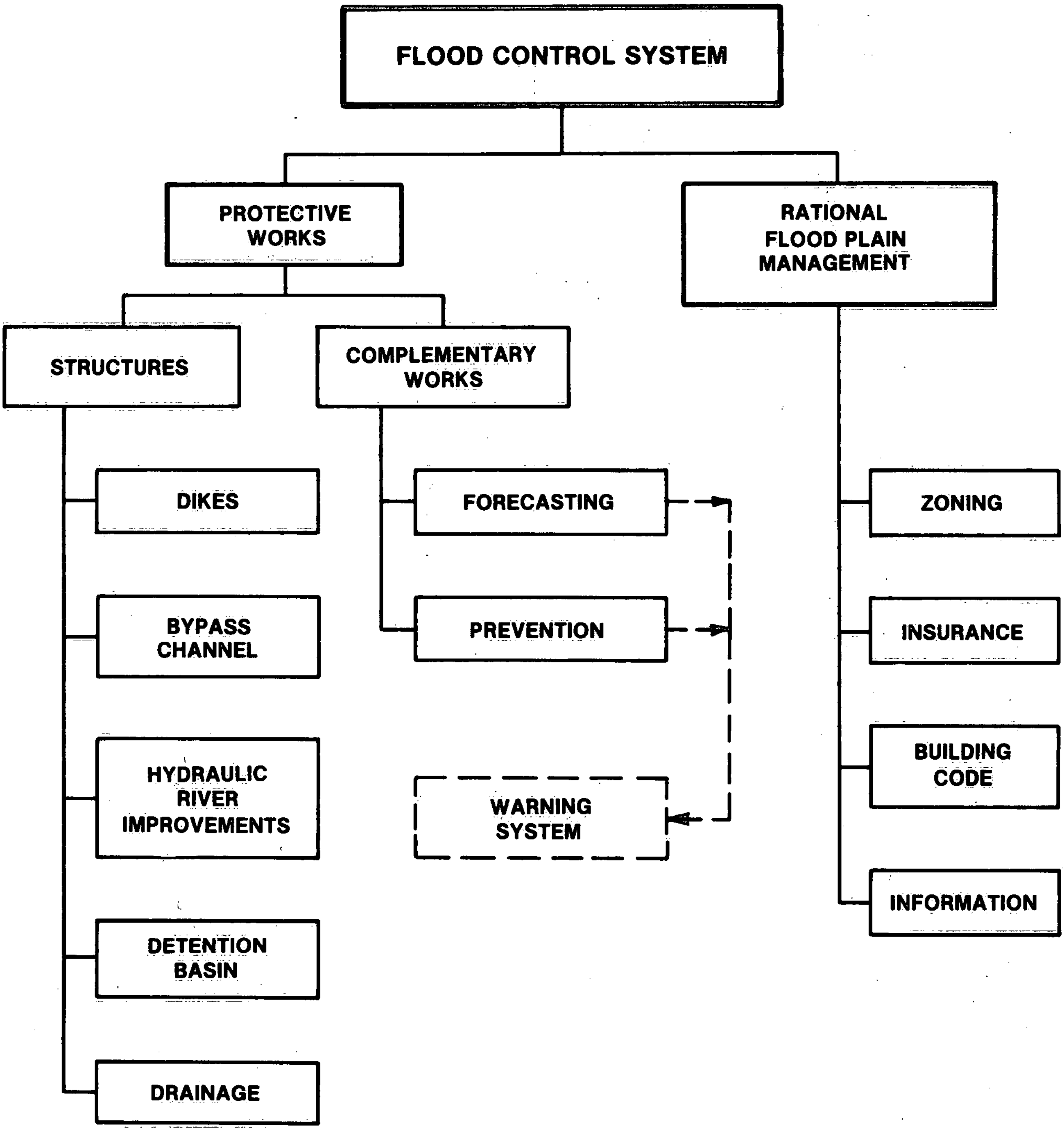

Figure 1.4. Flood control system.

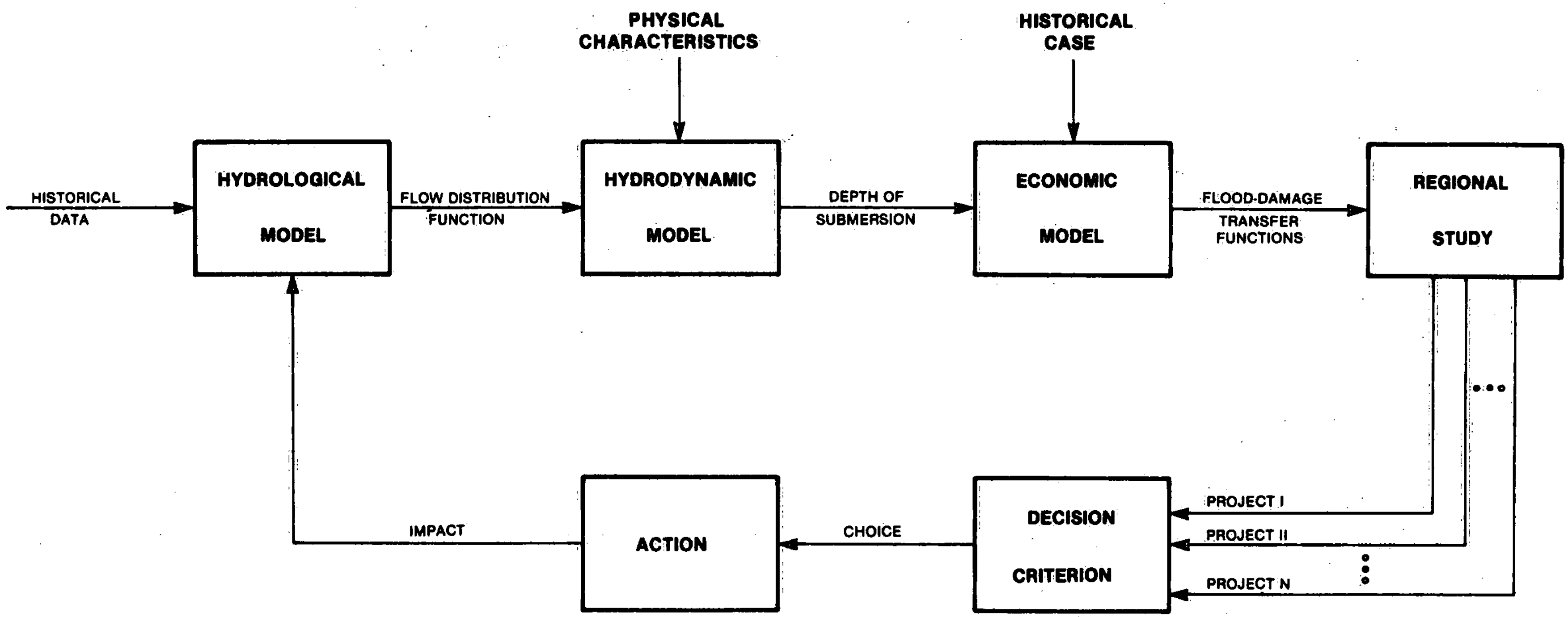

Figure 1.5. Flood-plain system.

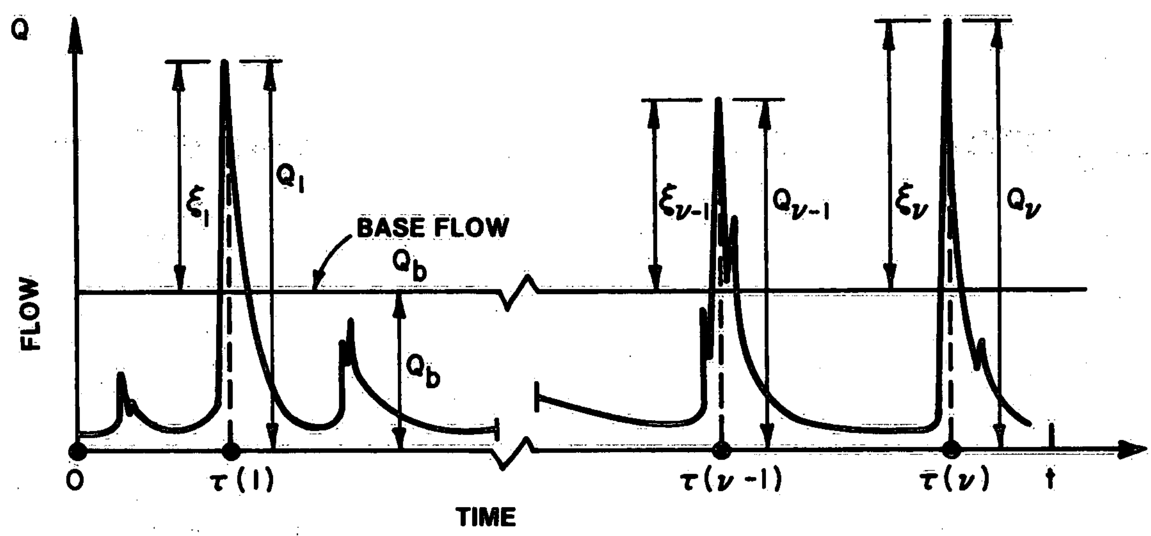

Figure 2.1. Hydrograph of instantaneous flow of a river at a given station.

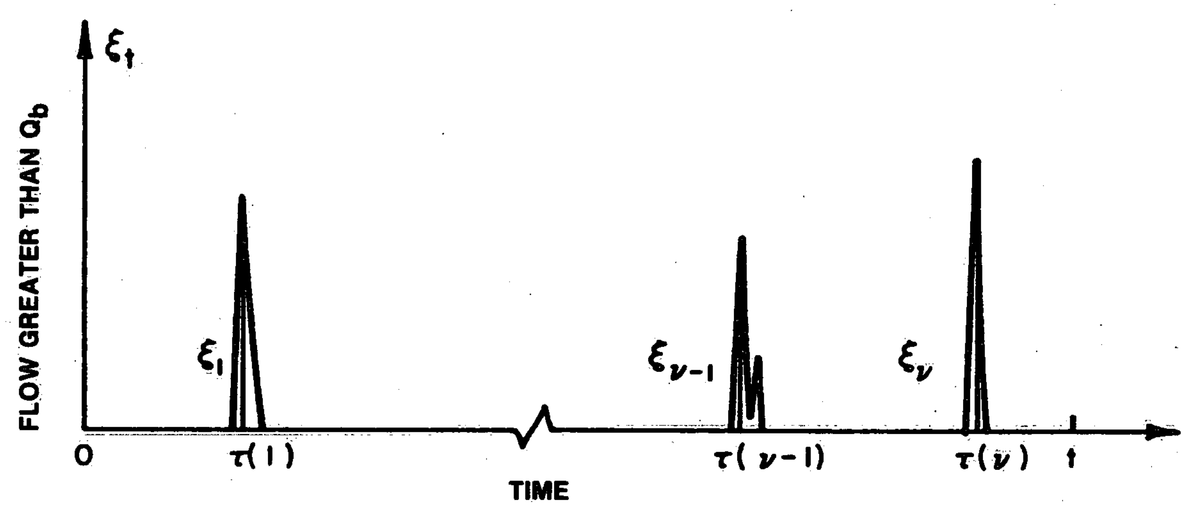

Figure 2.2. Hydrograph of flood flow.

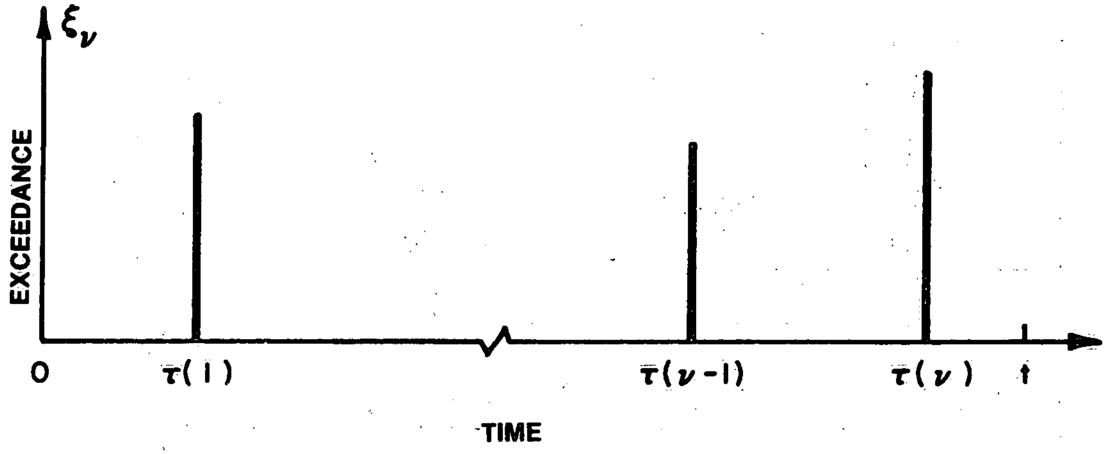

Figure 2.3. Stochastic process of exceedances over an interval (0,t].

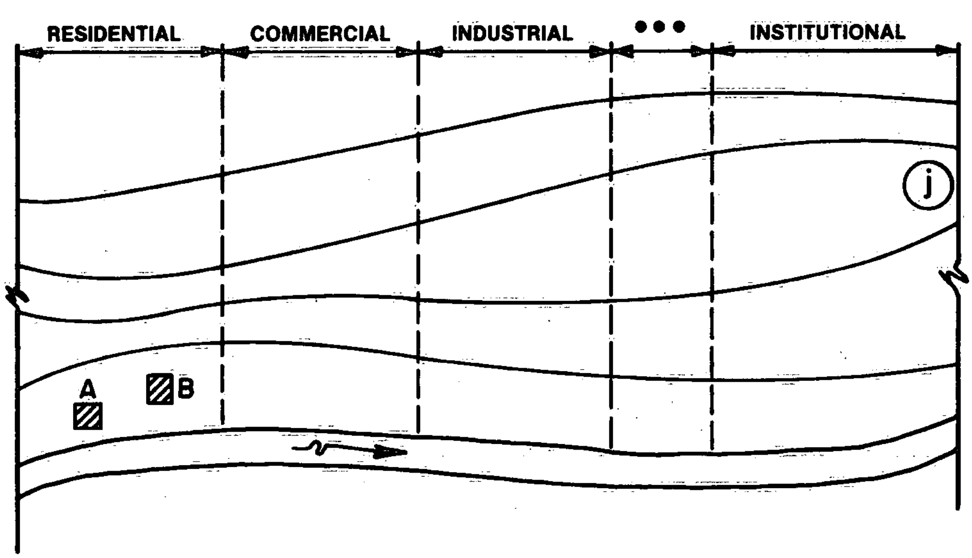

Figure 2.4. Schematic representation of a flood plain.

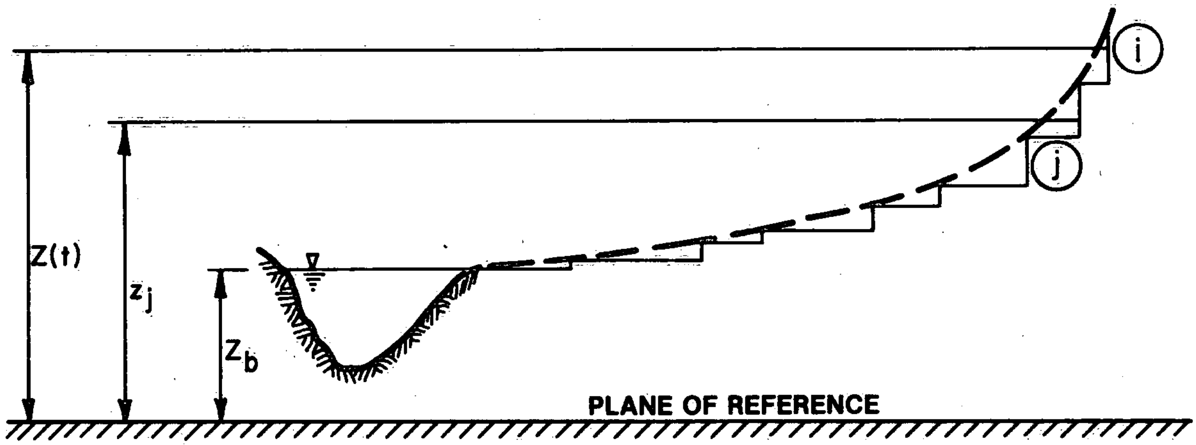

Figure 2.5. Flood process.

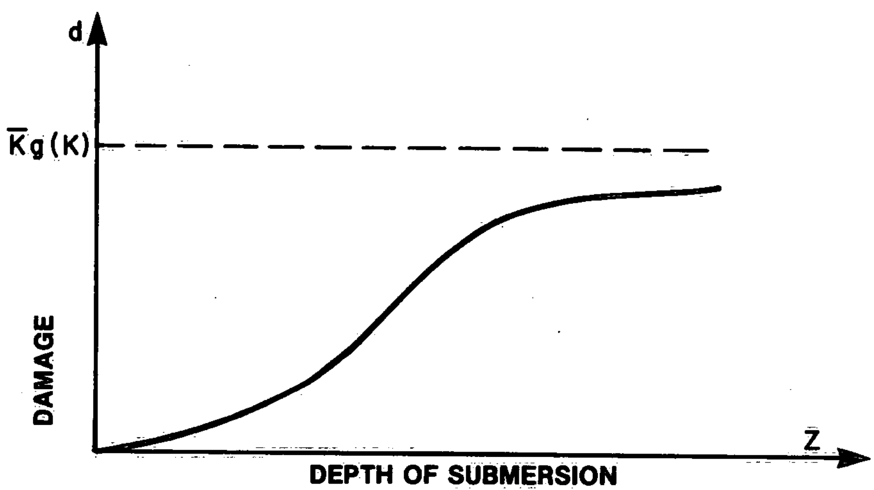

Figure 2.6. Gompertz total damage function.

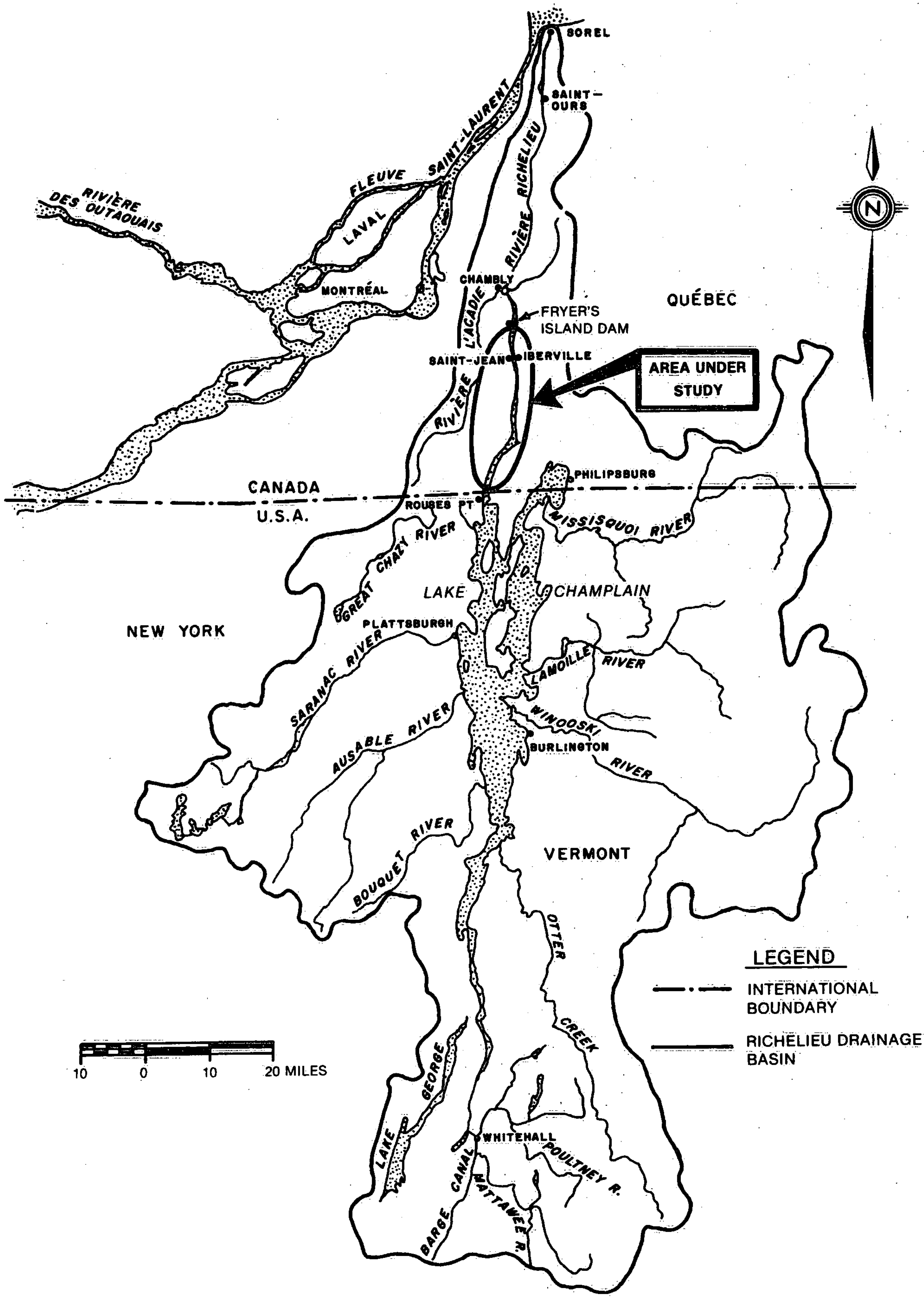

Figure 3.1. Richelieu River-Lake Champlain drainage basin.

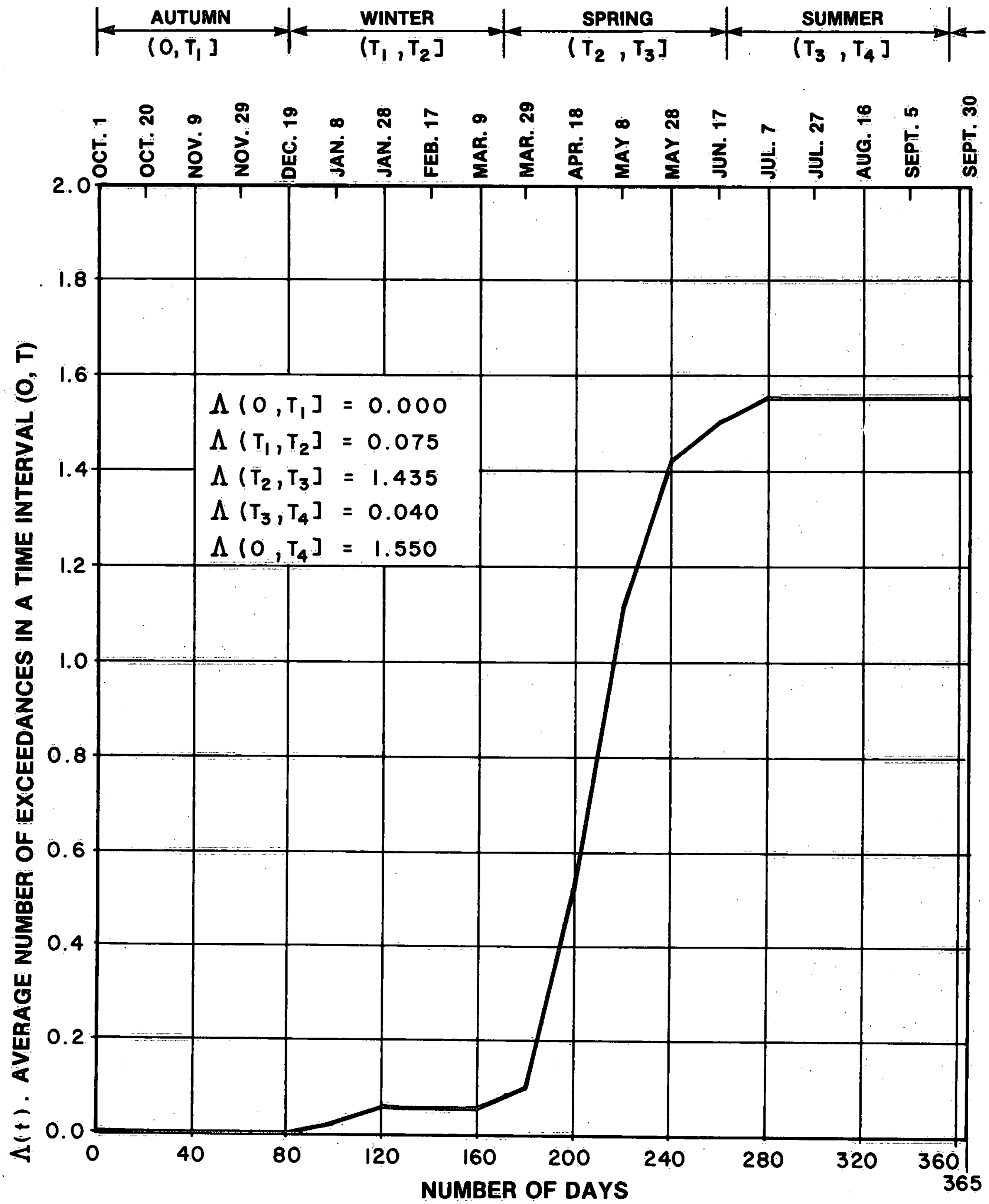

Figure 3.2. Observed values of frequency $\Lambda(t)$.

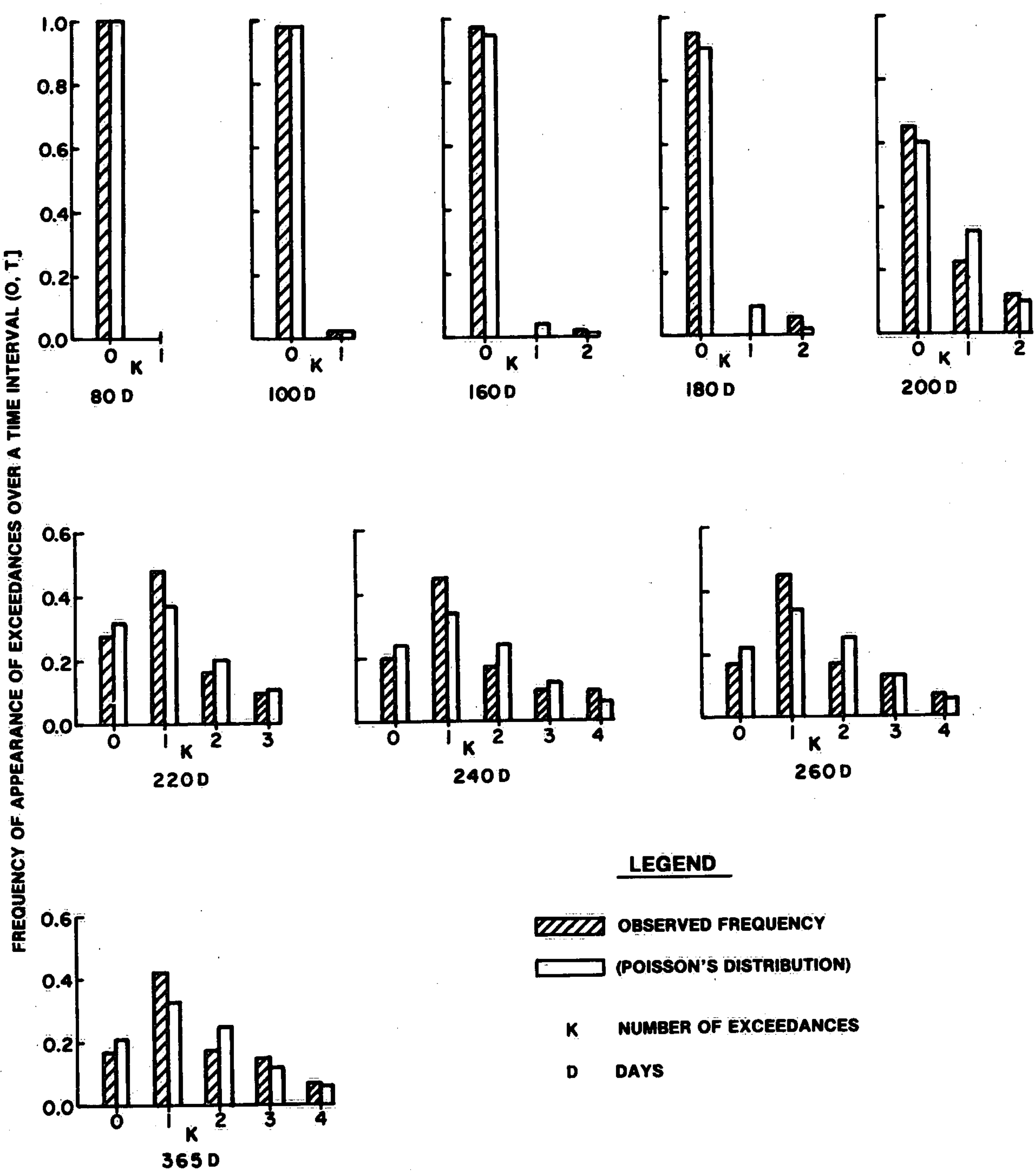

Figure 3.3. Observed and adjusted theoretical distributions for numbers of exceedances for various time intervals (0,t].

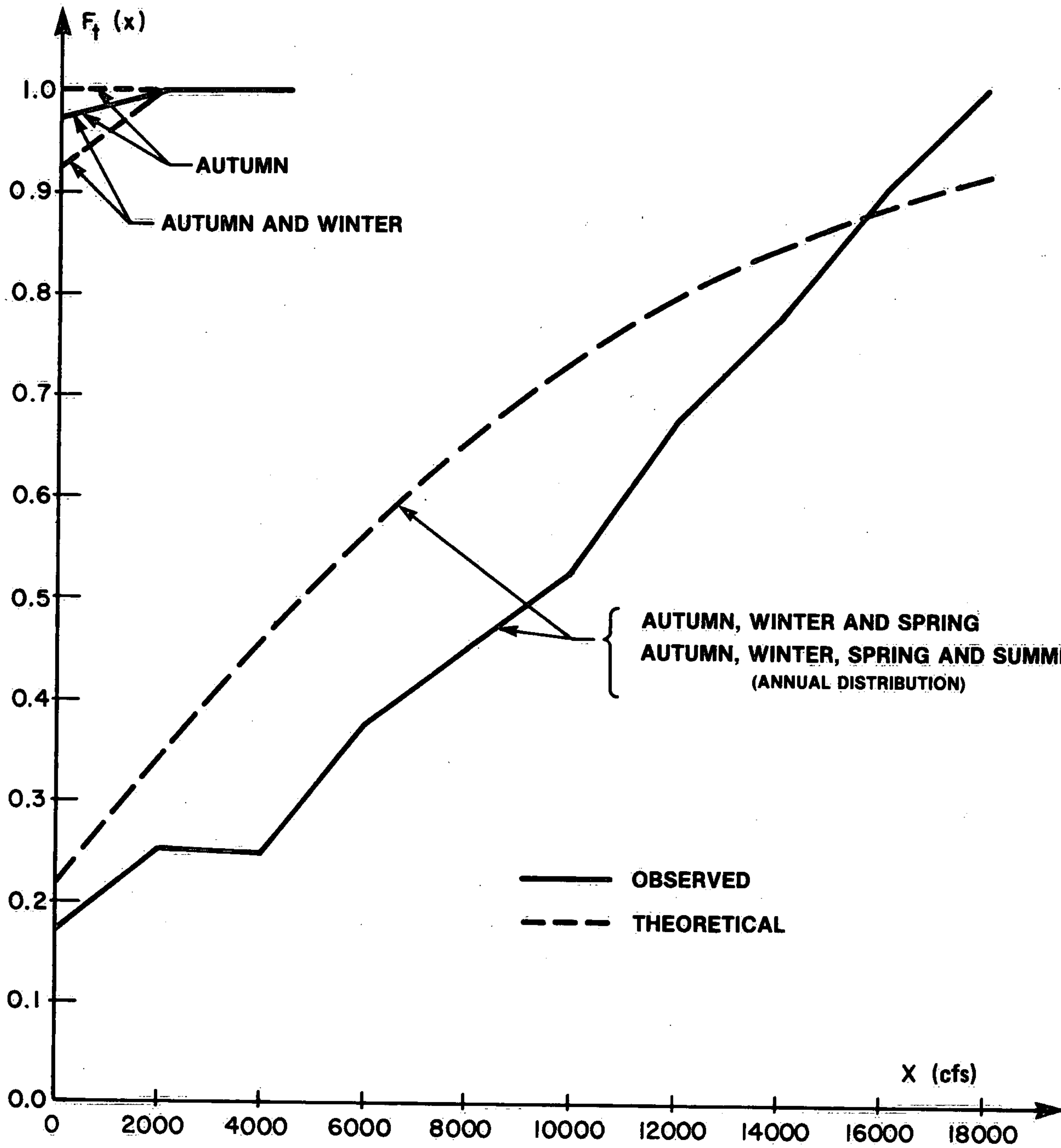

Figure 3.4. Observed and theoretical distributions of the maximum exceedance for various seasonal combinations.

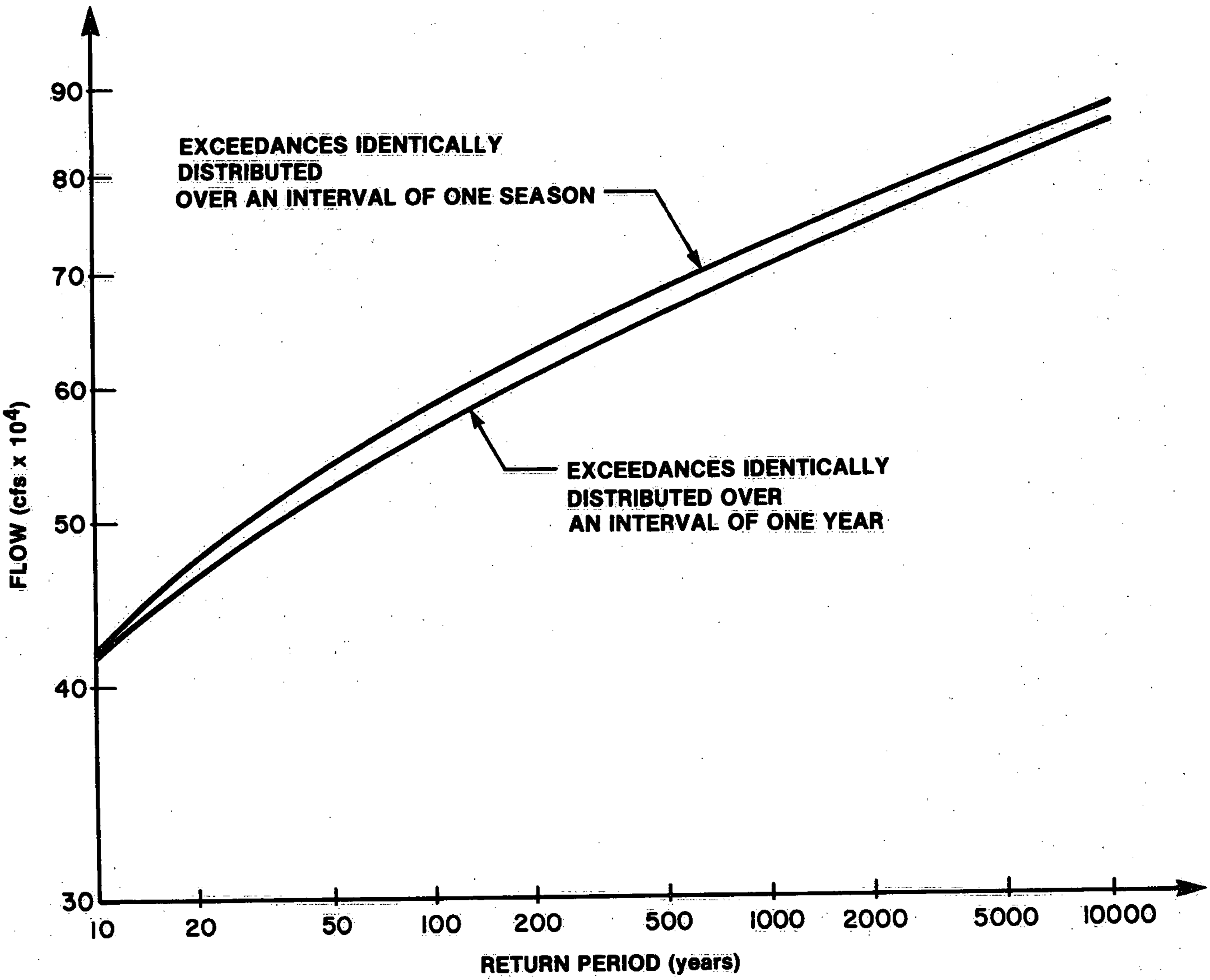

Figure 3.5. Return period as a function of the flow.

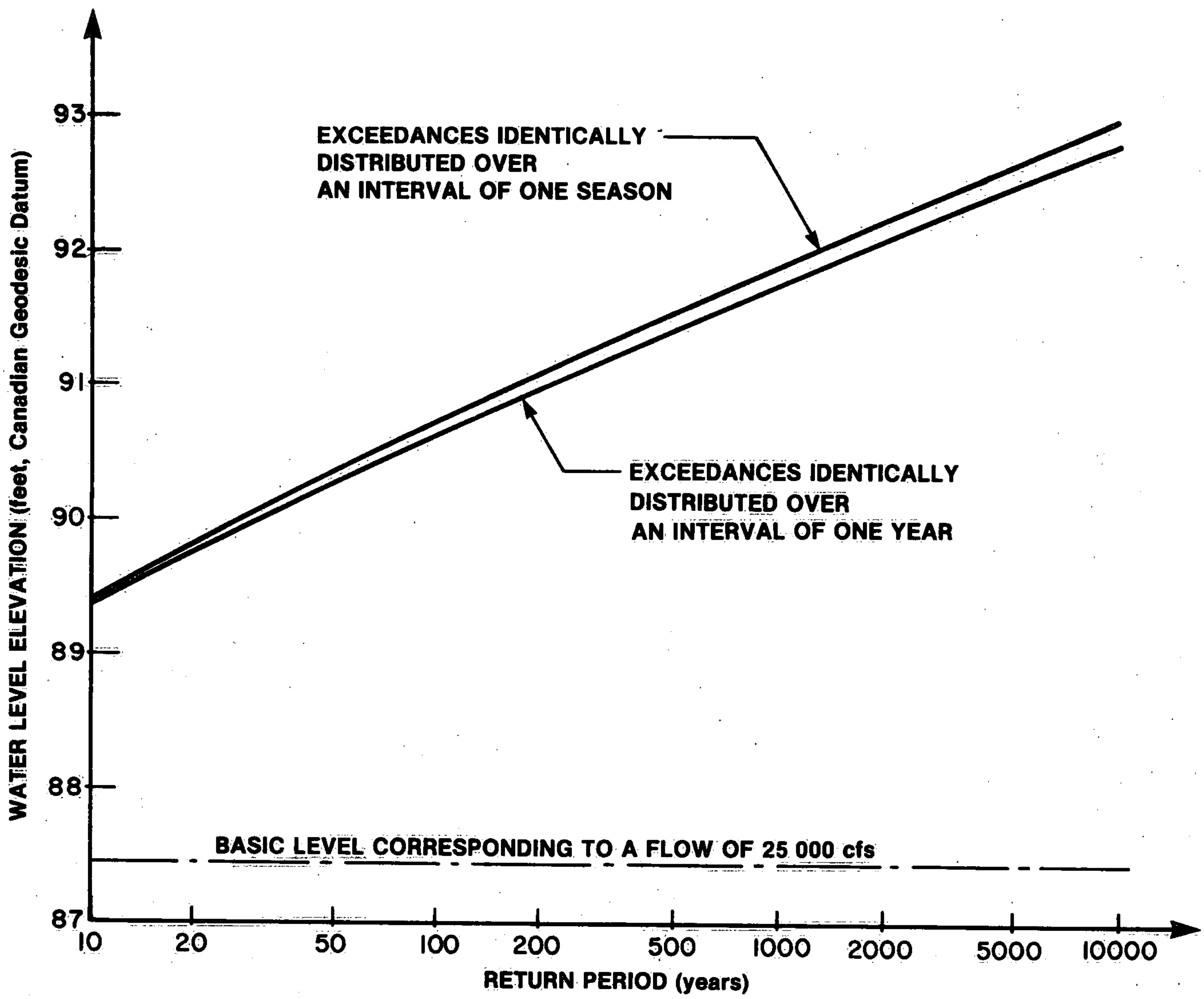

Figure 3.6. Return period as a function of the water level.

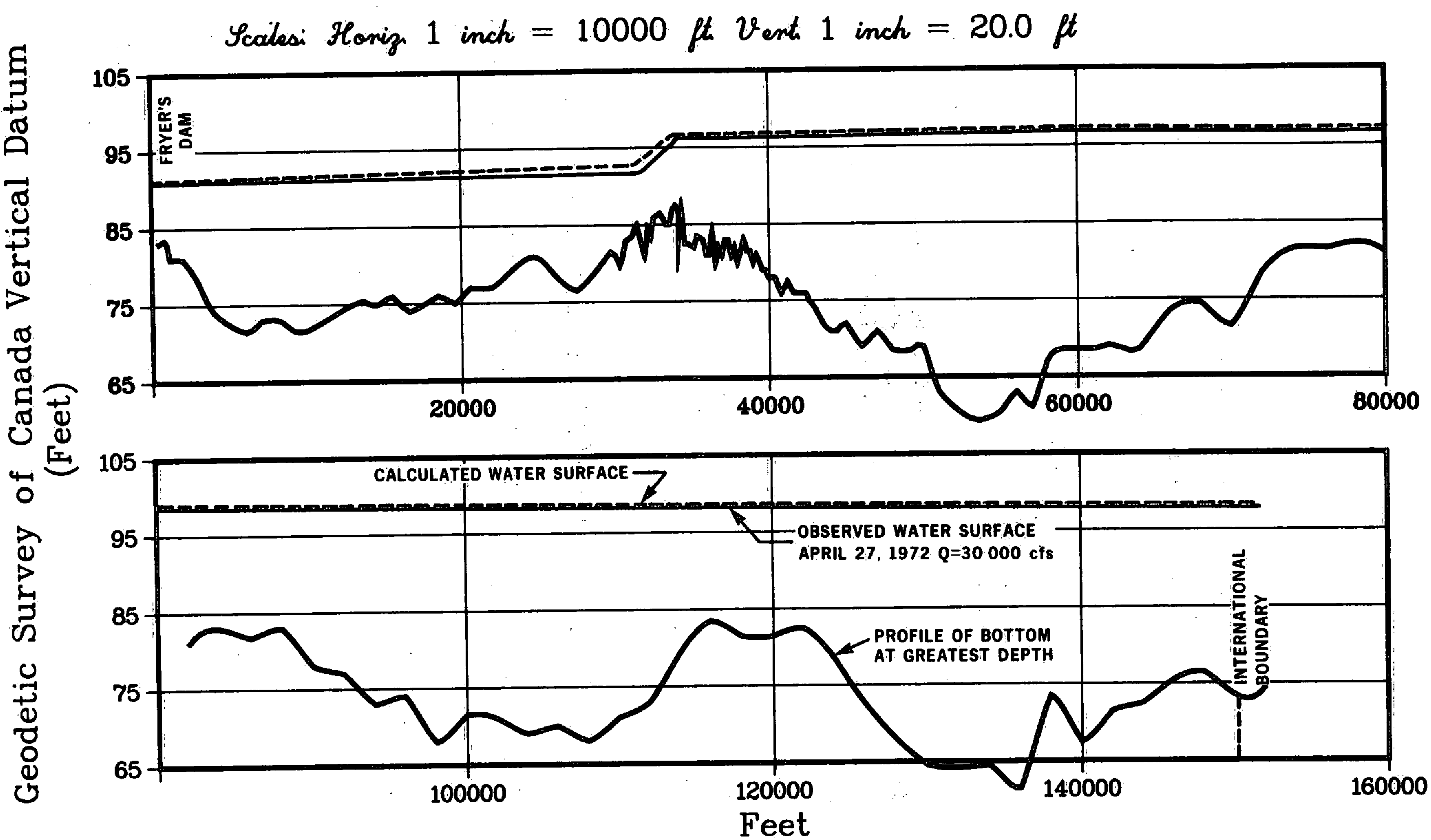

Figure 3.7. Adjustment of the observed and computed water lines for a flow of Q = 30 000 cfs, estimation of Manning coefficients.

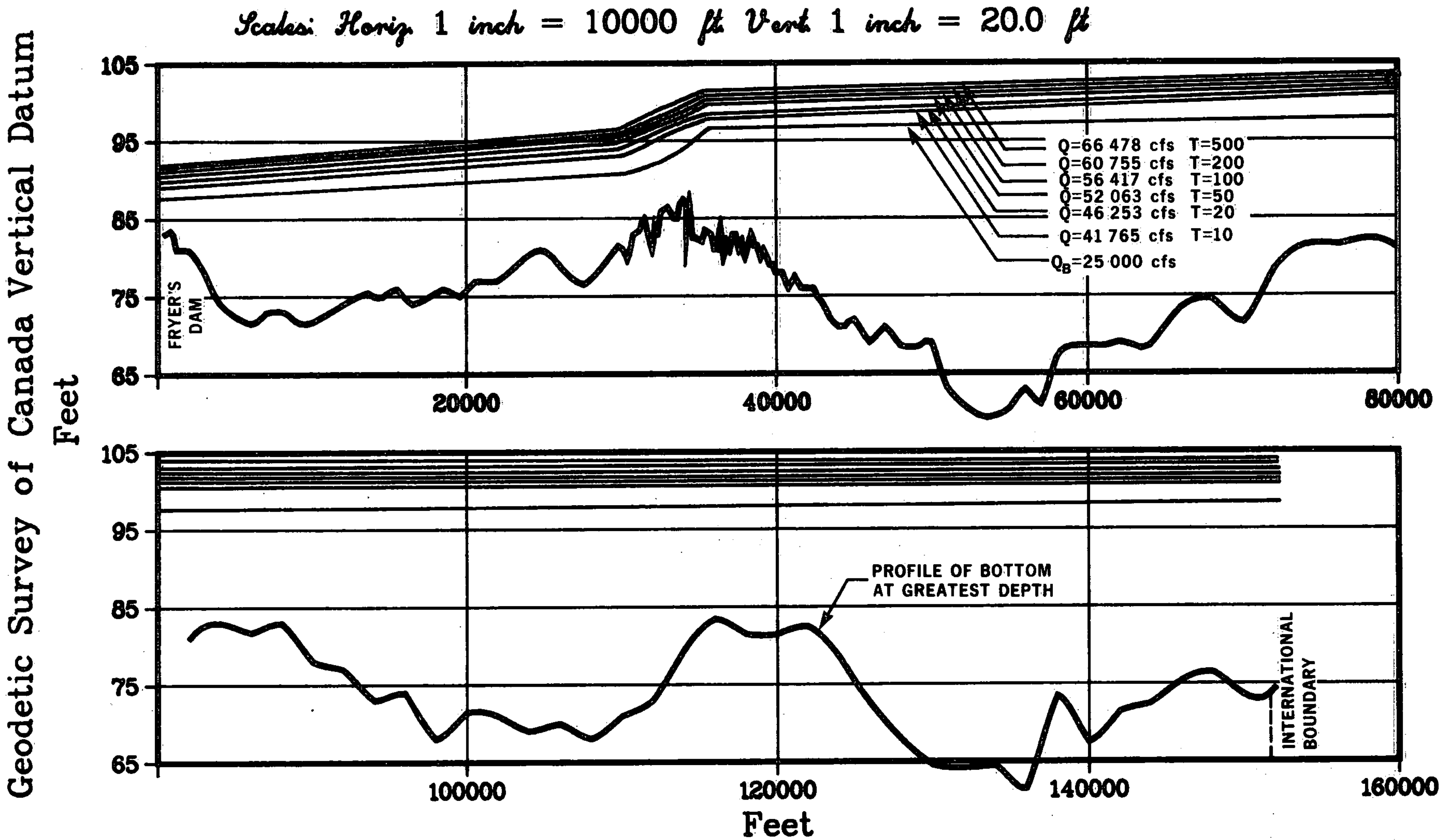

Figure 3.8. Backwater curves for flows of floods of various return periods, distribution of annual exceedances.

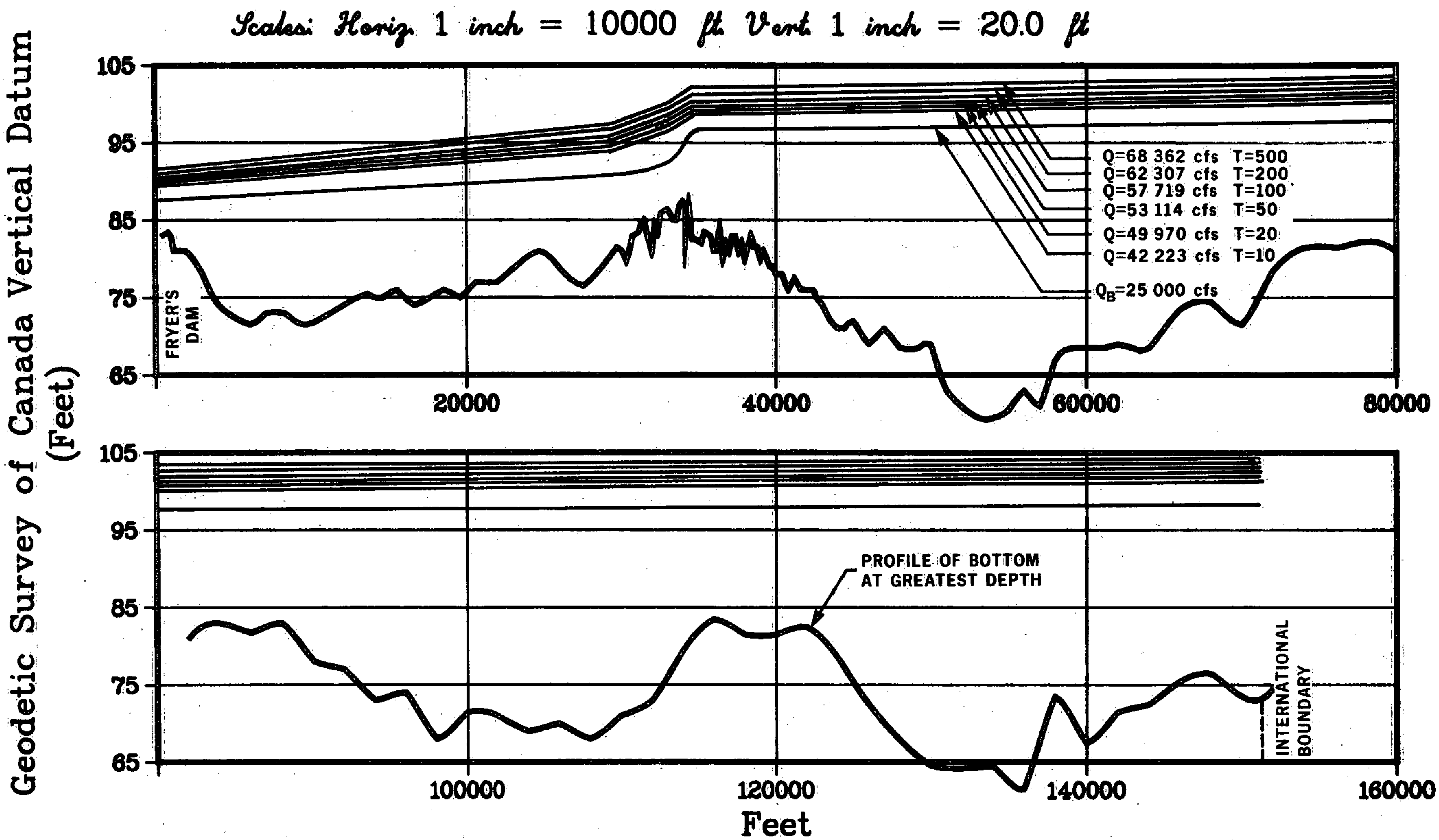

Figure 3.9. Backwater curves for flows of floods of various return periods, distribution of seasonal exceedances.

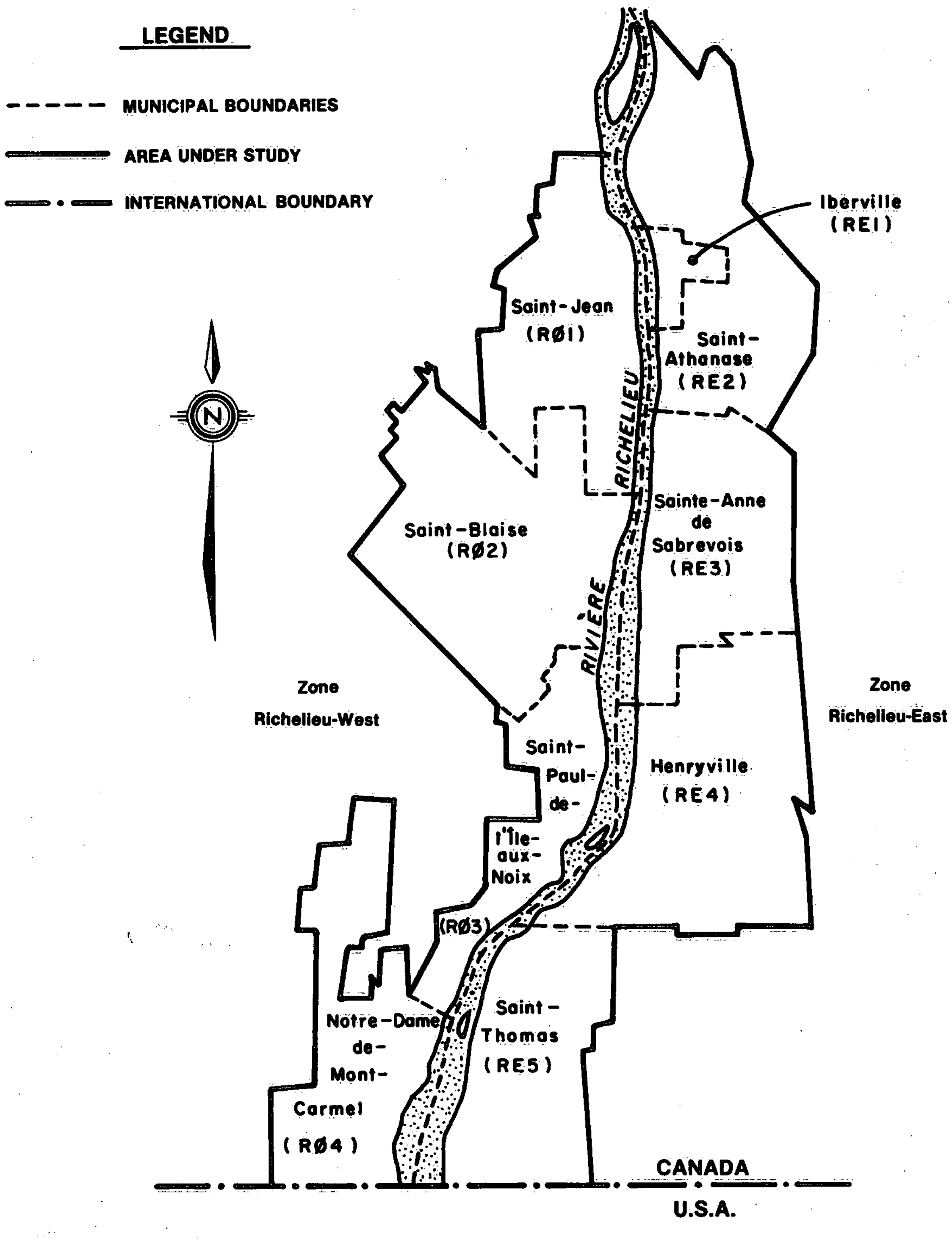

Figure 3.10. Municipal administrative division of the area under study.

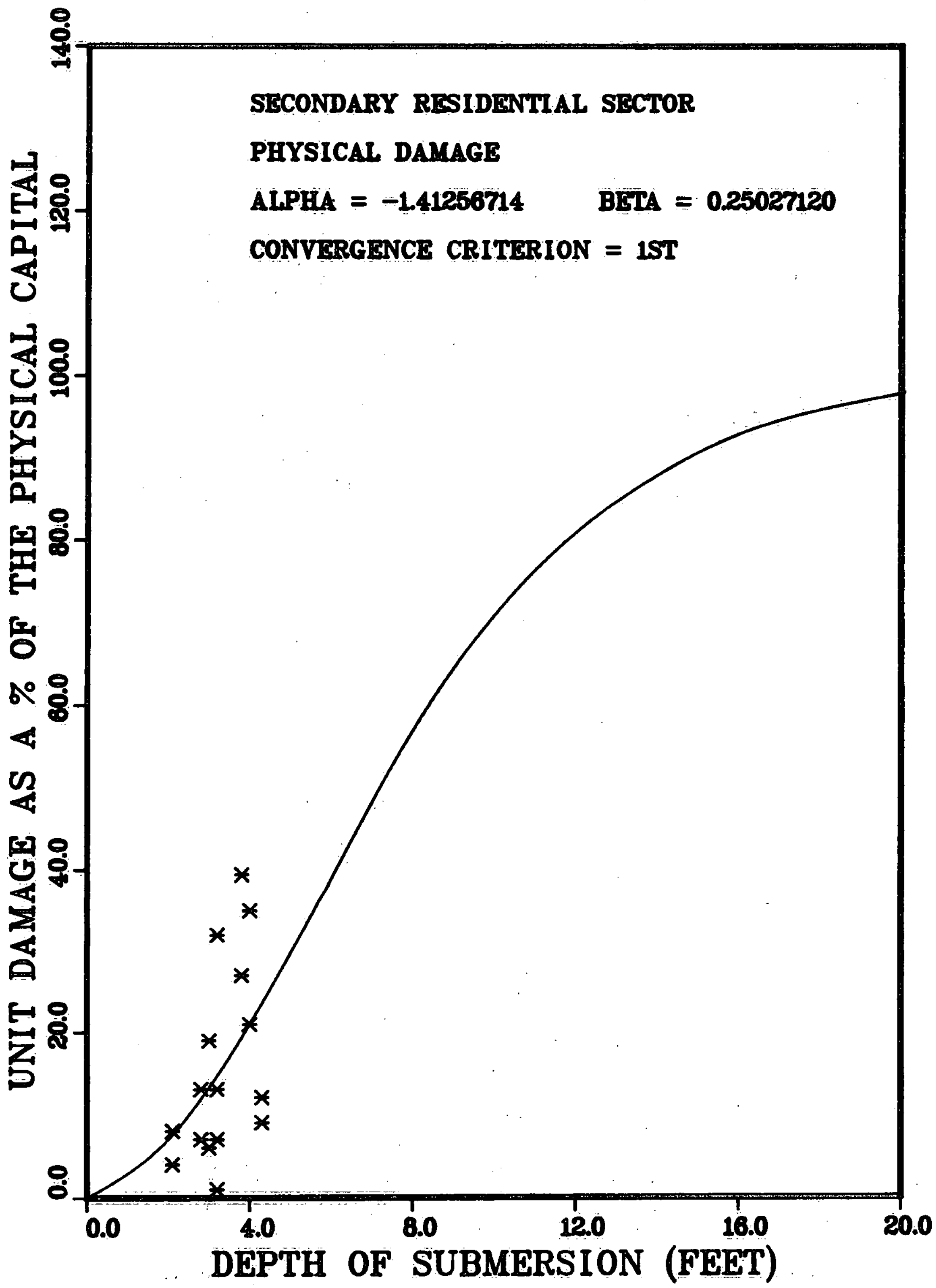

Figure 3.11. Total damage function, SRS*D010.

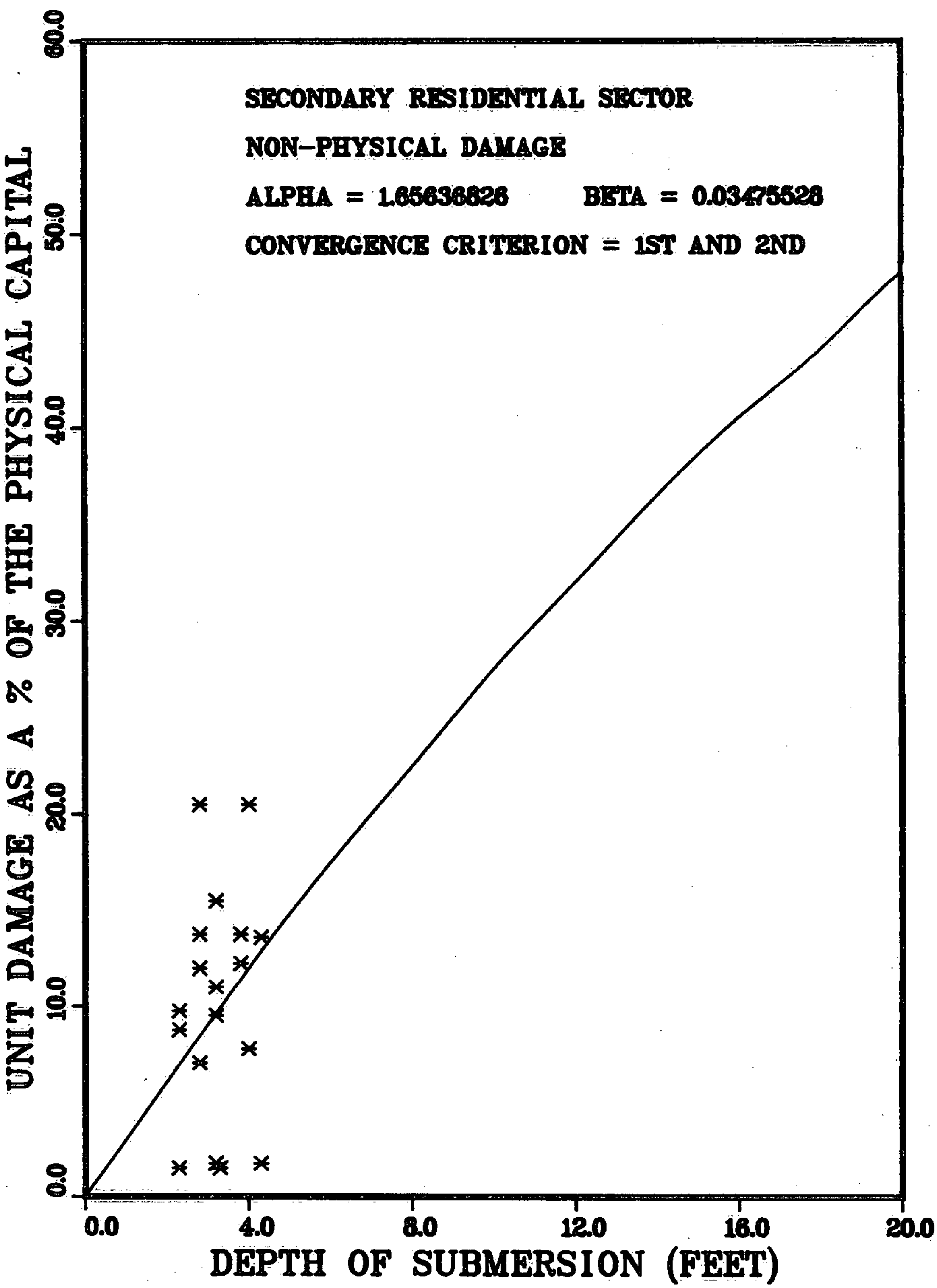

Figure 3.12. Total damage function, SRS*D020.

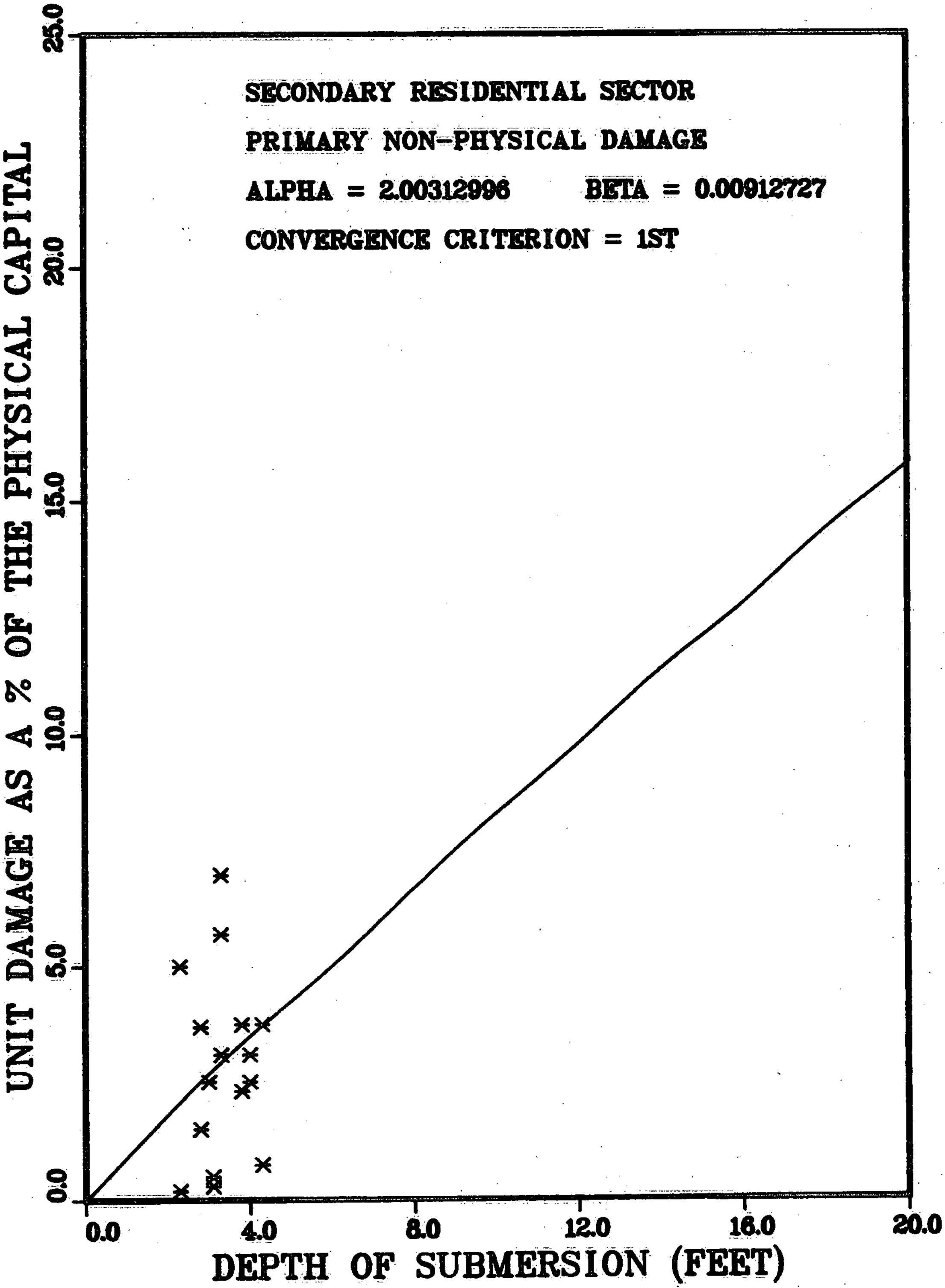

Figure 3.13. Total damage function, SRS*D021.

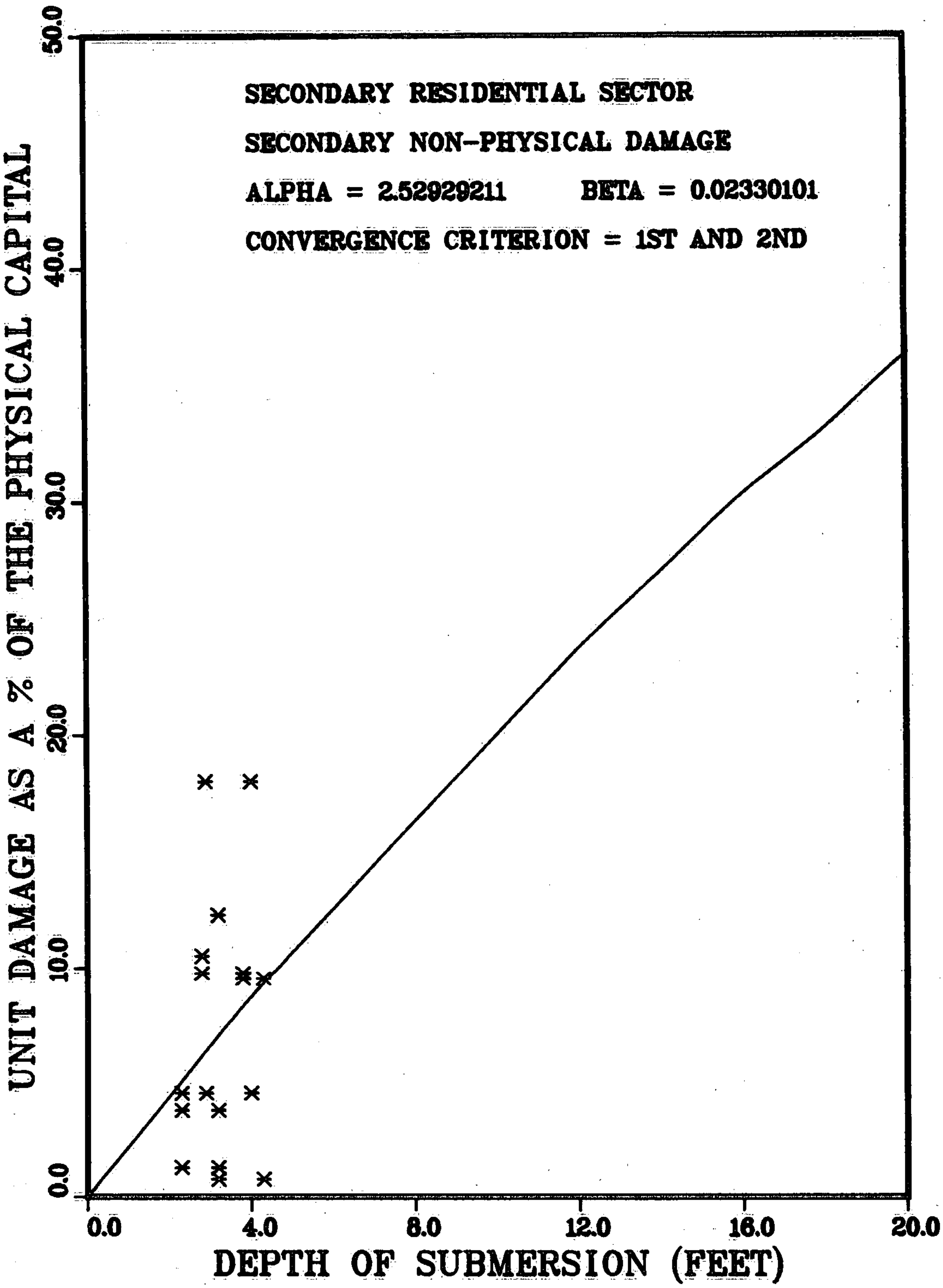

Figure 3.14. Total damage function, SRS*D022.

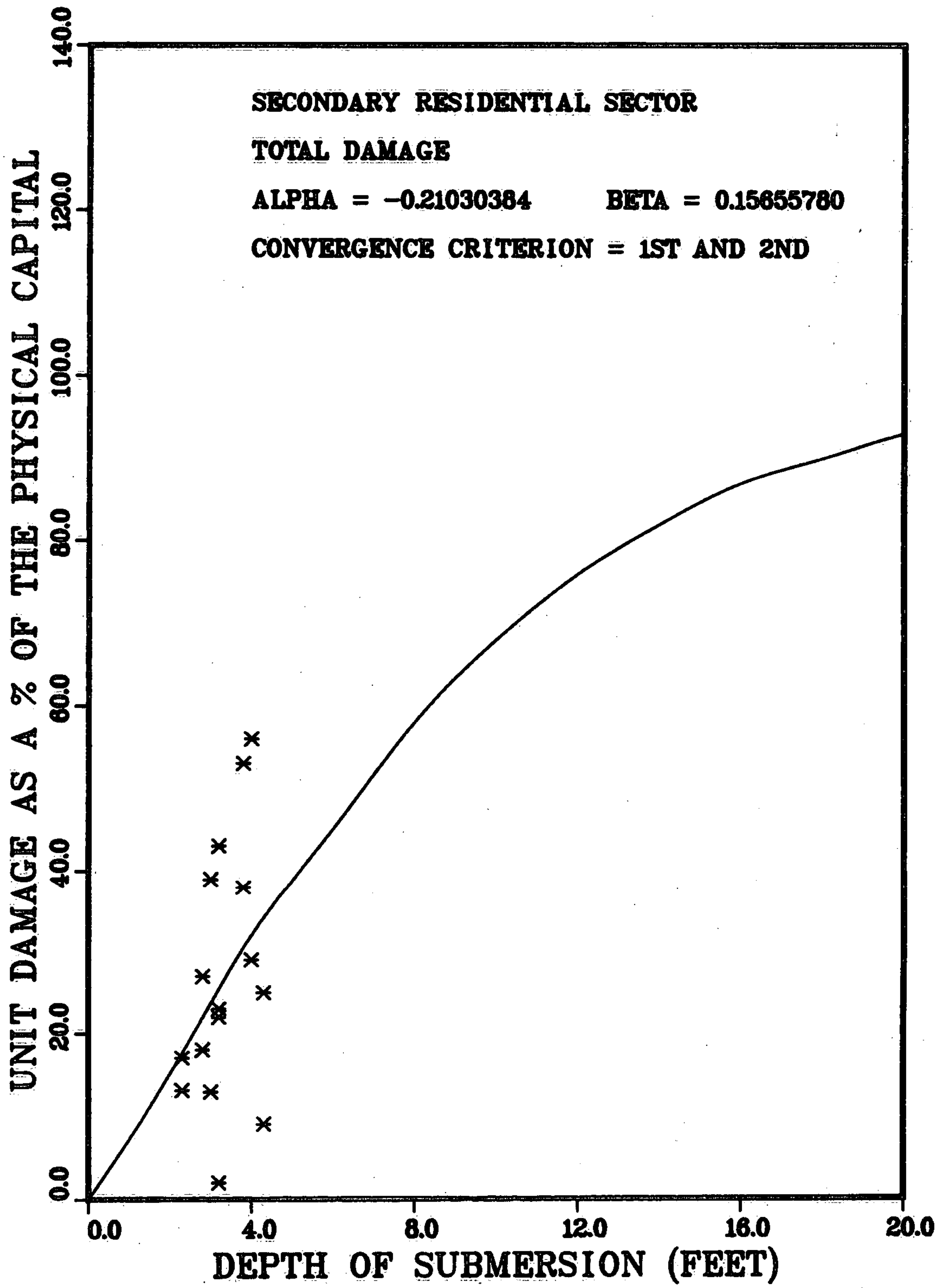

Figure 3.15. Total damage function, SRS*DTØT.

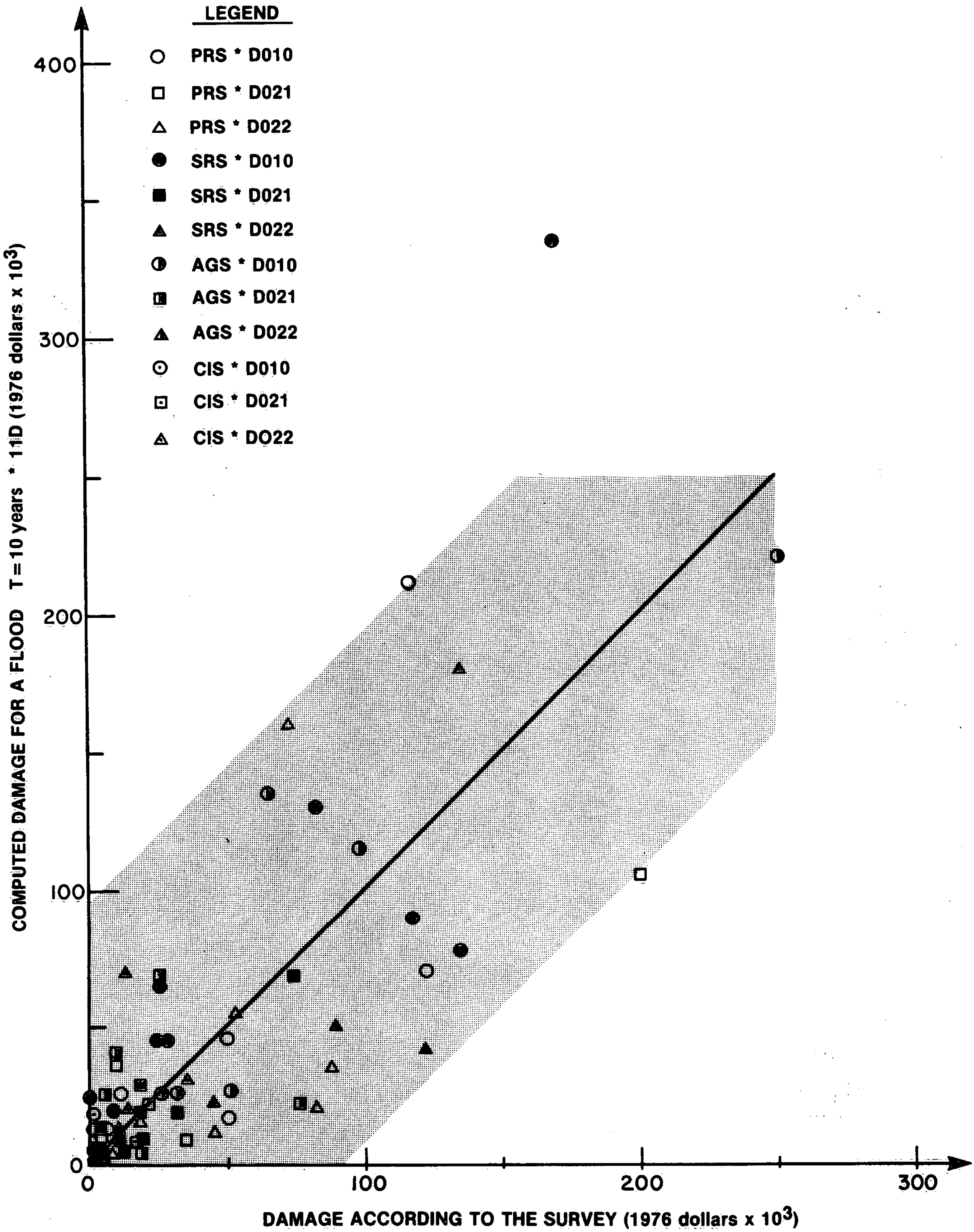

Figure 3.16. Comparison between observed and computed values for a flood T = 10, (IID).

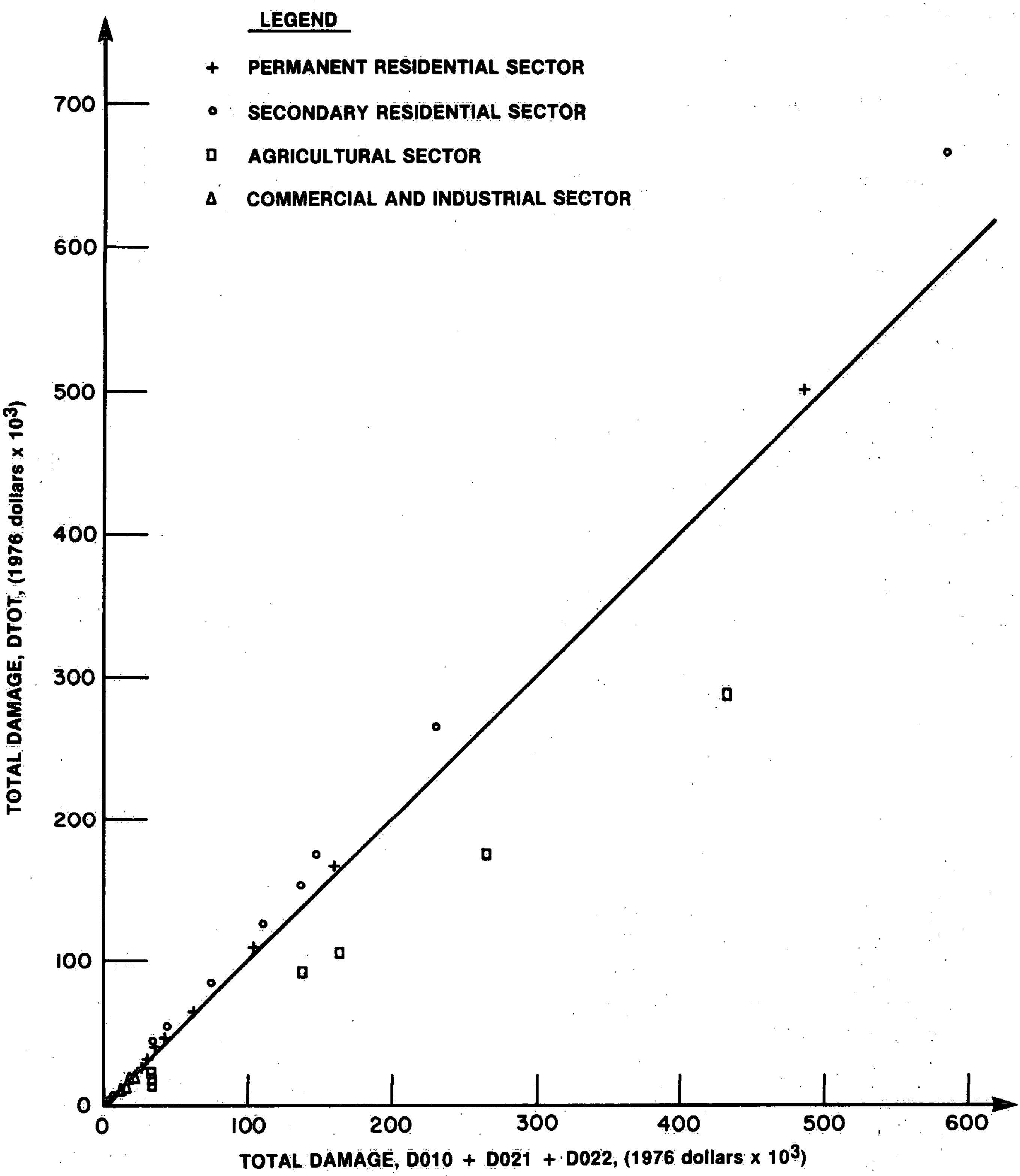

Figure 3.17. Comparison between total damage and the sum of its components.

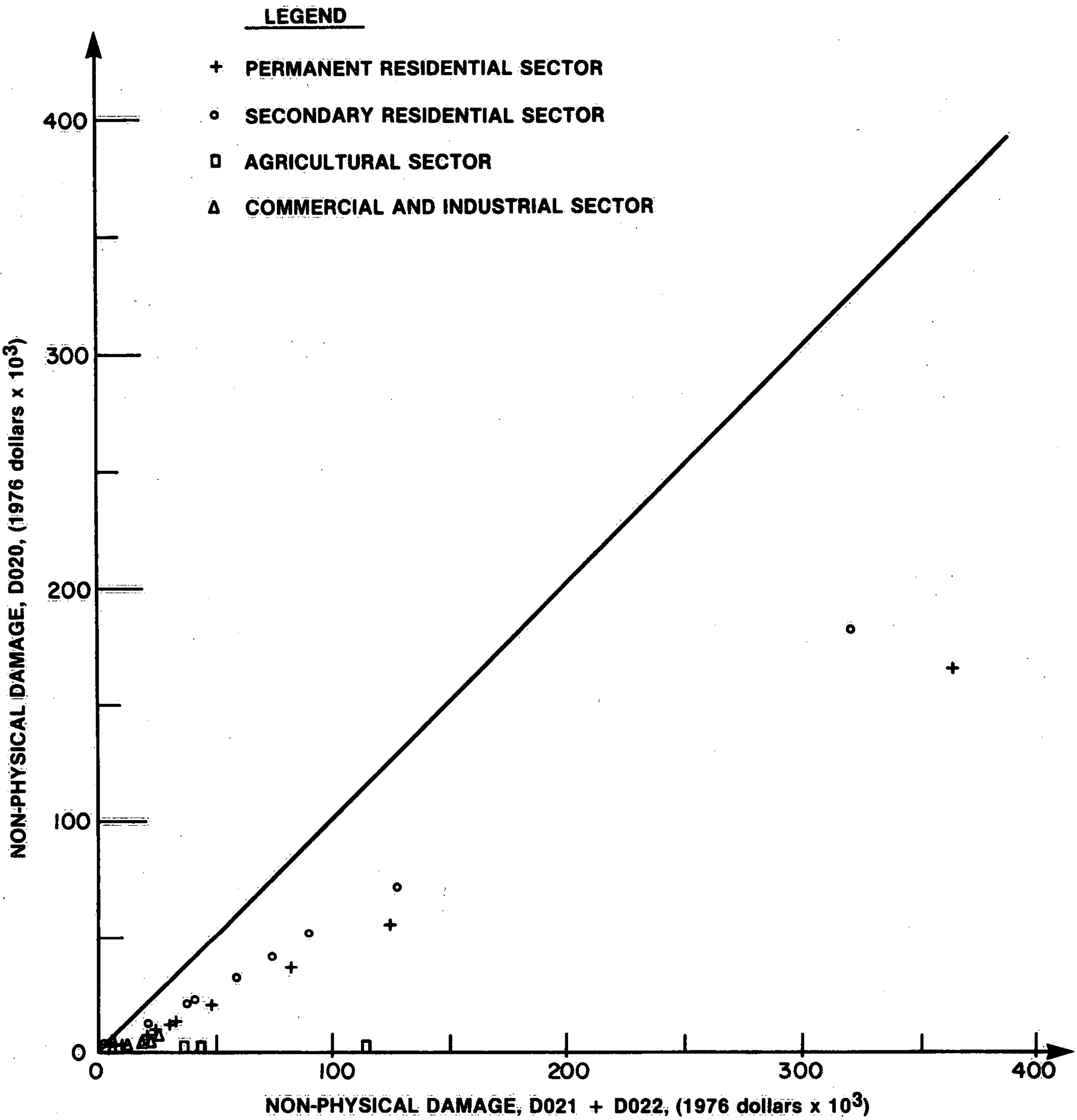

Figure 3.18. Comparison between non-physical damage and the sum of its primary and secondary components.

Appendix A
Total Damage Function

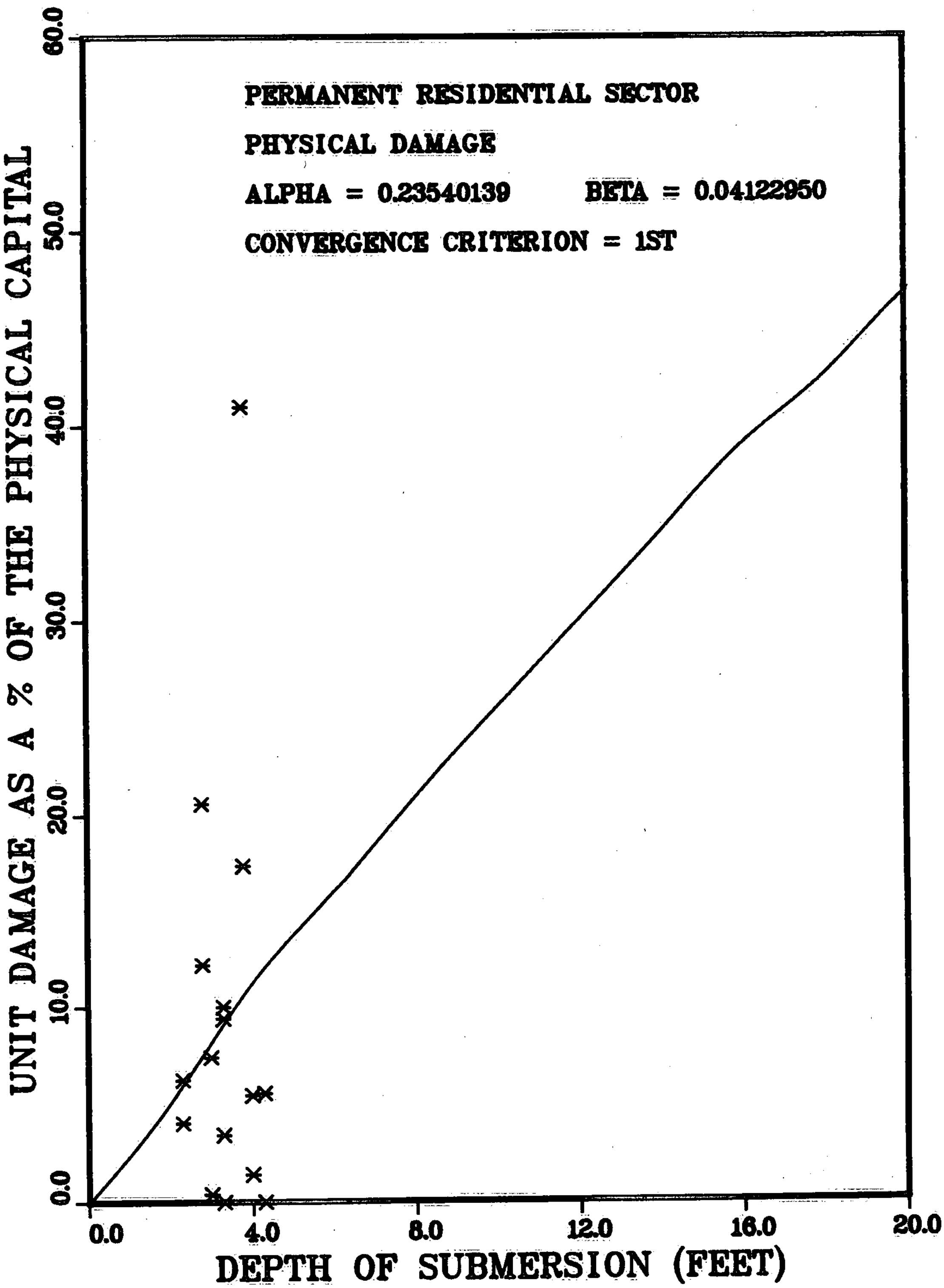

Figure A.1. Total damage function, PRS*D010.

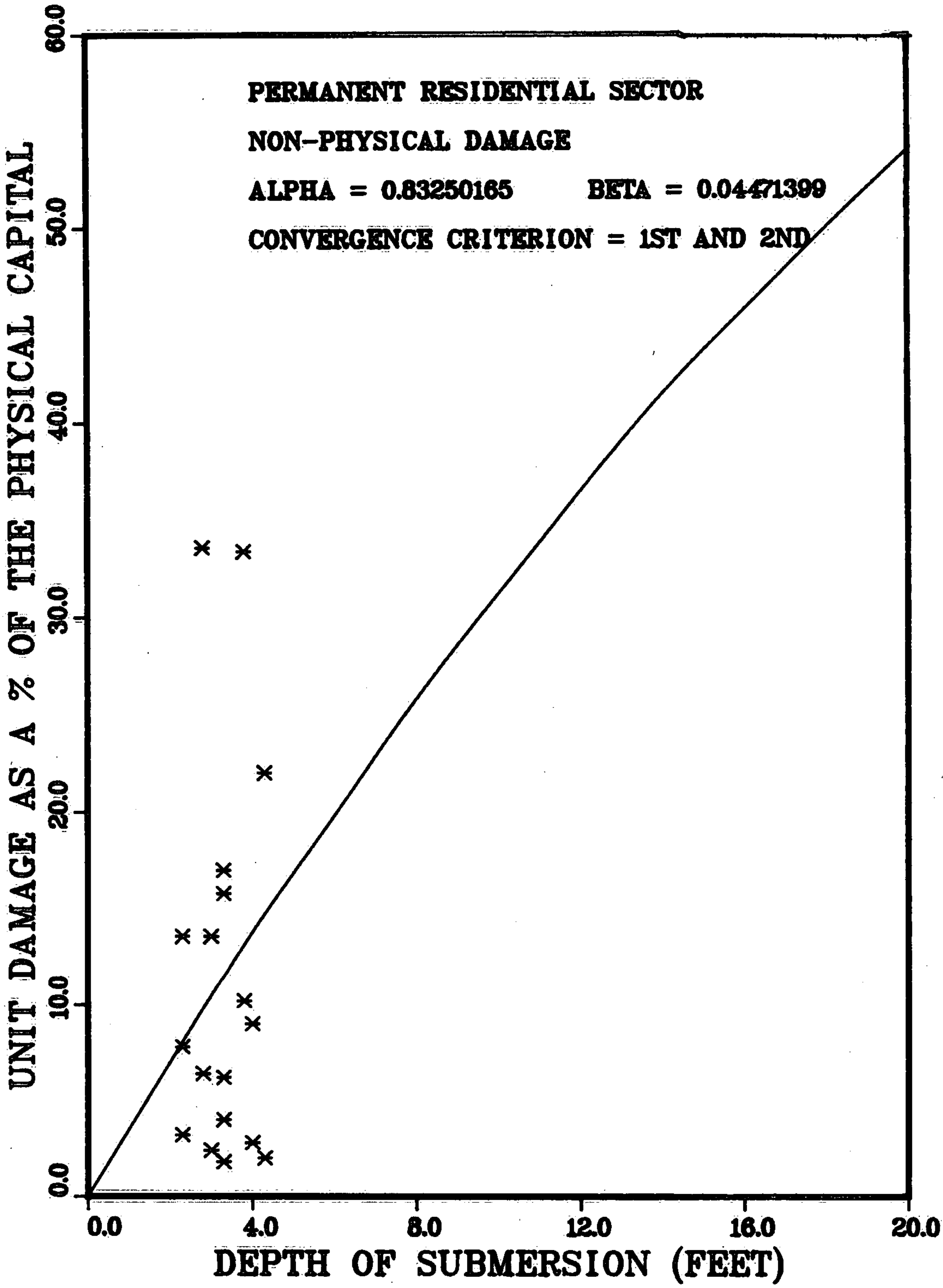

Figure A.2. Total damage function, PRS*D020.

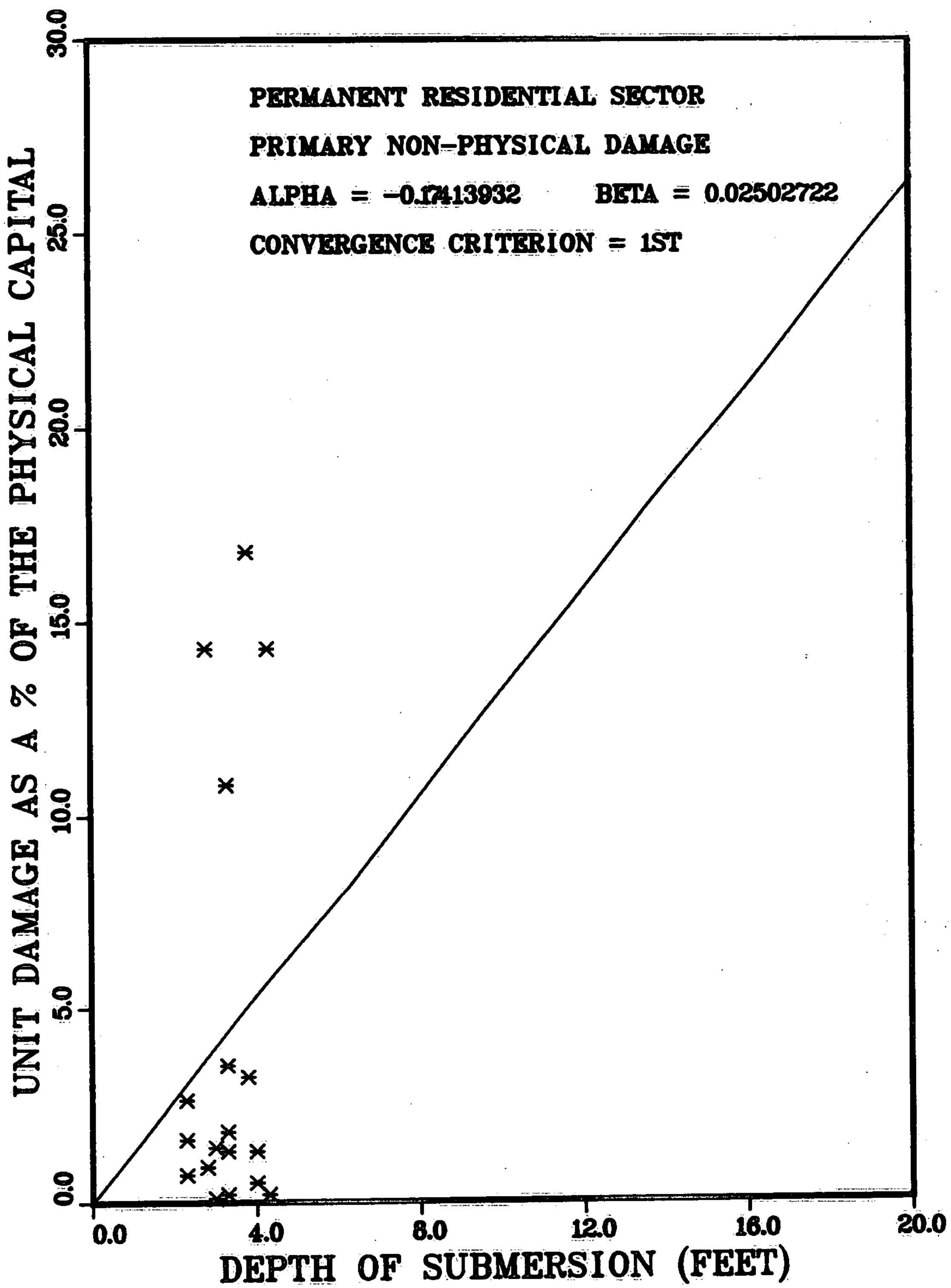

Figure A.3. Total damage function, PRS*D021.

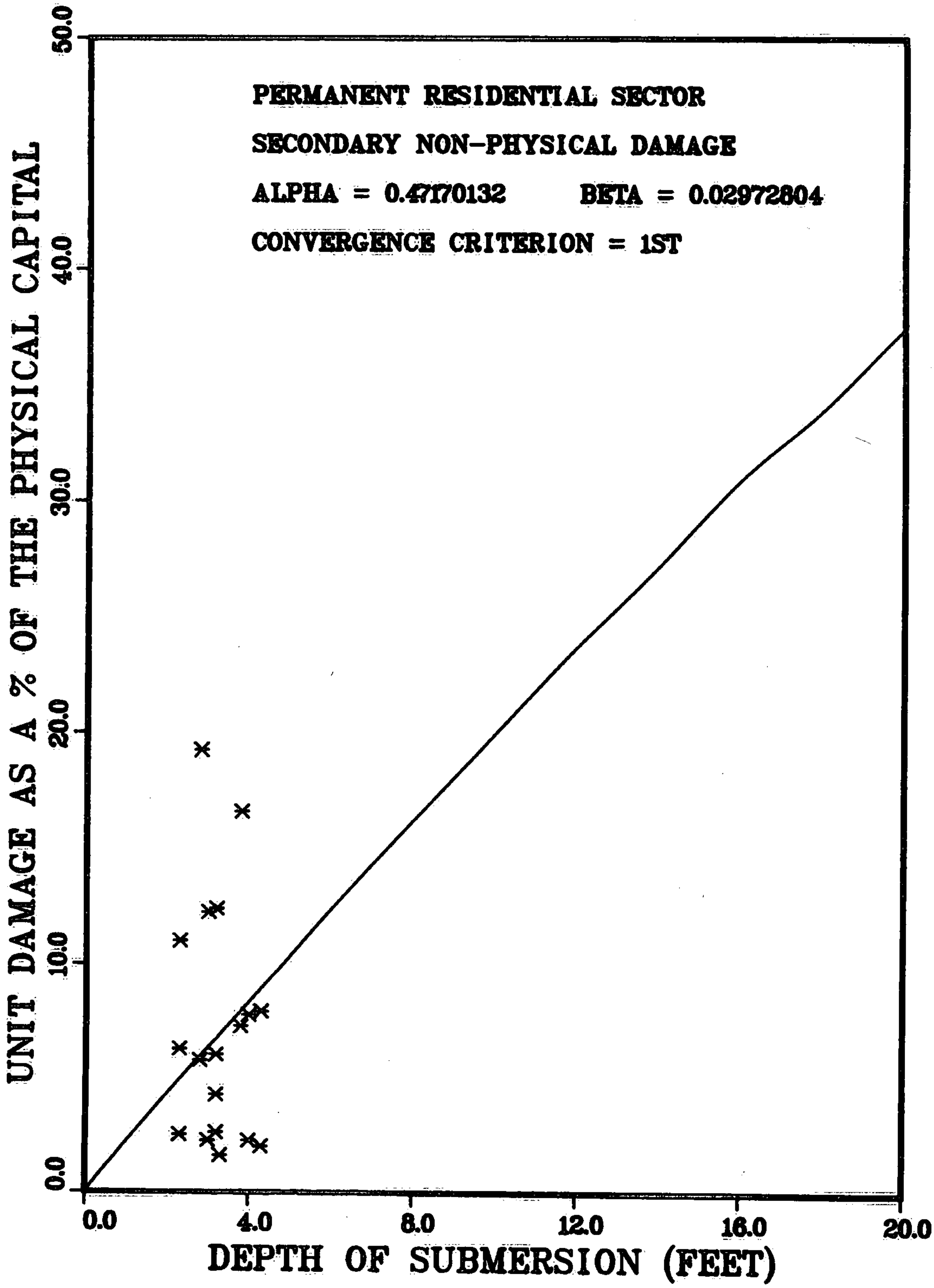

Figure A.4. Total damage function, PRS*D022.

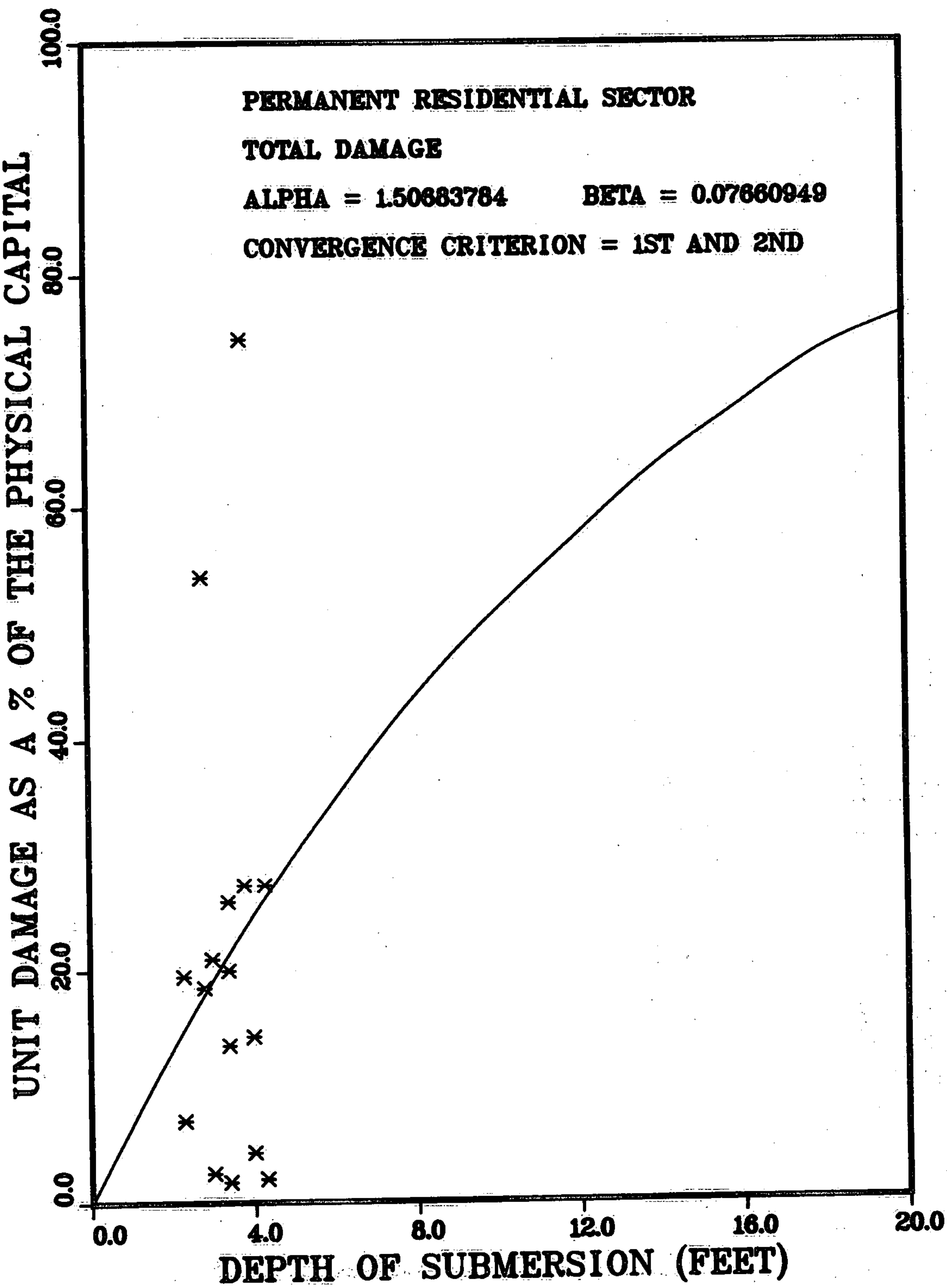

Figure A.5. Total damage function, PRS*DTØT.

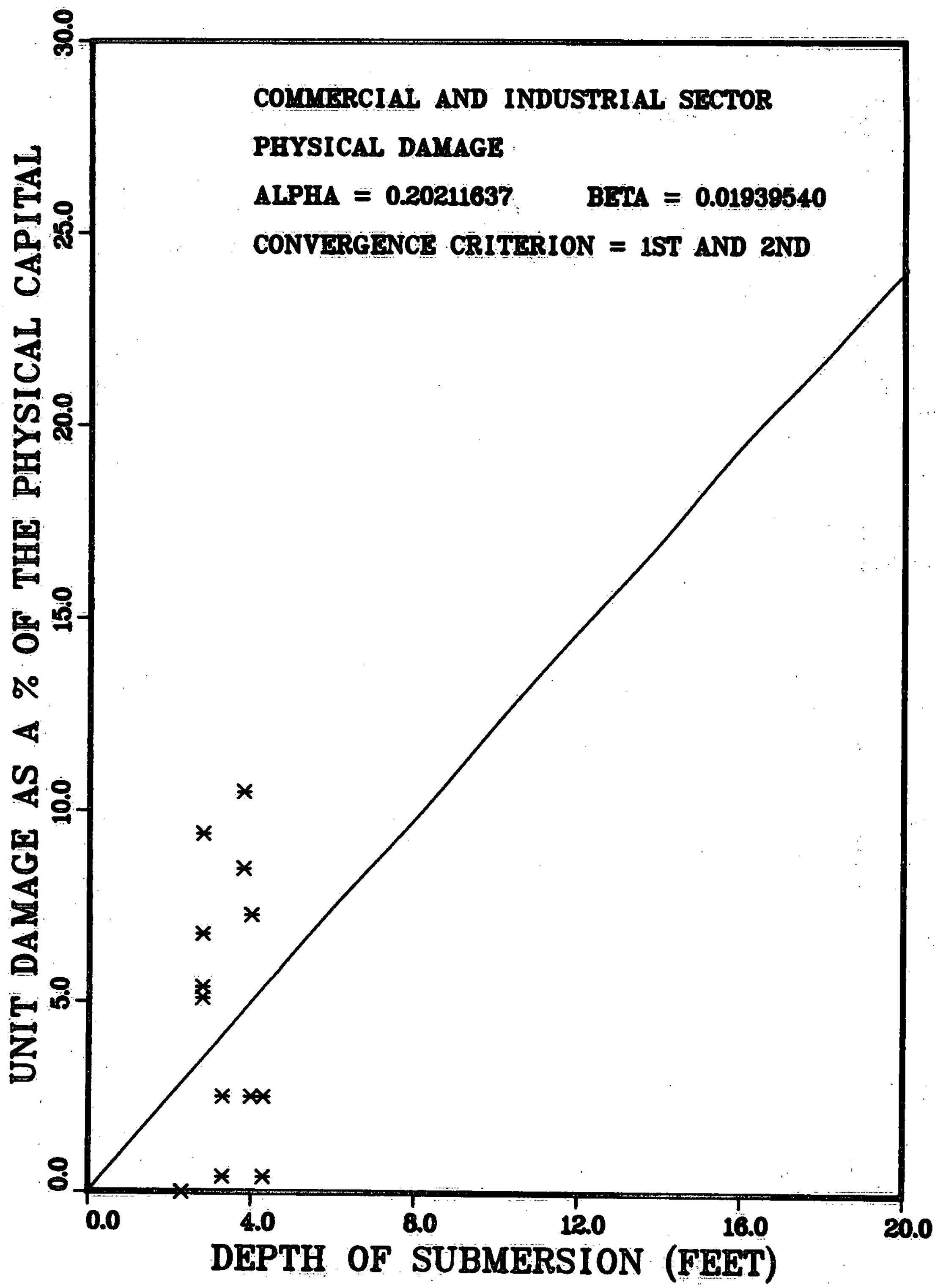

Figure A.6. Total damage function, CIS*D010.

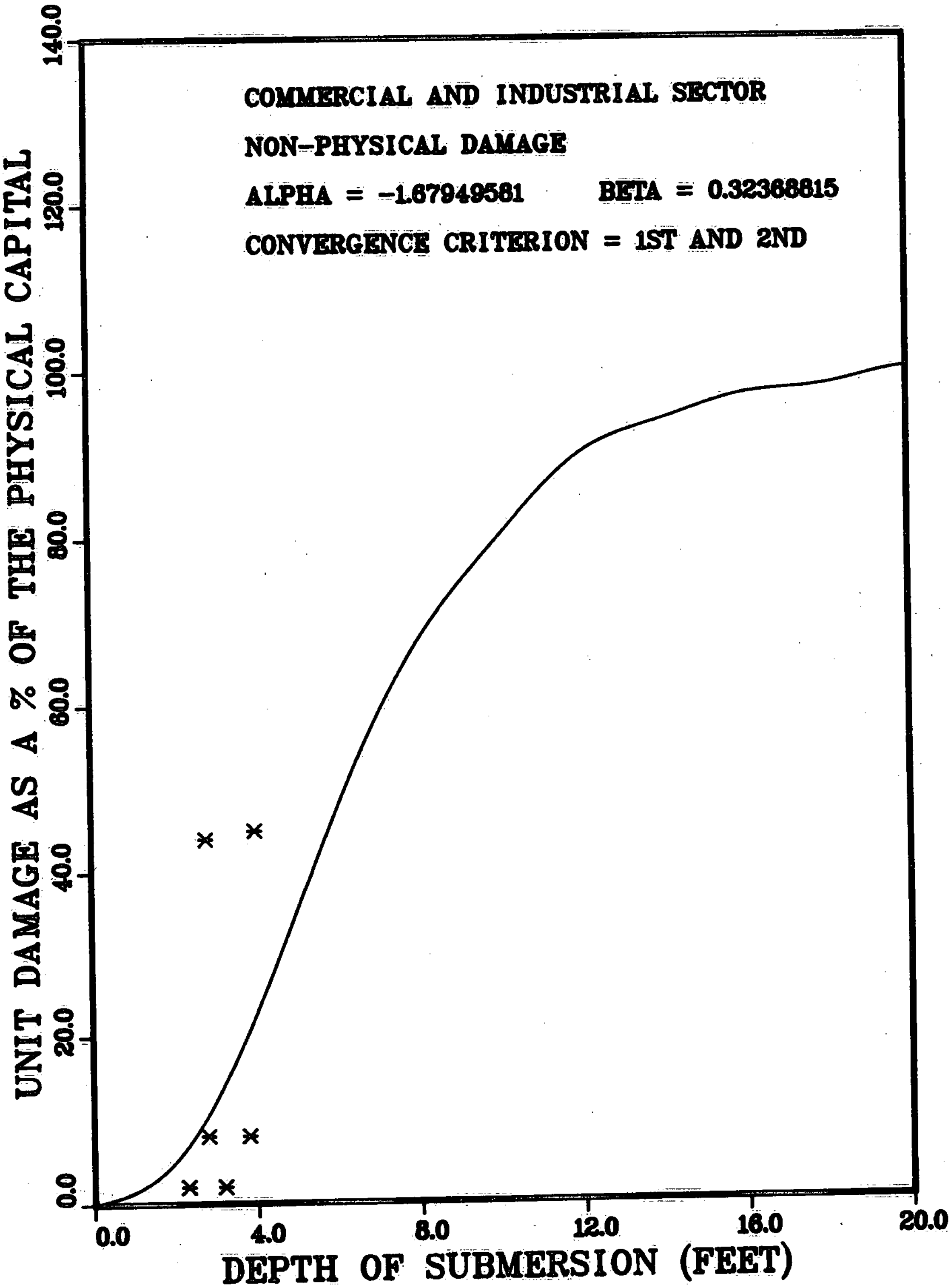

Figure A.7. Total damage function, CIS*D020.

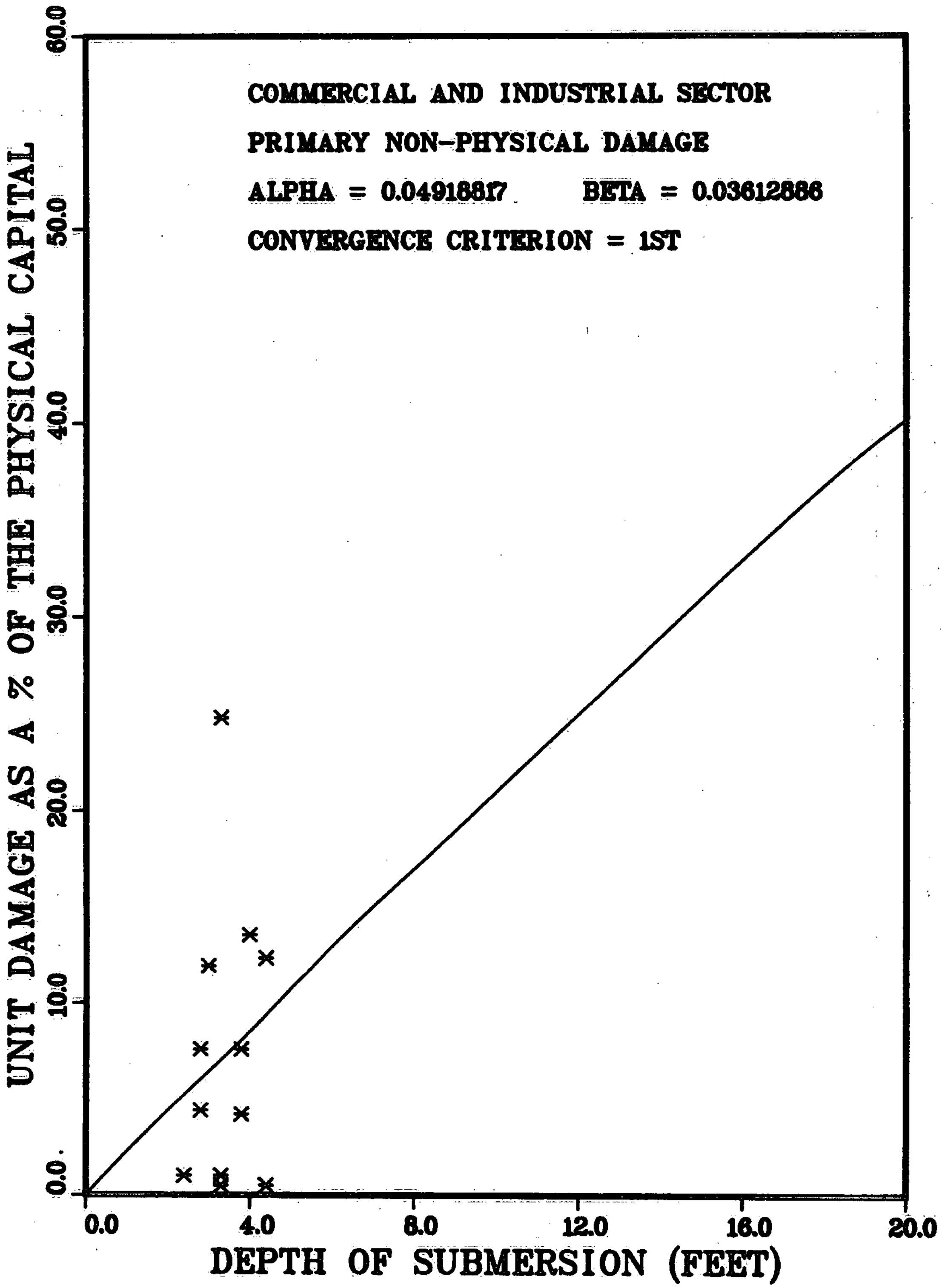

Figure A.8. Total damage function, CIS*D021.

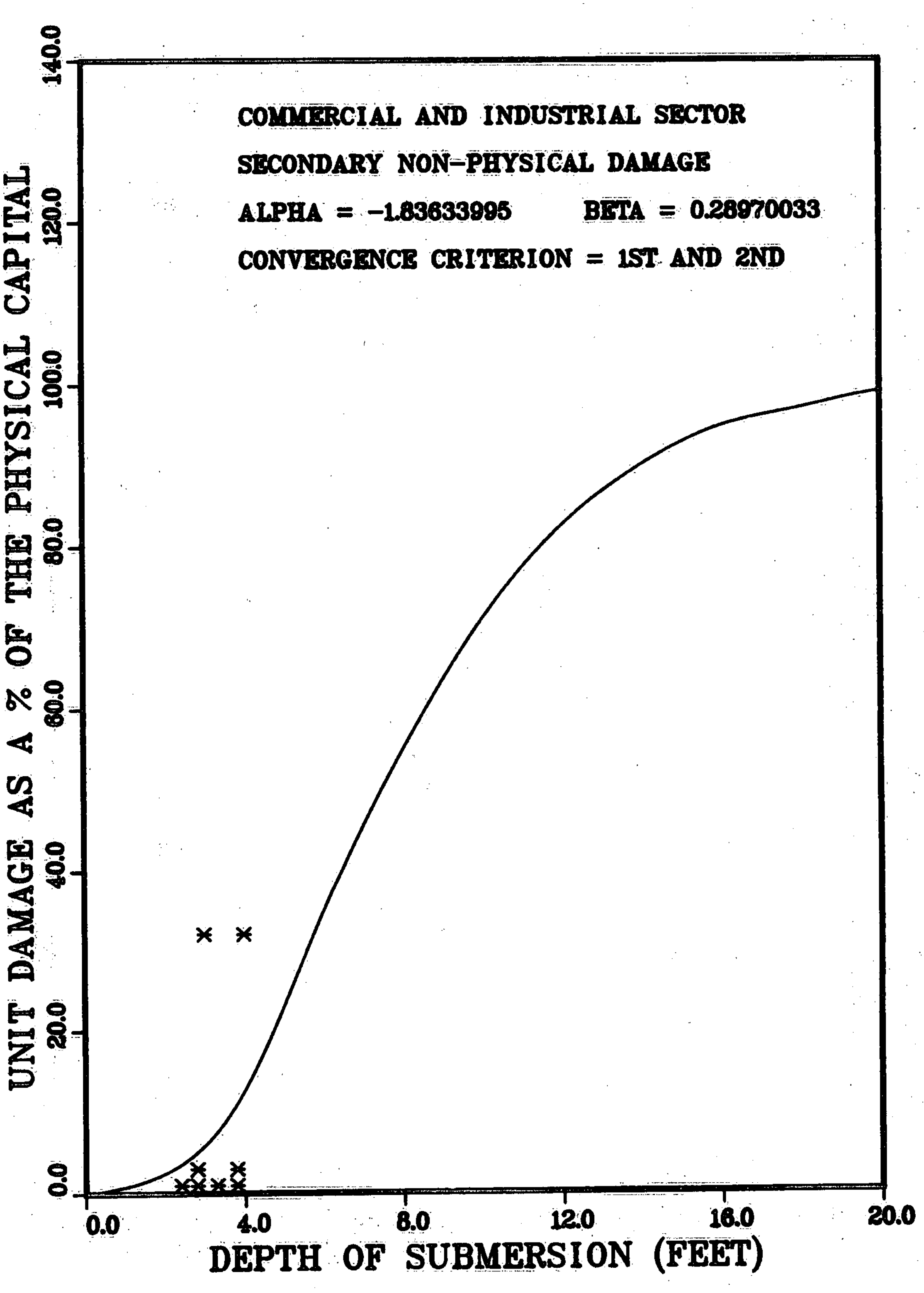

Figure A.9. Total damage function, CIS*D022.

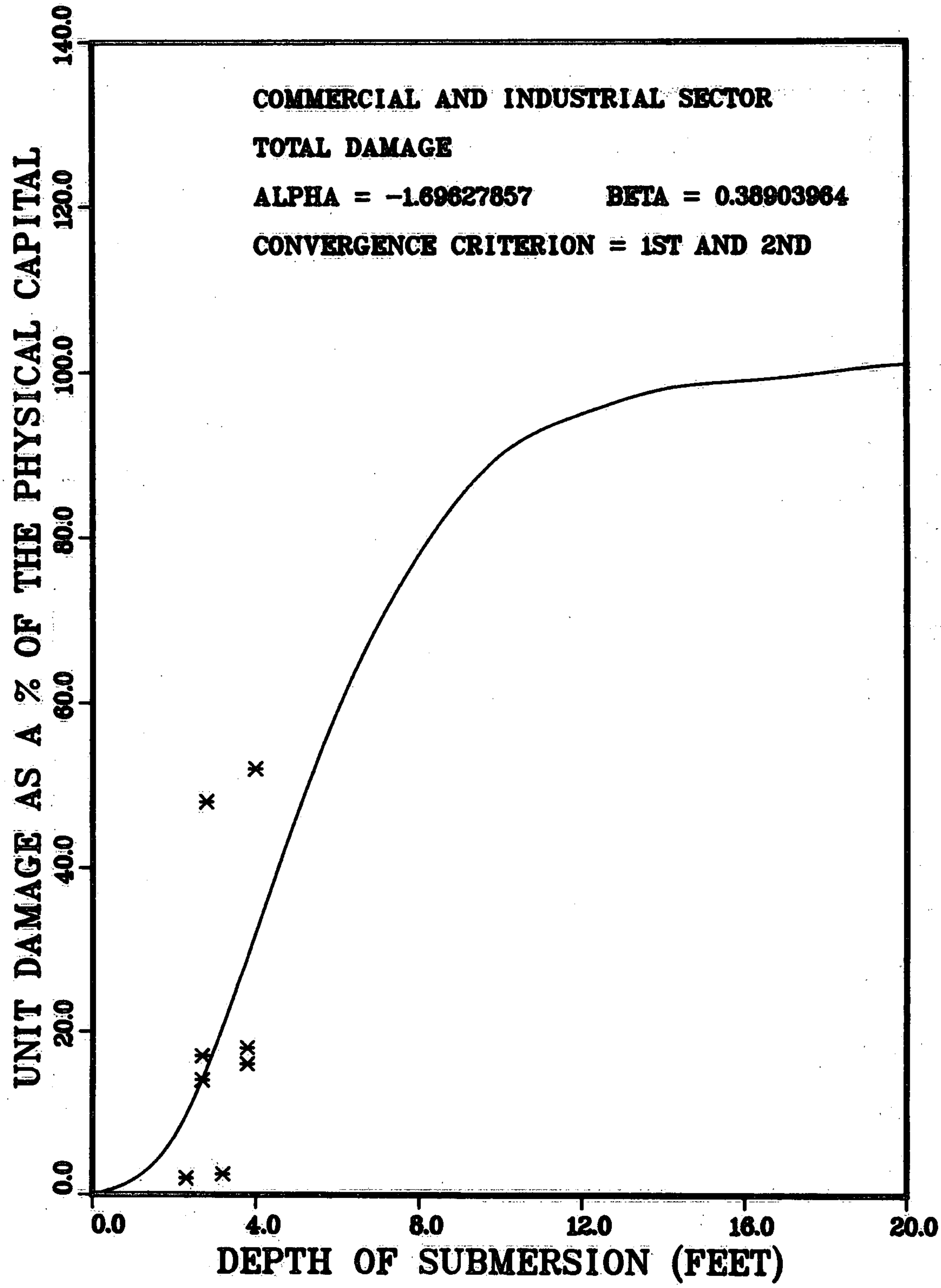

Figure A.10. Total damage function, CIS*DTØT.

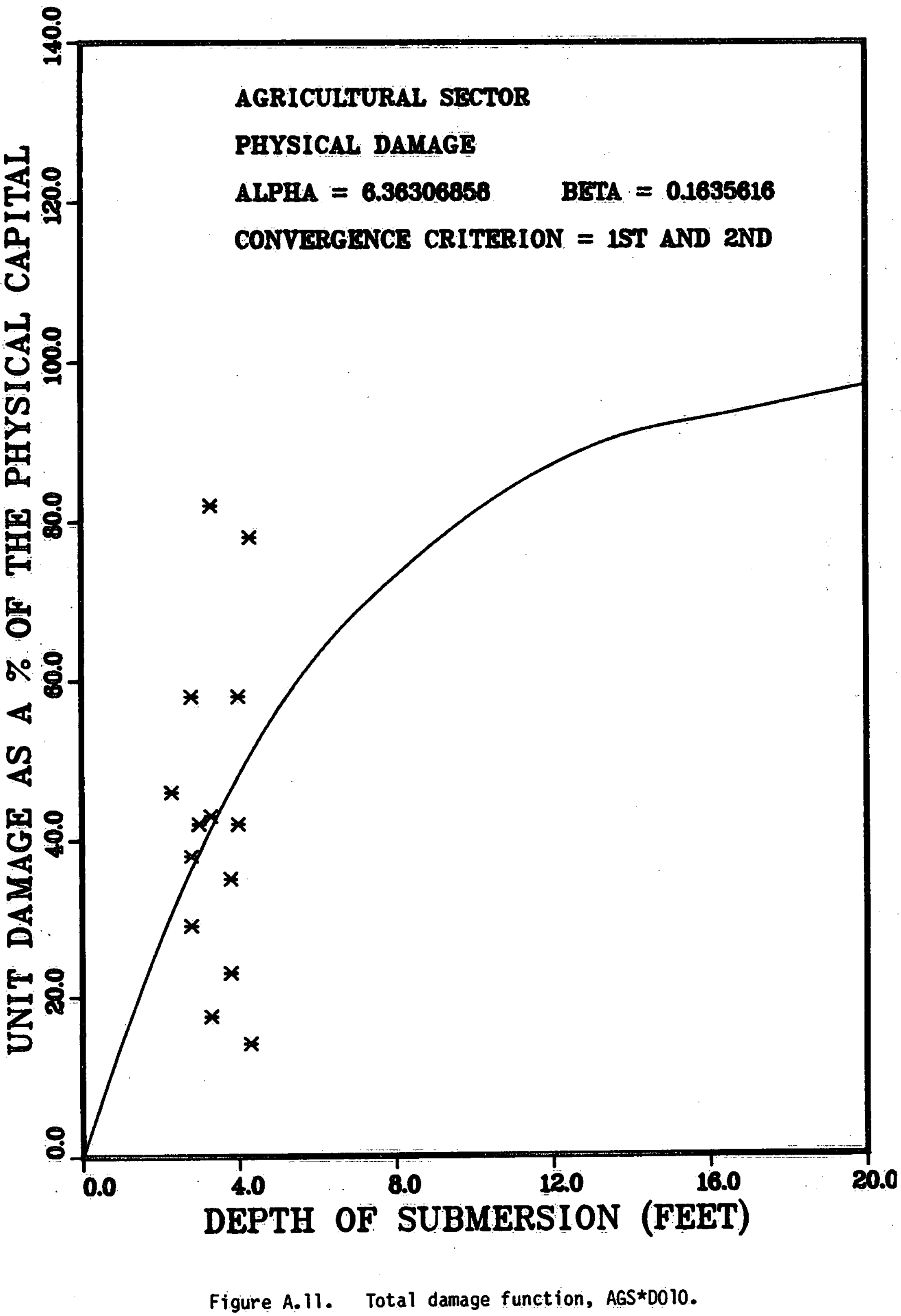

Figure A.11. Total damage function, AGS*D010.

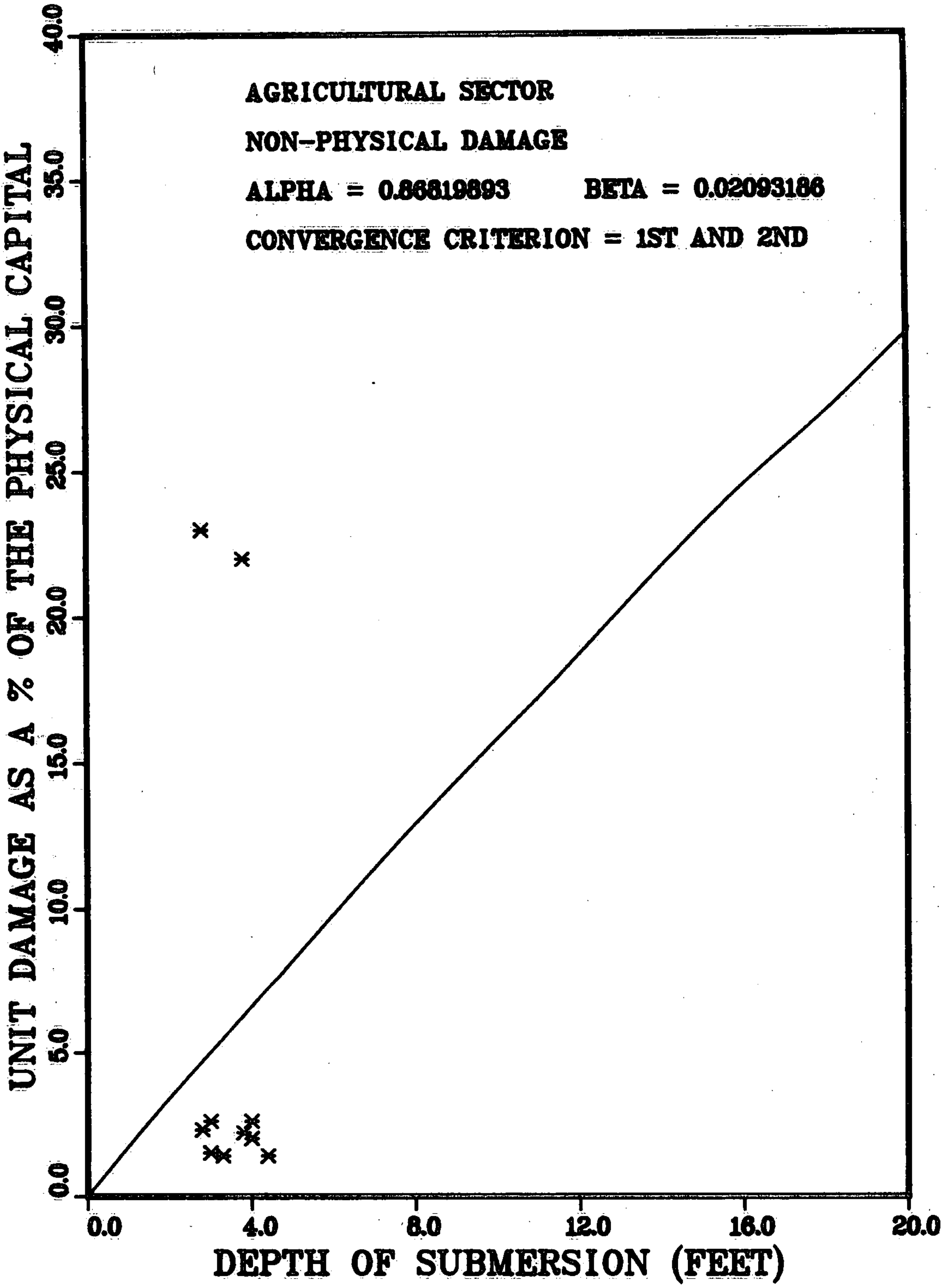

Figure A.12. Total damage function, AGS*D020.

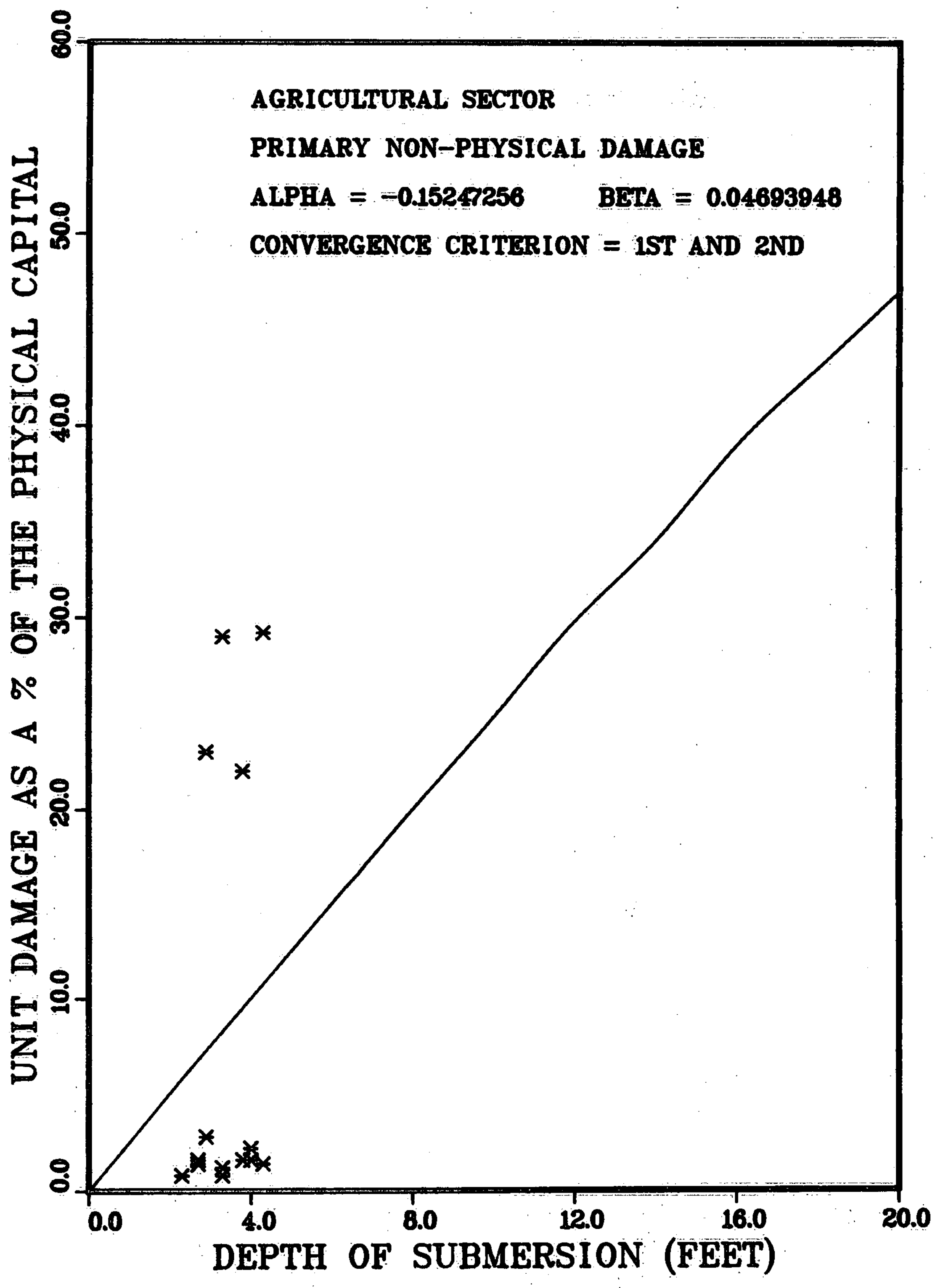

Figure A.13. Total damage function, AGS*D021.

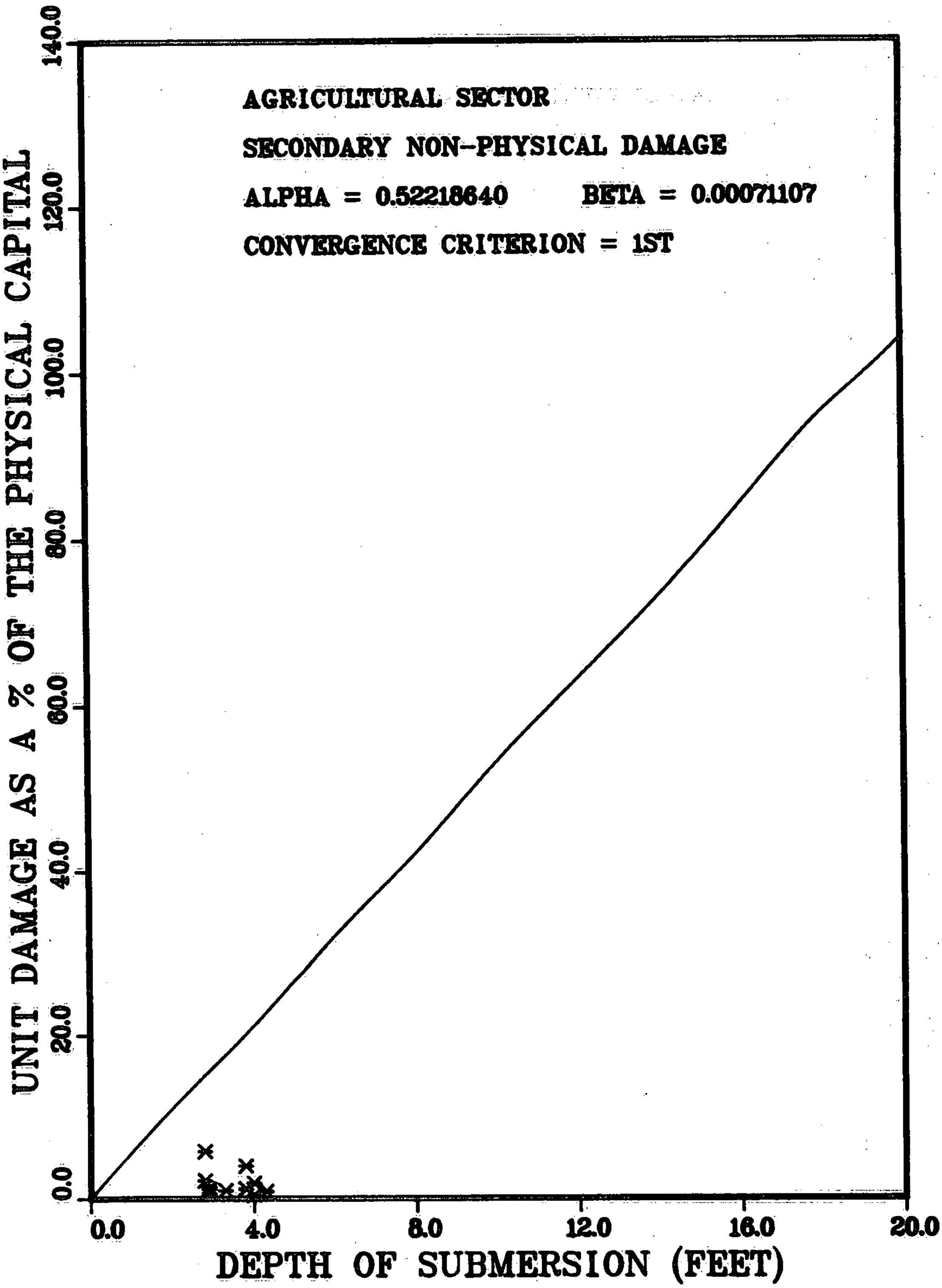

Figure A.14. Total damage function, AGS*D022.

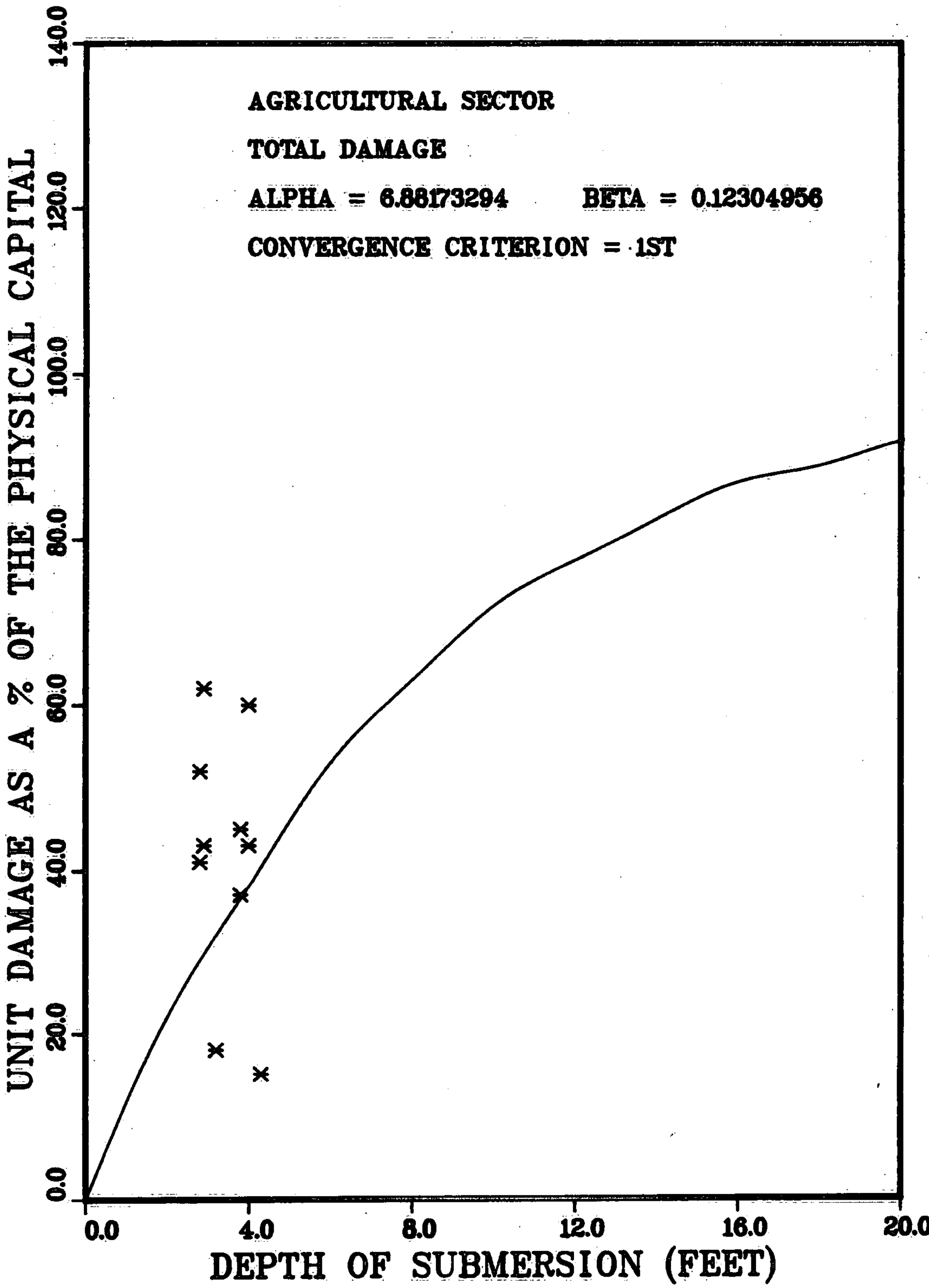

Figure A.15. Total damage function, AGS*DTØT.

Appendix B
Unit Damage for Different Return Periods

TABLE 8.1 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, PRS*D010

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
P R S ** D 0 1 0

..................................DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL............

MUNICIPA-LITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION						SEASONAL DISTRIBUTION					
		RETURN PERIOD											
		10	20	50	100	200	500	10	20	50	100	200	500
R01	25679.	1858.	2282.	2789.	3153.	3487.	3904.	1906.	2349.	2882.	3252.	3598.	4033.
		7.24	8.89	10.86	12.28	13.58	15.20	7.42	9.15	11.22	12.66	14.01	15.71
R02	11228.	789.	1001.	1191.	1341.	1482.	1653.	810.	1001.	1228.	1384.	1528.	1704.
		7.03	8.91	10.60	11.94	13.20	14.72	7.21	8.91	10.94	12.33	13.61	15.18
R03	12270.	894.	1100.	1345.	1513.	1673.	1865.	917.	1132.	1402.	1563.	1726.	1927.
		7.29	8.97	10.97	12.33	13.63	15.20	7.47	9.23	11.43	12.74	14.06	15.71
R04	15216.	1137.	1396.	1708.	1919.	2121.	2367.	1165.	1436.	1759.	1981.	2190.	2443.
		7.47	9.18	11.22	12.61	13.94	15.55	7.66	9.44	11.56	13.02	14.39	16.06
RE1	15600.	911.	1113.	1358.	1525.	1686.	1883.	931.	1145.	1399.	1573.	1739.	1947.
		5.84	7.13	8.71	9.77	10.81	12.07	5.97	7.34	8.97	10.09	11.15	12.48
RE2	6288.	355.	442.	554.	634.	709.	804.	360.	455.	574.	657.	735.	838.
		5.65	7.03	8.81	10.09	11.28	12.79	5.73	7.24	9.12	10.45	11.69	13.33
RE3	4731.	324.	399.	489.	552.	610.	681.	332.	412.	505.	570.	630.	703.
		6.84	8.44	10.34	11.66	12.89	14.39	7.03	8.71	10.68	12.05	13.33	14.85
RE4	5900.	427.	524.	642.	723.	798.	889.	438.	540.	662.	746.	824.	919.
		7.24	8.89	10.89	12.25	13.53	15.08	7.42	9.15	11.22	12.64	13.96	15.58
RE5	9150.	677.	830.	1015.	1142.	1261.	1407.	693.	854.	1046.	1180.	1303.	1453.
		7.39	9.07	11.09	12.48	13.78	15.38	7.58	9.33	11.43	12.89	14.24	15.88

TABLE B.2 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, PRS*D020

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
P R S ** D 0 2 0

DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL

MUNICIPA-LITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION						SEASONAL DISTRIBUTION					
		RETURN PERIOD											
		10	20	50	100	200	500	10	20	50	100	200	500
R01	25679.	2398.	2931.	3562.	4009.	4418.	4923.	2458.	3015.	3676.	4130.	4553.	5079.
		9.34	11.41	13.87	15.61	17.21	19.17	9.57	11.74	14.32	16.08	17.73	19.78
R02	11228.	1019.	1285.	1521.	1707.	1880.	2088.	1045.	1285.	1568.	1760.	1935.	2149.
		9.07	11.45	13.55	15.20	16.74	18.59	9.31	11.45	13.97	15.68	17.24	19.14
R03	12270.	1154.	1413.	1718.	1924.	2119.	2352.	1183.	1453.	1788.	1985.	2183.	2427.
		9.41	11.51	14.00	15.68	17.27	19.17	9.64	11.84	14.57	16.18	17.79	19.78
R04	15216.	1467.	1791.	2178.	2438.	2684.	2982.	1502.	1841.	2241.	2514.	2768.	3074.
		9.64	11.77	14.32	16.02	17.64	19.60	9.87	12.10	14.73	16.52	18.19	20.20
RE1	15600.	1180.	1436.	1745.	1953.	2154.	2396.	1206.	1478.	1796.	2013.	2218.	2475.
		7.57	9.21	11.19	12.52	13.81	15.36	7.73	9.47	11.51	12.91	14.22	15.87
RE2	6288.	461.	571.	712.	812.	904.	1021.	467.	587.	736.	840.	936.	1062.
		7.33	9.07	11.32	12.91	14.38	16.24	7.43	9.34	11.71	13.36	14.89	16.90
RE3	4731.	418.	514.	626.	703.	774.	861.	429.	529.	646.	725.	799.	887.
		8.84	10.86	13.23	14.86	16.37	18.19	9.07	11.19	13.65	15.33	16.90	18.74
RE4	5900.	551.	673.	820.	919.	1012.	1122.	565.	693.	845.	947.	1043.	1158.
		9.34	11.41	13.90	15.58	17.14	19.02	9.57	11.74	14.32	16.05	17.67	19.63
RE5	9150.	873.	1065.	1295.	1452.	1597.	1774.	894.	1095.	1333.	1498.	1648.	1829.
		9.54	11.64	14.16	15.87	17.45	19.38	9.77	11.97	14.57	16.37	18.01	19.99

TABLE B.3 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, PRS*D021

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
P R S ** D 0 2 1

DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL

MUNICIPA-LITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION						SEASONAL DISTRIBUTION					
		RETURN PERIOD											
		10	20	50	100	200	500	10	20	50	100	200	500
RO1	25679.	911.	1124.	1381.	1568.	1741.	1958.	935.	1158.	1429.	1619.	1799.	2026.
		3.55	4.38	5.38	6.11	6.78	7.63	3.64	4.51	5.56	6.30	7.00	7.89
RO2	11228.	387.	493.	589.	666.	739.	828.	397.	493.	608.	689.	763.	855.
		3.44	4.39	5.25	5.93	6.58	7.37	3.53	4.39	5.42	6.13	6.79	7.61
RO3	12270.	439.	542.	667.	752.	835.	936.	450.	558.	696.	778.	863.	968.
		3.57	4.42	5.43	6.13	6.81	7.63	3.67	4.55	5.67	6.34	7.03	7.89
RO4	15216.	558.	688.	847.	955.	1060.	1189.	572.	708.	873.	987.	1096.	1229.
		3.67	4.52	5.56	6.28	6.96	7.81	3.76	4.65	5.74	6.49	7.20	8.08
RE1	15600.	445.	545.	669.	753.	835.	936.	455.	562.	689.	777.	862.	969.
		2.85	3.50	4.29	4.83	5.35	6.00	2.92	3.60	4.42	4.98	5.52	6.21
RE2	6288.	174.	216.	273.	313.	352.	401.	176.	223.	283.	325.	365.	418.
		2.76	3.44	4.34	4.98	5.59	6.37	2.80	3.55	4.50	5.17	5.80	6.65
RE3	4731.	159.	197.	242.	274.	304.	341.	163.	203.	250.	283.	314.	352.
		3.35	4.15	5.12	5.79	6.42	7.20	3.44	4.29	5.29	5.99	6.65	7.44
RE4	5900.	209.	258.	318.	359.	398.	446.	215.	266.	328.	371.	412.	462.
		3.55	4.38	5.39	6.09	6.75	7.56	3.64	4.51	5.56	6.29	6.98	7.82
RE5	9150.	332.	409.	503.	568.	630.	706.	340.	421.	519.	588.	652.	730.
		3.63	4.47	5.50	6.21	6.89	7.72	3.72	4.60	5.67	6.42	7.12	7.98

TABLE B.4 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, PRS*D022

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
P R S ** D 0 2 2

MUNICIPA-LITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION 10	20	50	100	200	500	SEASONAL DISTRIBUTION 10	20	50	100	200	500
		DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL — RETURN PERIOD											
R01	25679.	1467.	1801.	2200.	2487.	2750.	3079.	1504.	1854.	2273.	2564.	2838.	3181.
		5.71	7.01	8.57	9.68	10.71	11.99	5.86	7.22	8.85	9.99	11.05	12.39
R02	11228.	623.	790.	939.	1058.	1169.	1304.	639.	790.	969.	1092.	1205.	1344.
		5.55	7.03	8.36	9.42	10.41	11.61	5.69	7.03	8.63	9.72	10.73	11.97
R03	12270.	706.	868.	1061.	1193.	1319.	1471.	724.	893.	1106.	1233.	1361.	1520.
		5.75	7.07	8.65	9.72	10.75	11.99	5.90	7.28	9.02	10.05	11.09	12.39
R04	15216.	897.	1101.	1347.	1513.	1673.	1867.	920.	1133.	1387.	1562.	1727.	1927.
		5.90	7.24	8.85	9.95	10.99	12.27	6.04	7.44	9.12	10.27	11.35	12.66
RE1	15600.	719.	878.	1072.	1203.	1330.	1485.	735.	904.	1104.	1241.	1372.	1536.
		4.61	5.63	6.87	7.71	8.53	9.52	4.71	5.79	7.07	7.96	8.79	9.85
RE2	6288.	281.	349.	437.	500.	559.	634.	285.	359.	453.	518.	580.	661.
		4.46	5.55	6.95	7.96	8.89	10.09	4.53	5.71	7.20	8.24	9.22	10.51
RE3	4731.	256.	315.	386.	435.	481.	537.	262.	325.	399.	450.	497.	554.
		5.40	6.66	8.16	9.20	10.17	11.35	5.55	6.87	8.43	9.50	10.51	11.71
RE4	5900.	337.	414.	507.	570.	630.	702.	346.	426.	522.	588.	650.	725.
		5.71	7.01	8.59	9.66	10.67	11.89	5.86	7.22	8.85	9.97	11.01	12.29
RE5	9150.	534.	655.	801.	901.	995.	1110.	547.	674.	825.	930.	1028.	1146.
		5.84	7.16	8.75	9.85	10.87	12.13	5.98	7.36	9.02	10.17	11.23	12.53

TABLE B.5 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, PRS*DTOT

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
P R S ** D T O T

DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL

MUNICIPALITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION						SEASONAL DISTRIBUTION					
		RETURN PERIOD											
		10	20	50	100	200	500	10	20	50	100	200	500
RO1	25679.	4391.	5310.	6372.	7108.	7768.	8565.	4495.	5453.	6561.	7304.	7983.	8806.
		17.10	20.68	24.81	27.68	30.25	33.35	17.50	21.24	25.55	28.44	31.09	34.30
RO2	11228.	1868.	2328.	2726.	3033.	3313.	3643.	1913.	2328.	2804.	3119.	3402.	3740.
		16.63	20.74	24.28	27.01	29.50	32.45	17.04	20.74	24.97	27.78	30.30	33.31
RO3	12270.	2112.	2558.	3070.	3409.	3724.	4093.	2162.	2626.	3187.	3509.	3826.	4208.
		17.22	20.85	25.02	27.78	30.35	33.35	17.62	21.40	25.97	28.60	31.18	34.30
RO4	15216.	2681.	3240.	3888.	4313.	4708.	5176.	2742.	3323.	3992.	4436.	4841.	5318.
		17.62	21.29	25.55	28.34	30.94	34.02	18.02	21.84	26.23	29.15	31.82	34.95
RE1	15600.	2180.	2631.	3165.	3518.	3854.	4254.	2227.	2704.	3252.	3620.	3961.	4382.
		13.98	16.87	20.29	22.55	24.71	27.27	14.28	17.33	20.85	23.20	25.39	28.09
RE2	6288.	852.	1046.	1290.	1459.	1613.	1804.	864.	1075.	1332.	1507.	1666.	1871.
		13.56	16.63	20.51	23.20	25.66	28.70	13.74	17.10	21.18	23.96	26.49	29.75
RE3	4731.	768.	933.	1123.	1251.	1367.	1505.	787.	960.	1156.	1288.	1408.	1546.
		16.23	19.73	23.74	26.44	28.90	31.82	16.63	20.29	24.44	27.22	29.75	32.69
RE4	5900.	1009.	1220.	1467.	1630.	1779.	1954.	1033.	1253.	1508.	1675.	1828.	2010.
		17.10	20.68	24.87	27.63	30.15	33.12	17.50	21.24	25.55	28.39	30.99	34.06
RE5	9150.	1596.	1928.	2314.	2570.	2804.	3082.	1633.	1978.	2376.	2644.	2885.	3168.
		17.45	21.07	25.29	28.09	30.64	33.69	17.85	21.62	25.97	28.90	31.53	34.63

TABLE B.6 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, CIS*D010

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
C I S ** D 0 1 0

DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL

MUNICIPALITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION — RETURN PERIOD 10	20	50	100	200	500	SEASONAL DISTRIBUTION — RETURN PERIOD 10	20	50	100	200	500
R01	40000.	1352.	1664.	2040.	2311.	2561.	2875.	1387.	1714.	2109.	2384.	2645.	2972.
		3.38	4.16	5.10	5.78	6.40	7.19	3.47	4.28	5.27	5.96	6.61	7.43
R02	40000.	1313.	1669.	1991.	2247.	2488.	2782.	1347.	1669.	2055.	2321.	2566.	2870.
		3.28	4.17	4.98	5.62	6.22	6.95	3.37	4.17	5.14	5.80	6.42	7.17
R03	40000.	1362.	1679.	2060.	2321.	2571.	2875.	1397.	1729.	2148.	2399.	2654.	2972.
		3.41	4.20	5.15	5.80	6.43	7.19	3.49	4.32	5.37	6.00	6.64	7.43
R04	40000.	1397.	1719.	2109.	2375.	2630.	2943.	1432.	1768.	2173.	2453.	2718.	3041.
		3.49	4.30	5.27	5.94	6.57	7.36	3.58	4.42	5.43	6.13	6.80	7.60
RE1	40000.	1089.	1332.	1630.	1833.	2030.	2271.	1114.	1372.	1679.	1892.	2094.	2350.
		2.72	3.33	4.07	4.58	5.07	5.68	2.78	3.43	4.20	4.73	5.24	5.88
RE2	40000.	1054.	1313.	1650.	1892.	2119.	2409.	1069.	1352.	1709.	1961.	2198.	2512.
		2.64	3.28	4.12	4.73	5.30	6.02	2.67	3.38	4.27	4.90	5.49	6.28
RE3	40000.	1278.	1580.	1941.	2193.	2429.	2718.	1313.	1630.	2005.	2266.	2512.	2806.
		3.19	3.95	4.85	5.48	6.07	6.80	3.28	4.07	5.01	5.67	6.28	7.02
RE4	40000.	1352.	1664.	2045.	2306.	2551.	2850.	1387.	1714.	2109.	2380.	2635.	2948.
		3.38	4.16	5.11	5.76	6.38	7.13	3.47	4.28	5.27	5.95	6.59	7.37
RE5	40000.	1382.	1699.	2084.	2350.	2600.	2909.	1417.	1749.	2148.	2429.	2689.	3007.
		3.46	4.25	5.21	5.88	6.50	7.27	3.54	4.37	5.37	6.07	6.72	7.52

TABLE B.7 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, CIS*D020

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
C I S ** D 0 2 0

DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL

MUNICIPALITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION						SEASONAL DISTRIBUTION					
		RETURN PERIOD											
		10	20	50	100	200	500	10	20	50	100	200	500
RO1	40000.	4130.	6329.	9502.	12032.	14459.	17504.	4351.	6717.	10132.	12741.	15272.	18438.
		10.33	15.82	23.76	30.08	36.15	43.76	10.88	16.79	25.33	31.85	38.18	46.09
RO2	40000.	3885.	6367.	9059.	11423.	13742.	16607.	4099.	6367.	9636.	12126.	14507.	17457.
		9.71	15.92	22.65	28.56	34.35	41.52	10.25	15.92	24.09	30.32	36.27	43.64
RO3	40000.	4193.	6444.	9681.	12126.	14555.	17504.	4416.	6836.	10497.	12884.	15368.	18438.
		10.48	16.11	24.20	30.32	36.39	43.76	11.04	17.09	26.24	32.21	38.42	46.09
RO4	40000.	4416.	6757.	10132.	12646.	15129.	18159.	4645.	7156.	10727.	13408.	15988.	19083.
		11.04	16.89	25.33	31.62	37.82	45.40	11.61	17.89	26.82	33.52	39.97	47.71
RE1	40000.	2656.	4006.	6063.	7689.	9413.	11656.	2780.	4256.	6444.	8194.	9996.	12410.
		6.64	10.02	15.16	19.22	23.53	29.14	6.95	10.64	16.11	20.48	24.99	31.02
RE2	40000.	2489.	3885.	6214.	8194.	10223.	12979.	2560.	4130.	6678.	8796.	10958.	13981.
		6.22	9.71	15.53	20.48	25.56	32.45	6.40	10.33	16.70	21.99	27.39	34.95
RE3	40000.	3677.	5691.	8623.	10912.	13169.	15988.	3885.	6063.	9191.	11610.	13981.	16843.
		9.19	14.23	21.56	27.28	32.92	39.97	9.71	15.16	22.98	29.02	34.95	42.11
RE4	40000.	4130.	6329.	9547.	11985.	14363.	17269.	4351.	6717.	10132.	12694.	15177.	18205.
		10.33	15.82	23.87	29.96	35.91	43.17	10.88	16.79	25.33	31.73	37.94	45.51
RE5	40000.	4319.	6600.	9906.	12410.	14842.	17832.	4546.	6995.	10497.	13169.	15702.	18761.
		10.80	16.50	24.76	31.02	37.10	44.58	11.36	17.49	26.24	32.92	39.26	46.90

TABLE B.8 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, CIS*D021

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
C I S ** D 0 2 1

MUNICIPA-LITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION						SEASONAL DISTRIBUTION					
		RETURN PERIOD											
		10	20	50	100	200	500	10	20	50	100	200	500
DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL													
RO1	40000.	2335.	2874.	3521.	3988.	4419.	4958.	2395.	2959.	3640.	4115.	4563.	5126.
		5.84	7.18	8.80	9.97	11.05	12.39	5.99	7.40	9.10	10.29	11.41	12.81
RO2	40000.	2266.	2882.	3436.	3878.	4293.	4798.	2326.	2882.	3547.	4005.	4428.	4949.
		5.67	7.21	8.59	9.69	10.73	12.00	5.82	7.21	8.87	10.01	11.07	12.37
RO3	40000.	2352.	2899.	3555.	4005.	4436.	4958.	2412.	2985.	3708.	4140.	4579.	5126.
		5.88	7.25	8.89	10.01	11.09	12.39	6.03	7.46	9.27	10.35	11.45	12.81
RO4	40000.	2412.	2968.	3640.	4098.	4537.	5075.	2472.	3053.	3751.	4233.	4689.	5243.
		6.03	7.42	9.10	10.25	11.34	12.69	6.18	7.63	9.38	10.58	11.72	13.11
RE1	40000.	1880.	2300.	2814.	3164.	3504.	3920.	1923.	2369.	2899.	3266.	3615.	4056.
		4.70	5.75	7.03	7.91	8.76	9.80	4.81	5.92	7.25	8.16	9.04	10.14
RE2	40000.	1820.	2266.	2848.	3266.	3657.	4157.	1845.	2335.	2950.	3385.	3793.	4335.
		4.55	5.67	7.12	8.16	9.14	10.39	4.61	5.84	7.38	8.46	9.48	10.84
RE3	40000.	2206.	2728.	3351.	3785.	4191.	4689.	2266.	2814.	3462.	3912.	4335.	4840.
		5.52	6.82	8.38	9.46	10.48	11.72	5.67	7.03	8.65	9.78	10.84	12.10
RE4	40000.	2335.	2874.	3530.	3980.	4402.	4916.	2395.	2959.	3640.	4107.	4546.	5084.
		5.84	7.18	8.82	9.95	11.01	12.29	5.99	7.40	9.10	10.27	11.36	12.71
RE5	40000.	2386.	2933.	3598.	4056.	4487.	5017.	2446.	3019.	3708.	4191.	4638.	5184.
		5.97	7.33	8.99	10.14	11.22	12.54	6.11	7.55	9.27	10.48	11.60	12.96

TABLE B.9 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, CIS*D022

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
C I S ** D 0 2 2

DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL

MUNICIPALITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION – RETURN PERIOD 10	20	50	100	200	500	SEASONAL DISTRIBUTION – RETURN PERIOD 10	20	50	100	200	500
R01	40000.	2217. 5.54	3619. 9.05	5842. 14.61	7768. 19.42	9738. 24.34	12376. 30.94	2352. 5.88	3879. 9.70	6310. 15.77	8331. 20.83	10424. 26.06	13223. 33.06
R02	40000.	2068. 5.17	3645. 9.11	5519. 13.80	7292. 18.23	9143. 22.86	11579. 28.95	2198. 5.49	3645. 9.11	5941. 14.85	7842. 19.61	9778. 24.44	12334. 30.83
R03	40000.	2255. 5.64	3696. 9.24	5974. 14.94	7842. 19.61	9818. 24.54	12376. 30.94	2392. 5.98	3959. 9.90	6584. 16.46	8446. 21.11	10506. 26.26	13223. 33.06
R04	40000.	2392. 5.98	3906. 9.76	6310. 15.77	8255. 20.64	10302. 25.76	12968. 32.42	2534. 6.33	4177. 10.44	6758. 16.90	8870. 22.17	11040. 27.60	13819. 34.55
RE1	40000.	1350. 3.38	2142. 5.35	3443. 8.61	4545. 11.36	5777. 14.44	7474. 18.68	1420. 3.55	2294. 5.73	3696. 9.24	4899. 12.25	6208. 15.52	8067. 20.17
RE2	40000.	1256. 3.14	2068. 5.17	3543. 8.86	4899. 12.25	6378. 15.94	8522. 21.31	1296. 3.24	2217. 5.54	3853. 9.63	5329. 13.32	6934. 17.34	9340. 23.35
RE3	40000.	1943. 4.86	3200. 8.00	5204. 13.01	6899. 17.25	8676. 21.69	11040. 27.60	2068. 5.17	3443. 8.61	5615. 14.04	7437. 18.59	9340. 23.35	11788. 29.47
RE4	40000.	2217. 5.54	3619. 9.05	5875. 14.69	7731. 19.33	9658. 24.14	12165. 30.41	2352. 5.88	3879. 9.70	6310. 15.77	8293. 20.73	10343. 25.86	13011. 32.53
RE5	40000.	2333. 5.83	3800. 9.50	6141. 15.35	8067. 20.17	10059. 25.15	12672. 31.68	2472. 6.18	4067. 10.17	6584. 16.46	8676. 21.69	10792. 26.98	13521. 33.80

TABLE B.10 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, CIS*DTOT

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
C I S ** D T O T

DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL

MUNICIPALITY	PHYSICAL CAPITAL ($/UNIT)	ANNUAL DISTRIBUTION — RETURN PERIOD 10	20	50	100	200	500	SEASONAL DISTRIBUTION — RETURN PERIOD 10	20	50	100	200	500
R01	40000.	5835. 14.59	8907. 22.27	13113. 32.78	16269. 40.67	19137. 47.84	22521. 56.30	6150. 15.37	9437. 23.59	13916. 34.79	17123. 42.81	20064. 50.16	23512. 58.78
R02	40000.	5485. 13.71	8960. 22.40	12543. 31.36	15525. 38.81	18306. 45.76	21548. 53.87	5791. 14.48	8960. 22.40	13285. 33.21	16384. 40.96	19192. 47.98	22470. 56.18
R03	40000.	5924. 14.81	9065. 22.66	13342. 33.36	16384. 40.96	19247. 48.12	22521. 56.30	6241. 15.60	9598. 24.00	14376. 35.94	17293. 43.23	20172. 50.43	23512. 58.78
R04	40000.	6241. 15.60	9491. 23.73	13916. 34.79	17010. 42.52	19902. 49.75	23218. 58.05	6565. 16.41	10031. 25.08	14663. 36.66	17914. 44.78	20866. 52.17	24165. 60.46
RE1	40000.	3716. 9.29	5659. 14.15	8542. 21.35	10744. 26.86	12999. 32.50	15812. 39.53	3895. 9.74	6014. 15.03	9065. 22.66	11413. 28.53	13744. 34.36	16726. 41.81
RE2	40000.	3473. 8.68	5485. 13.71	8750. 21.88	11413. 28.53	14031. 35.08	17407. 43.52	3576. 8.94	5835. 14.59	9384. 23.46	12202. 30.50	14950. 37.38	18584. 46.46
RE3	40000.	5187. 12.97	8029. 20.07	11975. 29.94	14893. 37.23	17632. 44.08	20866. 52.17	5485. 13.71	8542. 21.35	12714. 31.78	15754. 39.39	18584. 46.46	21807. 54.52
RE4	40000.	5835. 14.59	8907. 22.27	13170. 32.93	16212. 40.53	19027. 47.57	22268. 55.67	6150. 15.37	9437. 23.59	13916. 34.79	17067. 42.67	19956. 49.89	23267. 58.17
RE5	40000.	6104. 15.26	9277. 23.19	13629. 34.07	16726. 41.81	19576. 48.94	22872. 57.18	6425. 16.06	9814. 24.53	14376. 35.94	17632. 44.08	20547. 51.37	23851. 59.63

TABLE B.11 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, AGS*D010

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
A G S ** D 0 1 0

MUNICIPA-LITY	PHYSICAL CAPITAL ($/ACRE)	DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL											
		ANNUAL DISTRIBUTION						SEASONAL DISTRIBUTION					
		RETURN PERIOD											
		10	20	50	100	200	500	10	20	50	100	200	500
RO1	700.	250.	294.	342.	373.	399.	429.	255.	301.	350.	380.	407.	437.
		35.77	42.07	48.81	53.23	56.94	61.25	36.48	43.01	49.97	54.34	58.15	62.47
RO2	700.	245.	295.	336.	366.	391.	420.	250.	295.	344.	374.	399.	428.
		34.94	42.12	47.98	52.24	55.89	60.03	35.66	42.12	49.09	53.40	57.05	61.19
RO3	700.	252.	296.	344.	374.	400.	429.	257.	303.	354.	382.	408.	437.
		35.99	42.34	49.14	53.40	57.10	61.25	36.71	43.28	50.64	54.56	58.26	62.47
RO4	700.	257.	301.	350.	380.	406.	435.	262.	308.	357.	388.	414.	443.
		36.71	43.06	49.97	54.23	57.93	62.13	37.42	44.00	51.02	55.39	59.15	63.35
RE1	700.	210.	247.	290.	316.	341.	368.	214.	253.	296.	324.	348.	377.
		29.96	35.32	41.40	45.16	48.65	52.63	30.51	36.21	42.34	46.27	49.75	53.84
RE2	700.	204.	245.	293.	324.	351.	383.	207.	250.	300.	332.	360.	394.
		29.13	34.94	41.79	46.27	50.14	54.73	29.52	35.77	42.90	47.48	51.41	56.27
RE3	700.	239.	283.	330.	359.	385.	414.	245.	290.	338.	368.	394.	423.
		34.16	40.41	47.10	51.35	55.00	59.15	34.94	41.40	48.26	52.52	56.27	60.36
RE4	700.	250.	294.	342.	372.	398.	426.	255.	301.	350.	380.	406.	435.
		35.77	42.07	48.92	53.12	56.83	60.92	36.48	43.01	49.97	54.28	57.99	62.19
RE5	700.	255.	299.	347.	377.	403.	432.	260.	305.	354.	385.	411.	440.
		36.37	42.73	49.59	53.84	57.55	61.69	37.09	43.62	50.64	55.00	58.76	62.91

TABLE B.12 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, AGS*D020

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U R I V E R
A G S ** D 0 2 0

DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL

MUNICIPA-LITY	PHYSICAL CAPITAL ($/ACRE)	ANNUAL DISTRIBUTION						SEASONAL DISTRIBUTION					
		RETURN PERIOD											
		10	20	50	100	200	500	10	20	50	100	200	500
R01	700.	31.	39.	47.	53.	59.	66.	32.	40.	49.	55.	61.	68.
		4.49	5.51	6.73	7.61	8.42	9.42	4.60	5.67	6.96	7.85	8.69	9.74
R02	700.	31.	39.	46.	52.	57.	64.	31.	39.	47.	54.	59.	66.
		4.36	5.53	6.57	7.40	8.18	9.13	4.47	5.53	6.78	7.64	8.43	9.41
R03	700.	32.	39.	48.	54.	59.	66.	32.	40.	50.	55.	61.	68.
		4.52	5.56	6.80	7.64	8.45	9.42	4.64	5.72	7.09	7.90	8.72	9.74
R04	700.	32.	40.	49.	55.	60.	68.	33.	41.	50.	56.	62.	70.
		4.64	5.69	6.96	7.82	8.64	9.64	4.75	5.85	7.17	8.07	8.92	9.96
RE1	700.	25.	31.	38.	42.	47.	52.	26.	32.	39.	44.	48.	54.
		3.62	4.42	5.40	6.06	6.70	7.48	3.71	4.55	5.56	6.25	6.91	7.74
RE2	700.	25.	31.	38.	44.	49.	55.	25.	31.	40.	45.	51.	58.
		3.51	4.36	5.46	6.25	6.99	7.93	3.56	4.49	5.66	6.48	7.25	8.26
RE3	700.	30.	37.	45.	51.	56.	62.	31.	38.	46.	52.	58.	64.
		4.25	5.24	6.41	7.23	7.99	8.92	4.36	5.40	6.62	7.47	8.26	9.21
RE4	700.	31.	39.	47.	53.	59.	65.	32.	40.	49.	55.	61.	68.
		4.49	5.51	6.75	7.60	8.39	9.35	4.60	5.67	6.96	7.83	8.66	9.66
RE5	700.	32.	39.	48.	54.	60.	67.	33.	41.	50.	56.	62.	69.
		4.59	5.62	6.88	7.74	8.55	9.53	4.70	5.79	7.09	7.99	8.83	9.85

TABLE B.13 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, AGS*D021

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
A G S ** D 0 2 1

MUNICIPA-LITY	PHYSICAL CAPITAL ($/ACRE)	DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL — ANNUAL DISTRIBUTION — RETURN PERIOD 10	20	50	100	200	500	SEASONAL DISTRIBUTION — RETURN PERIOD 10	20	50	100	200	500
RO1	700.	47.	58.	72.	81.	90.	102.	49.	60.	74.	84.	93.	105.
		6.77	8.35	10.26	11.64	12.91	14.51	6.95	8.60	10.61	12.01	13.34	15.01
RO2	700.	46.	59.	70.	79.	88.	98.	47.	59.	72.	82.	91.	101.
		6.57	8.38	10.01	11.31	12.54	14.04	6.74	8.38	10.33	11.69	12.94	14.49
RO3	700.	48.	59.	73.	82.	91.	102.	49.	61.	76.	85.	94.	105.
		6.82	8.43	10.36	11.69	12.96	14.51	7.00	8.68	10.81	12.09	13.39	15.01
RO4	700.	49.	60.	74.	84.	93.	104.	50.	62.	77.	87.	96.	107.
		7.00	8.63	10.61	11.96	13.26	14.86	7.17	8.88	10.93	12.36	13.71	15.36
RE1	700.	38.	47.	57.	64.	71.	80.	39.	48.	59.	67.	74.	83.
		5.44	6.67	8.17	9.20	10.21	11.44	5.57	6.87	8.43	9.50	10.53	11.84
RE2	700.	37.	46.	58.	67.	75.	85.	37.	47.	60.	69.	77.	89.
		5.26	6.57	8.28	9.50	10.66	12.14	5.34	6.77	8.58	9.86	11.06	12.66
RE3	700.	45.	55.	68.	77.	86.	96.	46.	57.	71.	80.	89.	99.
		6.39	7.92	9.76	11.03	12.24	13.71	6.57	8.17	10.08	11.41	12.66	14.16
RE4	700.	47.	58.	72.	81.	90.	101.	49.	60.	74.	84.	93.	104.
		6.77	8.35	10.28	11.61	12.86	14.39	6.95	8.60	10.61	11.99	13.29	14.88
RE5	700.	48.	60.	73.	83.	92.	103.	50.	61.	76.	86.	95.	106.
		6.92	8.53	10.48	11.84	13.11	14.68	7.10	8.78	10.81	12.24	13.56	15.18

TABLE B.14 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, AGS*D022

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
A G S ** D 0 2 2

....DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL....

MUNICIPA-LITY	PHYSICAL CAPITAL ($/ACRE)	ANNUAL DISTRIBUTION						SEASONAL DISTRIBUTION					
		RETURN PERIOD											
		10	20	50	100	200	500	10	20	50	100	200	500
RO1	700.	1. 0.14	1. 0.17	1. 0.21	2. 0.24	2. 0.27	2. 0.30	1. 0.14	1. 0.18	2. 0.22	2. 0.25	2. 0.28	2. 0.31
RO2	700.	1. 0.14	1. 0.17	1. 0.21	2. 0.24	2. 0.26	2. 0.29	1. 0.14	1. 0.17	2. 0.21	2. 0.24	2. 0.27	2. 0.30
RO3	700.	1. 0.14	1. 0.18	2. 0.22	2. 0.24	2. 0.27	2. 0.30	1. 0.15	1. 0.18	2. 0.22	2. 0.25	2. 0.28	2. 0.31
RO4	700.	1. 0.15	1. 0.18	2. 0.22	2. 0.25	2. 0.28	2. 0.31	1. 0.15	1. 0.18	2. 0.23	2. 0.26	2. 0.29	2. 0.32
RE1	700.	1. 0.11	1. 0.14	1. 0.17	1. 0.19	1. 0.21	2. 0.24	1. 0.12	1. 0.14	1. 0.18	1. 0.20	2. 0.22	2. 0.25
RE2	700.	1. 0.11	1. 0.14	1. 0.17	1. 0.20	2. 0.22	2. 0.25	1. 0.11	1. 0.14	1. 0.18	1. 0.21	2. 0.23	2. 0.26
RE3	700.	1. 0.13	1. 0.16	1. 0.20	2. 0.23	2. 0.25	2. 0.29	1. 0.14	1. 0.17	1. 0.21	2. 0.24	2. 0.26	2. 0.29
RE4	700.	1. 0.14	1. 0.17	1. 0.21	2. 0.24	2. 0.27	2. 0.30	1. 0.14	1. 0.18	2. 0.22	2. 0.25	2. 0.28	2. 0.31
RE5	700.	1. 0.14	1. 0.18	2. 0.22	2. 0.25	2. 0.27	2. 0.31	1. 0.15	1. 0.18	2. 0.22	2. 0.25	2. 0.28	2. 0.32

TABLE 8.15 - UNIT DAMAGE FOR VARIOUS RETURN PERIODS, AGS*DTOT

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U R I V E R
A G S ** D T O T

DAMAGE IN 1976 DOLLARS AND AS A PERCENTAGE PER UNIT OF PHYSICAL CAPITAL

MUNICIPALITY	PHYSICAL CAPITAL ($/ACRE)	ANNUAL DISTRIBUTION						SEASONAL DISTRIBUTION					
		RETURN PERIOD											
		10	20	50	100	200	500	10	20	50	100	200	500
RO1	700.	198.	236.	277.	305.	329.	357.	202.	241.	284.	312.	336.	366.
		28.35	33.64	39.59	43.59	46.93	51.02	28.90	34.48	40.61	44.61	48.05	52.23
RO2	700.	193.	236.	272.	299.	322.	349.	198.	236.	278.	306.	329.	357.
		27.60	33.74	38.85	42.66	46.00	49.81	28.25	33.74	39.78	43.68	47.03	50.93
RO3	700.	200.	237.	279.	306.	330.	357.	204.	243.	288.	314.	338.	366.
		28.53	33.92	39.87	43.68	47.12	51.02	29.09	34.76	41.17	44.80	48.23	52.23
RO4	700.	204.	242.	284.	311.	335.	363.	208.	247.	291.	319.	343.	371.
		29.09	34.57	40.61	44.42	47.86	51.86	29.74	35.32	41.54	45.54	49.07	52.97
RE1	700.	165.	196.	232.	254.	276.	301.	168.	201.	237.	262.	283.	308.
		23.51	27.97	33.09	36.34	39.41	43.03	23.98	28.72	33.92	37.36	40.43	44.05
RE2	700.	160.	193.	234.	262.	286.	314.	162.	198.	241.	269.	293.	324.
		22.86	27.60	33.46	37.36	40.80	44.89	23.14	28.35	34.39	38.38	41.91	46.28
RE3	700.	189.	226.	267.	293.	316.	343.	193.	232.	273.	301.	324.	351.
		26.95	32.25	38.10	41.82	45.17	49.07	27.60	33.09	39.03	42.94	46.28	50.19
RE4	700.	198.	236.	278.	304.	328.	355.	202.	241.	284.	312.	336.	363.
		28.35	33.64	39.68	43.49	46.84	50.65	28.90	34.48	40.61	44.52	47.96	51.86
RE5	700.	202.	239.	282.	308.	332.	360.	206.	245.	288.	316.	340.	368.
		28.81	34.20	40.24	44.05	47.49	51.39	29.46	35.04	41.17	45.17	48.61	52.60

Appendix C
Estimated Damage for a Ten-Year Flood

TABLE C.1 - ESTIMATED DAMAGE FOR A TEN-YEAR FLOOD (IID), PERMANENT RESIDENTIAL SECTOR

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
PRS ** IID * T=10 YEARS

MUNICIPALITY	PHYSICAL CAPITAL		DAMAGE IN 1976 DOLLARS				
				NON-PHYSICAL			
	($/UNIT)	NO. OF UNITS	PHYSICAL	PRIMARY	SECONDARY	TOTAL	TOTAL
R01	25679.	115.	213715.	275798.	104780.	168675.	504967.
R02	11228.	90.	71004.	91687.	34792.	56042.	168099.
R03	12270.	30.	26833.	34623.	13158.	21178.	63371.
R04	15216.	10.	11372.	14665.	5579.	8975.	26810.
RE1	15600.	20.	18215.	23604.	8897.	14381.	43606.
RE2	6288.	130.	46208.	59912.	22558.	36484.	110810.
RE3	4731.	52.	16832.	21747.	8244.	13286.	39919.
RE4	5900.	10.	4270.	5510.	2093.	3370.	10089.
RE5	9150.	20.	13533.	17455.	6638.	10680.	31928.
TOTAL DAMAGE IN 1976 DOLLARS :			421983.	545002.	206737.	333071.	999597.

TABLE C.2 - ESTIMATED DAMAGE FOR A TEN-YEAR FLOOD (IID), COMMERCIAL AND INDUSTRIAL SECTOR

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
CIS ** IID * T=10 YEARS

MUNICIPALITY	PHYSICAL CAPITAL		DAMAGE IN 1976 DOLLARS				
				NON-PHYSICAL			
	($/UNIT)	NO. OF UNITS	PHYSICAL	PRIMARY	SECONDARY	TOTAL	TOTAL
RO1	40000.	3.	4057.	12390.	7004.	6650.	17505.
RO2	40000.	2.	2625.	7769.	4532.	4136.	10970.
RO3	40000.	4.	5449.	16771.	9407.	9020.	23697.
RO4	40000.	1.	1397.	4416.	2412.	2392.	6241.
RE1	40000.	0.	0.	0.	0.	0.	0.
RE2	40000.	0.	0.	0.	0.	0.	0.
RE3	40000.	3.	3833.	11029.	6618.	5829.	15560.
RE4	40000.	1.	1352.	4130.	2335.	2217.	5835.
RE5	40000.	3.	4146.	12958.	7158.	6998.	18313.
TOTAL DAMAGE IN 1976 DOLLARS :			22859.	69464.	39465.	37241.	98120.

TABLE C.3 - ESTIMATED DAMAGE FOR A TEN-YEAR FLOOD (IID), AGRICULTURAL SECTOR

SYSTEMATIC APPROACH FOR FLOOD PLAIN MANAGEMENT
R I C H E L I E U   R I V E R
AGS ** IID * T=10 YEARS

MUNICIPALITY	PHYSICAL CAPITAL		DAMAGE IN 1976 DOLLARS				
	($/ACRE)	NO. OF ACRES	PHYSICAL	NON-PHYSICAL PRIMARY	NON-PHYSICAL SECONDARY	NON-PHYSICAL TOTAL	TOTAL
R01	700.	105.	26288.	3300.	4975.	104.	20834.
R02	700.	105.	25678.	3204.	4828.	101.	20288.
R03	700.	884.	222686.	27984.	42199.	880.	176553.
R04	700.	529.	135920.	17168.	25903.	540.	107717.
RE1	700.	0.	0.	0.	0.	0.	0.
RE2	700.	0.	0.	0.	0.	0.	0.
RE3	700.	487.	116460.	14472.	21794.	454.	91878.
RE4	700.	****	363021.	45571.	68709.	1432.	287709.
RE5	700.	100.	25462.	3211.	4844.	101.	20167.
TOTAL DAMAGE IN 1976 DOLLARS :			915514.	114910.	173252.	3611.	725147.

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