University of Washington
Department of Civil and Environmental Engineering

DATA AND ADMINISTRATIVE CONSIDERATIONS FOR TWO DISTRICT FLOOD PLAIN ZONING

Stephen J. Burges
John S. Hillmer

Water Resources Series
Technical Report No. 38
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State of Washington Department of Ecology

WATER RESOURCES INFORMATION SYSTEM

WASHINGTON STATE WATER PROGRAM

WRIS Technical Bulletin No. 2

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by

Stephen J. Burges and John S. Hillmer

Charles W. Harris Hydraulics Laboratory

University of Washington

Seattle, Washington

Under Contract to the Department of Ecology

July 1974

TECHNICAL INFORMATION BULLETINS

The purpose of the Technical Bulletins is to present the results of research funded by the Department of Ecology and to allow the presentation of ideas and work of Department of Ecology personnel. The technical bulletins do not necessarily present the official viewpoints nor policy of the Department of Ecology or the State of Washington.

In March of 1973, the Department of Ecology entered into a contract with Stephen J. Burges of the Charles W. Harris Hydraulics Laboratory, University of Washington in which Dr. Burges was to investigate the hydrologic data requirements of a Water Resources Information System. Three specific areas were to be investigated - 1. data requirements for water quality management, 2. data requirements for a flood damage reduction, and 3. data requirements for low flow management.

This report by Burges and Hillmer is the report on data requirements for flood damage reduction.

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January 1974

Technical Report No. 38

Project Completion Report
DOE Project No: W-12
DOE Accounting No: 001-01-030-0220, SWP Contract No 30/R Milhous
Project Period: March 15, 1973 - September 1, 1973

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ACKNOWLEDGEMENTS

Considerable parts of this report were taken from the second author's M.S. thesis which was completed during a sabbatical leave from the U.S. Army Corps of Engineers. The authors wish to express their thanks to Gerry Gardner and Bill Spurlock of the U.S. Army Corps of Engineers; Ry Tanino (HUD); Ed Hammersmith of the Washington State Department of Ecology; and Brad Gillespie of the King County Division of Flood Control. These persons were instrumental in providing important information for the investigation.

Thanks are also due to Professors E.P. Richey and B.W. Mar (University of Washington) for helpful suggestions. Dr. R. Milhous of the Washington State Department of Ecology was most helpful in his supervising role and in providing helpful criticism throughout this investigation.

Special thanks are due to Ms. Pamela Brink for her patience in typing this report.

ABSTRACT

National flood plain management policy has shifted from placing the primary emphasis on structural controls to a balance between structural and regulatory type controls. One regulatory type of management, two district flood plain zoning, in which the flood hazard area is divided into floodway and floodway fringe districts, is currently being strongly advocated by agencies of the federal government. Federal criteria for establishing a two district flood plain zoning ordinance are reviewed and examined herein. The principal standards evolved from the National Flood Insurance Program administered by the Department of Housing and Urban Development.

A relatively simple example is presented to illustrate some aspects of uncertainty in mapping resulting from use of short historical records of flood flows. The example indicates how regional uncertainty categorization schemes could be implemented by means of examining the flood frequency summary statistics and flow geometry. Specific recommendations are made concerning the use of uncertain information on past and future floods; socio-technical details of flood plain delineation are included.

While much technical detail is included, the report is intended to be a secondary resource of principal value to state personnel and particularly to community planners who are faced with choosing one approach or combining different approaches to mitigate flood losses.

LIST OF SYMBOLS

B	width of a rectangular river channel (ft)
D	bankfull depth of a rectangular river channel (ft)
CV	coefficient of variation
G	skew coefficient
m	mth largest flood in a sample of length N
N	sample size of flood peak data
N_R	Mannings roughness coefficient for river channel
N_S	Mannings roughness coefficient for overbank region
Q_{BF}	maximum flow that is contained by natural channel (cfs)
Q_{RF}	regulatory flood magnitude (cfs)
Q_{SPF}	magnitude of U.S. Army Corps of Engineers Standard Project Flood (cfs)
Q_{TOT}	total flow in river channel and overbank region (cfs)
Q_{100}	magnitude of 100 year recurrence interval flood (cfs)
Q_5	magnitude of 5 year recurrence interval flood (cfs)
$\overline{Q}$	average of the annual flood series (cfs)
SPF	Standard Project Flood
SS_R	hydraulic gradient for river channel flow
SS_S	hydraulic gradient for overbank flow
S^2_{RF}	variance of the regulatory flood (cfs)
S_{100}	standard deviation of the 100 year recurrence interval flood (cfs)
S_w	standard deviation of flood plain inundation width (ft)
S_y	standard deviation of maximum flood water depth (ft)
W	flood plain inundated width (ft)
$\overline{W}$	expected value of flood plain inundation width (ft)
Y	maximum floodwater depth (ft)
$\overline{Y}$	expected value of maximum floodwater depth (ft)
α	slope of flood plain to the river channel

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INTRODUCTION

This report addresses the principal features of flood plain zoning with particular emphasis on two district flood plain zoning. It is intended to supplement federal, state, and local operational guidelines that communities are required to follow when performing flood plain zoning. Much of the material concerned with the details of zoning can be found elsewhere. However, we have summarized the salient features of zoning and have extensively referenced background material that engineers and planners might wish to examine in more detail in specific situations. We have further addressed the importance of the uncertainty of data used in zoning.

It should be recognized that zoning ordinance requirements specify the minimum zoning boundaries (consistent with sound engineering analysis and judgement) that are to be used. We have pointed out additional factors that should be considered by engineers and planners when determining circumstances where the minimum zoning requirements might be extended in the interests of the overall well being of a community.

The report therefore has two purposes:

(i) to synthesize current information on two district flood plain zoning particularly with respect to engineering and planning factors, federal guidelines and criteria, alternative zoning methods and implementation procedures, and

(ii) to specifically examine the data requirements for two district flood plain zoning with particular emphasis on the consequences of uncertain data and knowledge so that planners and engineers can categorize potentially troublesome situations not clearly covered by the National

Flood Insurance Program Guidelines.

The report is in four parts. The Summary and Conclusions (Chapter 4) contains information required by the National Flood Insurance Act as well as our conclusions that should be of interest to engineers and planners concerned with uncertainty in methods and data.

The main body of the report first places flood plain zoning in context with the all encompassing category of flood plain management. Regulatory approaches to guide land use in flood prone areas are evaluated and constraints to adopting a two district zoning ordinance are posed.

Engineering and planning considerations which are imperative to the delineation of the flood fringe and floodway district are addressed, with the emphasis placed on what data are needed and what effect the data uncertainty plays in establishing the delineation boundaries. Attention is also given to how the flood fringe and floodway are delineated.

The importance of the National Flood Insurance Program is considered and alternative methods of zoning are compared with respect to meeting Constitutional requirements and flood zoning criteria established by federal agencies.

Finally, implementation of a two district flood zoning ordinance is discussed and the importance of incorporating the flood zoning ordinance into the scheme of broader land use programs used in conjunction with other flood plain management alternatives to avert flood losses is emphasized.

CHAPTER 1

THE PROBLEM OF REDUCING FLOOD LOSS

> But a Great Society cannot rest on the achievements of the past. It must constantly strive to develop new means to meet the needs of the people. To hold the Nation's toll of flood losses in check and to promote wise use of its valley lands requires new and imaginative action.
> (Lyndon B. Johnson, 1966)

Flood damages in flood plains along rivers and streams and thin coastal strips currently exceed $1 billion annually in spite of enormous private and governmental expenditures for flood prevention. Despite a federal expenditure of more than $7 billion since 1936, flood losses continue to mount. (U.S. Water Resources Council, 1971:13)

Flood plain land adjacent to rivers and streams has historically offered advantages to the developer. Rivers provide a transportation artery, a recreation source, industrial power, water supply, and waste removal mechanism. Flood plain fertility encourages agriculture; flatness encourages urban, railroad, and highway development.

Man creates flood damage potential with the construction of a single structure on a flood plain either at an elevation below past or potential flood inundation depths or without regard to the effect of the structure upon flood flows. Initial development tends to establish a pattern for similar development over the flood plain. The presence of structures on the flood plain alters its hydraulic characteristics causing flood heights and velocities to increase relative to natural conditions. Increased flood heights and velocities, for a given discharge, cause flood damage losses to multiply particularly as further structures are added. When a catastrophic flood occurs, and the area is declared a "disaster area" people who have been flooded may receive emergency assistance.. It can be expected that this phase will then be followed by another in which financial support is requested from the Federal Government, or from the state or city for flood protection works.

Engineering works such as dams and reservoirs, levees, flood walls, and channel improvements, while greatly effective, usually will not afford complete flood control, and the public, with complete faith in the protection works may rush in with development clear to the river bank, not realizing the inevitability of catastrophic damages which will result from the occurrence of a major flood.

In essence, the dilemma of flood plain occupancy is the problem of determining the best use of the nation's flood plain lands. The National Water Commission (NWC) in a report which has recently been submitted to the President and Congress, recommends:

> That the people of the United States treat their flood plain lands as an especially important resource that should be so managed that it makes the maximum possible contribution to national welfare, keeping in mind, (a) that the material wealth of a nation is not enhanced by development of any tract of land subject to flood overflow unless the net value of the resulting production exceeds the cost of development, plus the flood losses (or the cost of preventing such losses), and (b) that any non-material values sacrificed through development must also be counted as a cost (NWC, 1972:16).

FLOOD PLAIN MANAGEMENT GOALS AND ALTERNATIVES

Flood plain management is a purposely broad and all encompassing term, well defined by James E. Goddard (Dougal, *et al.*, 1969:12) as a term which,

> ...includes all measures for planning and action which are needed to determine, implement, revise and update comprehensive plans for the wise use of flood plain lands and their related water resources for the welfare of our nation.

The overall goal of flood plain management policy is to reduce flood loss by:

1. Minimizing the loss of life, personal suffering, and physical hardships.

2. Achieving optimum economical use of the flood plain.

To accomplish the goal of flood loss reduction effectively, many alternative measures must be considered. The National Water Commission (1972:16) recommends

> ...that in formulating plans for flood loss reduction full and equitable consideration be given to all practicable alternative measures for achieving that goal, with a view to finding the best combination of such measures.

These control measures or techniques may be classified in many ways. <u>Structural measures</u> may be distinguished from <u>nonstructural measures</u>. <u>Regulatory measures</u> may be separated from <u>non-regulatory measures</u>. The terms can easily be interpreted to have different meanings and might be used interchangeably dependent on one's specific understanding. For instance, flood plain zoning is often identified synonymously with flood plain regulation, while zoning is actually only one form of flood plain regulation, and flood plain regulation in turn, can be viewed as only one form of land use regulation. To establish a degree of consistency the following outline presents flood plain management alternatives in the context that they will be used in this report.

--Flood Plain Management Alternatives--

I. Structural

A. Major structures (dams and reservoirs, levees, flood walls, channel improvements)

B. Flood proofing (regulatory and voluntary)

II. Nonstructural
  A. Flood insurance
  B. Warning and evacuation
  C. Land treatment
  D. Land use adjustment
    1. Regulatory
      a. Statutes
      b. Zoning ordinances
      c. Subdivision regulations
      d. Building codes
      e. Miscellaneous ordinances
    2. Non-regulatory
      a. Government acquisition
      b. Building and financing
      c. Urban renewal
      d. Permanent evacuation

Typical structures include dams and reservoirs in upstream areas which reduce flood heights by storing peak flow; levees which confine waters to channels; and, channel improvements which increase the stream's capacity to carry floodwaters.

Floodproofing refers to a combination of structural provisions, changes, or adjustments which are designed to reduce flood damage to properties and structures subject to flooding. Shaeffer, et al., (1967) described flood proofing methods in detail which could be employed to prevent water from entering different types of buildings, and the Office of the Chief of Engineers, U.S. Army (OCOE) published draft floodproofing regulations, recommended for incorporation into building codes (OCOE, 1972).

Flood insurance is insurance that covers losses due to floods, and will be discussed in detail[1] with regard to flood plain zoning.

Warning and evacuation measures consist of flood forecasting and evacuation plans. Warning signs are placed in the flood plain area to warn people of flood hazards by showing high water marks for designated or experienced floods.

James and Lee (1971:238) describe land treatment measures as those that, "attempt to decrease runoff by increasing infiltration." Contour plowing, bush control, range seeding, on farm land; and, tree management and fire control on forest land typify land treatment methods.

Land use adjustment refers to changes in land use to reduce damage potential from flooding. This adjustment may be accomplished voluntarily or be induced through regulatory techniques. Nine land use adjustment techniques have been generally categorized with respect to their being regulatory or non-regulatory in accordance with a similar categorization presented by the Water Resources Council (1971:19-21). However, Murphy (1958:13-15) classifies all nine of the measures as regulatory measures, and describes them as follows:

> ...Statutes are those state laws which are concerned with channel encroachment, and channel encroachment is usually defined in the laws as construction in the width of the channel that aggravated flood conditions. Zoning ordinances specify the type of land use or development that is desirable and permissable from an overall planning viewpoint. Subdivision regulations are concerned with restrictions on development in flood areas or the necessary requirements a subdivider has to comply with to protect the area from flood. Building codes designate the type of construction of individual houses or buildings. Miscellaneous ordinances are those separate ordinances and

[1] See page 78.

> codes that cities and counties pass to establish certain prohibitions or certain minimum standards of construction and development that are not normally found in zoning ordinances, subdivision regulations, or building codes. Government acquisition is the procurement of land by any level of government by any of several means, Building and financing is the loaning or guaranteeing of loans for building construction. Urban renewal is the clearance and redevelopment of blighted development in order to greatly reduce losses from floods and eliminate the cause of blight. Permanent evacuation is the relocation of towns from flood areas. (Authors' emphasis)

While the flood plain management alternatives presented might not be all inclusive they illustrate a range of alternatives which may be considered in planning for the optimum utilization of the flood plain.

FLOOD PLAIN MANAGEMENT POLICY--SOME ISSUES

Historically large scale engineering works have been relied on to prevent or reduce the extent of flood inundation and damage in the nation. However, especially during the last 25 years, a greater awareness of the need for a broader concept of flood damage protection rather than a single action of flood control has prompted a shift in flood plain management policy from placing primary emphasis on structural controls to a balance between structural and regulatory type controls (Arey, 1971:34).

At the national level, this shift in policy is evidenced by several reports, administrative guidelines, public laws, and increased efforts of federal agencies to encourage and aid states and local communities to establish sound flood plain management programs with emphasis placed on regulation of land use. Significant measures include:

1. Congressional action in 1960 established and initiated a flood plain information program. The Flood Control Act of 1960, as ammended, authorizes the Secretary of the Army, through the Corps of Engineers (COE)

to compile and disseminate information on flood hazards and provide guidance to federal and nonfederal agencies in the use of flood plain areas. Under this authorization the Corps of Engineers carries out its Flood Plain Management Services Program (Dougal, et al., 1969:207-218).

2. House Document No. 465, A Unified National Program for Managing Flood Losses (House of Representatives, 1966), advised federal flood control policy be reevaluated to encourage a range of management techniques. Federal agencies were directed to coordinate and apply broad planning criteria for new federally funded developments on the flood plain, to improve basic knowledge about the flood hazard, to provide technical information and services to managers of flood plain properties, and to implement a national program for flood insurance. HD 465 expanded the scope, and accelerated flood-hazard information studies carried out by the Corps of Engineers and other federal agencies.

3. Executive Order 11296, in which the President directed federal agencies to consider flood hazards in locating federal installations (Office of the President..., 1966).

4. The U.S. Water Resources Council (WRC) report compiled by the Hydrology Committee, A Uniform Technique of Determining Flood-flow Frequencies (WRC, 1967), adopted the Log-Pearson Type III method and encouraged all agencies to use that statistical method in relating flood frequency to flood discharge.

5. The U.S. Department of Housing and Urban Development, National Flood Insurance Act of 1968 as Amended (HUD, 1971b), provides flood insurance on certain existing structures and their contents at rates subsidized by the federal government.[2]

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[2]Subsidized rates are discussed in detail on page 79.

6. The U.S. Water Resources Council publication, Regulation of Flood Hazard Areas to Reduce Flood Losses (WRC, 1971), covers: the legal and administrative issures and applications of the regulatory approach of flood plain management, and is designed to assist states and local units of government to adopt enabling legislation and zoning ordinances.

7. The U.S. Water Resources Council report (WRC, 1972a), established guidelines for implementation of the Presidential Executive Order 11296, and recommended that the 100 year flood be used to determine the limits of the regulatory-flood plain.

8. In 1972 the United States Senate passed a national land use bill (Liebman, 1973:16). While Senate Bill 292 has not yet passed the House of Representatives, its prospects of becoming law are likely in the next session of Congress.[3] If passed, the bill will grant states $100 million per year for the development of state land use plans and programs which are likely to include dollars for land use and adjustment with respect to controlling flood losses.

LAND USE ADJUSTMENT--ENABLING STATUTES

> ...Rivers were here long before man, and for untold ages every stream has periodically exercised its right to expand, when carrying more than normal flow. Man's error has not been the neglect of flood control measures but his refusal to recognize the right of rivers to their floodway...
>
> (Engineering News Record, 1937)

In order to carry out land use policies with respect to flood plain development, the boundaries of the floodway and flood plain have to be considered and in most cases specified. Zoning ordinances, strictly dealing with flood control zoning or flood hazard zoning, may or may

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[3] From the August 6, 1973 issue of the Seattle Times, p. A13.

not be part of existing land use policies in most communities. However, a 1971 Water Resources Council study found:

> Present state enabling legislation authorizes most cities and many counties, villages, towns and other units throughout the country to adopt zoning, subdivision regulations, and building codes. Some legislation specifically authorizes adoption of regulations to protect life and property against flood losses. Most acts do not. The Water Resources Council study has found no case where a court has invalidated flood hazard ordinance provisions on the basis of inadequate enabling legislation. Each state's enabling language differs somewhat, but it appears that in general, existing statutory authorization may be sufficiently broad to authorize local adoption of flood hazard area regulations as part of broader zoning subdivision regulations, or building codes (WRC, 1971:112).

This study (WRC, 1971:70-111) sets forth three alternative versions of model statutes which spell out state-local responsibilities with regard to regulation of flood hazard areas. The first version would authorize a state agency to regulate general development in flood hazard areas if local units of government fail to adopt satisfactory regulations. The second version would authorize a state agency to regulate flood hazard areas independent of any local effort. The third alternative would authorize a state agency to aid local units in regulating flood hazard areas.

The attractiveness of each of the draft alternatives to the state will depend upon the ordinance provisions and operational programs which currently exist; however, the report recommends the third alternative wherein a conjunctive state-local program is adopted with the following combination of regulatory provisions (WRC, 1971:14):

1. Legislative enactment of a statute authorizing a state agency to study, plan, and regulate selected classes of uses in developing regulatory programs and to regulate general development in flood hazard areas if local units of government fail to adopt satisfactory regulations.

2. Legislative enactment of a single broad statutory regulation, and building code enabling legislation for the purpose of specifically authorizing local units of government to adopt regulations for flood loss control.

3. Adoption by cities, villages, and counties of a two district zoning ordinance delineating floodway and floodway fringe districts.

This report is primarily concerned with the latter item, the two district zoning ordinance providing for delineation of floodway and floodway fringe districts.

CHAPTER 2

FLOOD PLAIN MANAGEMENT TERMINOLOGY

Most of the terms used for describing flood plain regulations in this report are illustrated in Figure 1. A detailed explanation of how the flood plain and floodway limits are arrived at is given in Chapter 3. The following definitions given by Kusler and Lee (1972:19) are used herein:

> FLOOD DISCHARGE is the quantity of water flowing down a stream valley. The water is the result of runoff from rainfall, snowmelt, or a combination of both.
>
> REGULATORY-FLOOD DISCHARGE is the discharge selected for the delineation of the flood plain, floodway, and flood-proofing requirements in flood plain regulations.
>
> THE REGULATORY-FLOOD PLAIN composed of the regulatory floodway and regulatory-flood fringe, is the area adjoining a river, stream, watercourse, or lake which is inundated by the regulatory-flood discharge.
>
> THE REGULATORY FLOODWAY is the unobstructed portion of a flood plain consisting of the stream channel and overbank areas capable of conveying a selected flood discharge and keeping it within designated heights and velocities. The floodway is intended to carry the deep and fast-moving water.
>
> THE REGULATORY-FLOOD FRINGE is the portion of the regulatory-flood plain beyond the limits of the floodway. Flood waters in this area are usually shallow and slow moving.

Satisfactory working definitions of flood frequency and the natural floodway are:

> FLOOD FREQUENCY. Floods along a single stream are commonly compared in terms of their frequency of occurrence which is indirectly related to the discharge. For example, if a flood with a 100 year recurrence interval is used for delineation of the flood plain, this means that the capacity of the designated floodway will be based on the discharge of the flood that has a 1 per cent chance of occurring in any given year, or over a very long period would

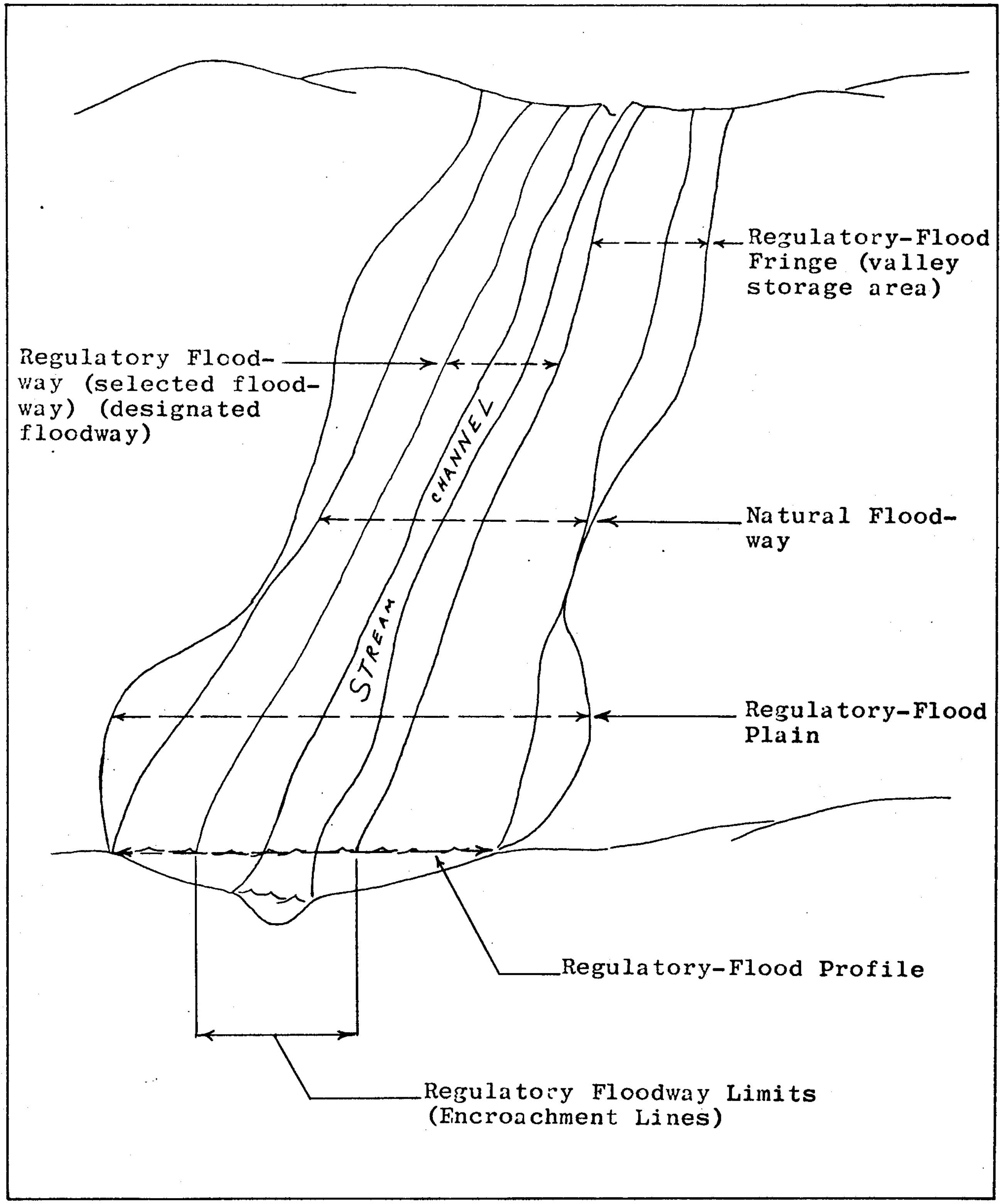

Figure 1. Plan View of The Regulatory-Flood Plain.

occur on the average of once in 100 years. It does not imply that the flood will occur at regular 100 year intervals but over a period of say 1,000 years, it could be expected to occur in 1 per cent of the years or 10 times. It would be possible to have occurrences in successive years, several occurrences in any given year, or periods of 100 years or more during which the flow was not exceeded.

THE NATURAL FLOODWAY is the channel of a watercourse and those portions of the adjoining flood plain which are required to carry and discharge the floodwaters of a selected probability-of-occurrence flood. The natural floodway boundaries consist of smooth lines depicting uniform hydraulic flow patterns. The natural floodway boundaries always lie within the regulatory-flood plain.

CHAPTER 3

FLOOD PLAIN ZONING

The standard zoning control acts[1] which form the basis for legislation in most states are generally adequate for authorizing local unit governments to regulate flood hazard areas. However, if state delegation of flood plain zoning authority to local units is required, it is recommended that it be accomplished through use of a broad state legislative amendment supplementing existing state enabling acts. This approach is favored by the Water Resources Council (1971:119) as it allows, "...regulation of flood hazard areas to take place within the context of comprehensive land use planning and land use control programs."

Flood plain regulations contained in a zoning ordinance, much like other land zoning ordinance provisions consist of a written text which sets forth regulations and maps which delineate the boundaries of districts. An important aspect of zoning is that regulations can be tailored to meet the needs of flood prone areas. Zoning can be used to restrict uses of floodways, to specify what and where uses may be located in flood fringe areas, and to establish floodproofing requirements (WRC, 1971:16).

REGULATORY APPROACH TO FLOOD PLAIN ZONING

Two basic regulatory approaches are employed to guide use of

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[1] Zoning enabling legislation in most states is similar due to wide use of the Standard State Zoning Enabling Act (SZEA) which was prepared in the early 1920's by the Department of Commerce and distributed nationwide to states and municipalities (WRC, 1971:112).

flood prone areas. These approaches, the plan approach and the case approach, are described as follows:

Plan Approach

> Comprehensive written specifications are sometimes incorporated in statutes, local ordinances, or administrative regulations detailing what uses are permitted under what conditions in designated flood-prone lands. Administration is more or less a mechanical process of issuing permits for uses allowed or denying permits for uses prohibited by the express terms of the regulations which state what uses may be conducted in particular districts in a specified manner. The landowner or developer can determine what he can or cannot do with his lands by examining the written regulations and maps (WRC, 1971:328).

A plan approach in most instances will need to combine pre-stated written regulations with some degree of case-by-case evaluation of proposed uses. This is especially true when alterations to existing developments are proposed or when application for proposed development is done on a special exception basis.

Case Approach

> The second approach involves the use of regulations which broadly authorize an administrative agency to determine on a case-by-case basis whether proposed uses will be allowed at particular flood-prone sites. The statute or ordinance authorizes the agency to consider applications for development in light of general standards set out in the ordinance or statute, and, having determined the necessary facts, to deny or permit the applications fully or conditionally. The regulations do not specifically allow or prohibit most uses, but authorize the agency to determine the appropriateness of particular uses at specific sites in light of program objectives. Landowners find out specifically what they can or cannot do with their land when they apply for development permission. This approach is presently used for most state-level evaluation of permits for dams, dikes, reservoirs, channel modifications or other obstructions in channel or broader floodway areas. It is commonly used for subdivision plat review at State or local levels. (WRC, 1971:329).

Community Considerations Needed to Adopt Zoning Ordinance

Essentially, the plan approach relies on application of pre-stated regulations detailing what uses are permitted under specific conditions in designated flood prone lands. This approach requires that specific flood flow data as well as topographical and hydraulic conveyance data be collected and analyzed to permit evaluation of flood hazards in the flood plain before enactment of a zoning ordinance.

The case approach relies on case-by-case evaluation to determine what uses are permitted under what conditions when landowners seek development permits. Evaluation of flood hazards and tailoring of development standards is done after enactment of the zoning ordinance.

Generally, a zoning ordinance which favors a plan approach for setting forth regulations is best suited for two or more districts, while a zoning ordinance which favors a case approach for setting forth regulations is best suited for a single district.

Before a local community decides which approach is most applicable to adoption of a particular zoning ordinance it should evaluate its own administrative, planning, and regulation enforcement capabilities with respect to the flood data available, and technical assistance which might be obtained from state and federal agencies.

A selection process (WRC, 1971) which a community might follow is summarized in Figure 2.

Combination of Zoning Methods

In some instances it may be advantageous to combine aspects of both the planning and case approaches. This strategy may use the two district and single district approach in one ordinance. When data and socio-technical expertise required to adopt a two district zone are not immediately available, delineation of the flood plain (single zone) may be undertaken first, with provision allowing for the floodway

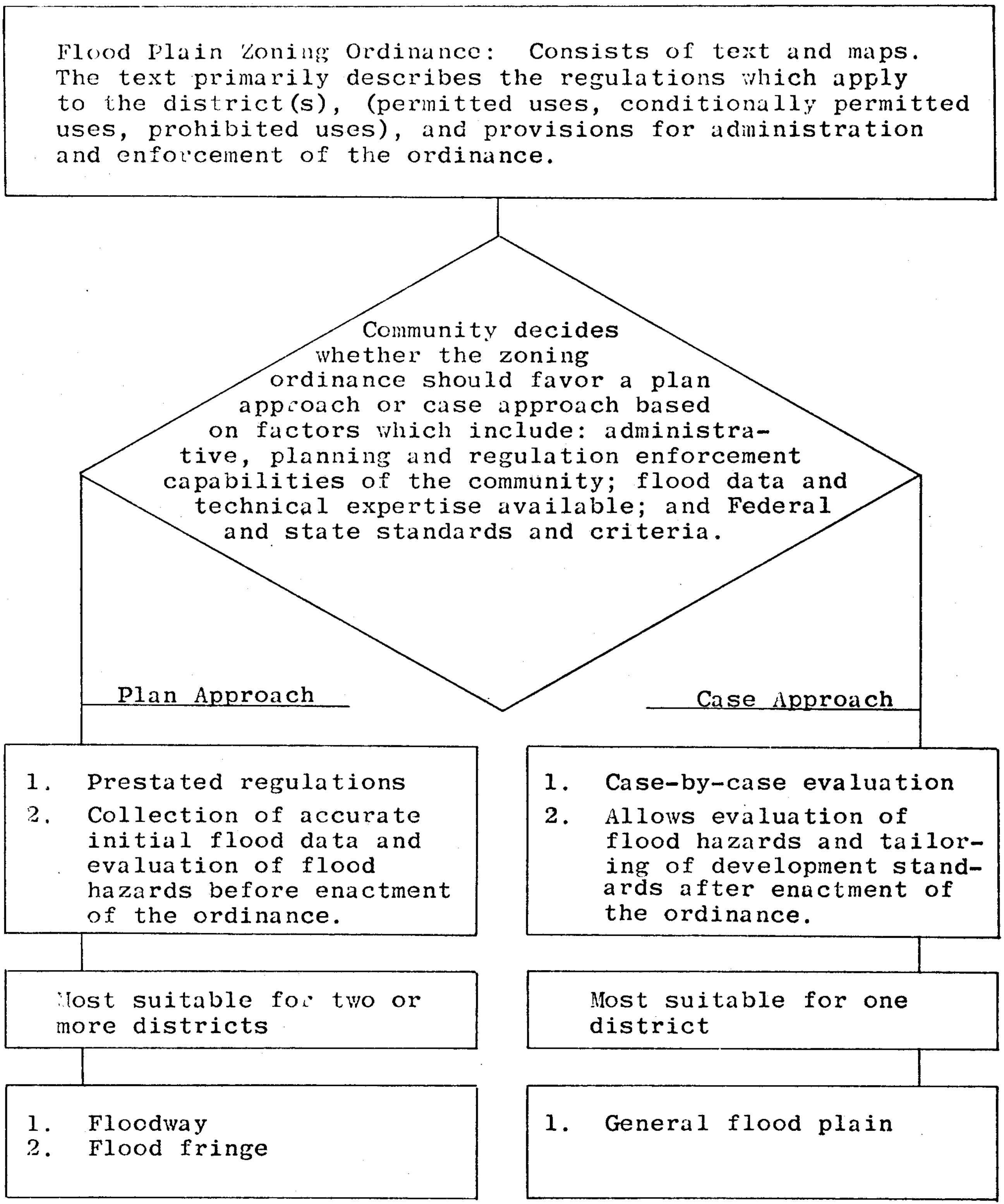

Figure 2. Systematic Comparison of Plan and Case Approaches to Flood Plain Zoning.

delineation to be effected as necessary data and technical assistance become available. This method is suitable for urban or rural communities.

Rarely are detailed data available or even needed for the entire length of each stream in a community. The single zone ordinance often permits immediate regulation of community lands even though detailed engineering studies are available for only part of the streams. As more data become available, the ordinance can be amended so that a two district zoning ordinance applies to more and more sections of the streams. (Kusler and Lee, 1972:43)

Summary

Selection of the best zoning method for a flood plain depends upon local physical and economic conditions, community acceptance, flood data, available technical assistance, and whether or not the zoning ordinance regulations are to be combined with other land use measures and flood plain management alternatives. It is important that the zoning method meet the criteria established by federal guidelines, particularly those of the National Flood Insurance Program.[2]

Generally, a two district zoning ordinance, with pre-stated regulations for riverine flood hazard areas is preferred over a single district approach (WRC, 1971:491) as it provides owners of flood prone lands the greatest certainty as to how they can develop their lands, lessens the chance of arbitrary or discriminatory decision making during administrative phases of a regulatory program, and lessens the need for special administrative expertise. However, a two district approach requires detailed flood flow data. Therefore, enactment of a two

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[2]Importance of participation in the National Insurance Program is discussed in detail on p. 78.

district flood plain zoning ordinance may not be practicable for areas such as rural recreation areas.

CONSTRAINTS

Constraints to adopting a two district zoning ordinance can be expected to exist in varying degrees among different flood prone communities. Principal constraints are planning and legal, engineering, financial, social, political, economic, and environmental.

Planning and Legal

In order to consider enacting a two district zoning ordinance it is essential that a great deal of planning effort be undertaken at both state and local levels. Adoption of basic enabling legislation by the state legislature is necessary if existing statutes are insufficient to authorize local units of government or a state agency (or both) to plan and regulate private and public uses in flood prone areas either as a part of a broader land use planning and regulatory effort or specifically for flood loss control. While local units of government generally possess sufficient enabling authority to adopt a two district flood zoning ordinance as part of a broader zoning authority it is imperative that they select policies which facilitate adoption, administration, and enforcement of the two district zoning ordinance.

Engineering

Lack of data and technical aid may be a barrier to flood plain zoning. Detailed engineering studies[3] are essential to the flood plain delineation required by the two district flood zoning ordinance and

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[3]Engineering considerations are discussed in detail on pp. 27-74.

should include:

1. Flood data reflecting peak flows available from historical stream-flow records or synthesized stream-flows.

2. Flood plain cross-section data obtained through field survey, from topographic maps or through photo stereoplotter techniques.

3. Hydraulic analysis considering duration, depth, and velocity of flooding.

4. Location of floodway and flood plain limits on large scale maps.

5. Evaluation of flood hazards with respect to specific uses of the flood plain and in light of flood control regulations which might be adopted to impose specific conditions on development.

Financial

Costs involved in obtaining and analyzing engineering data required to delineate the floodway and flood fringe area are high and might range from $20,000 to $40,000 for a five to ten mile reach of river (Kusler and Lee, 1972:32). In addition, it might take many months or even years before the engineering studies are completed.

Social

Essentially, public acceptance of a two district zoning ordinance depends on the public accepting the concept that a floodway district should be kept free of obstructions which increase flood heights and velocities (causing damage to other lands) and that land uses in the flood fringe district be restricted or structures be flood proofed to reduce flood losses in the flood fringe. The reasons for accepting or rejecting this concept can be expected to vary among different groups of people for different reasons. For instance, land developers proposing a construction project within the floodway can be expected to view settlement in flood plains in a much different light than members of conservation groups interested in preserving the flora and fauna of the wetlands. The successful implementation of a flood plain zoning ordinance requires that the views of the people in the flood plain area be evaluated and incorporated into the ordinance.

Public participation in planning has provided encouraging and impressive results towards this end. Some of the techniques used to involve the public according to Willeke (1973:22) include, "...workshops, forums, familiarization tours, brochures, opinion surveys, pro and con sheets, participation score cards, briefings, and modified public hearings."

Through these techniques, "...better communication, consideration of more and different alternatives, better definition of issues, and building of legitimacy and trust...," can be obtained between the planners and the people (Willeke, 1973:19).

James (1973:25) points out that it is ridiculous for planners to propose cure-all nonstructural solutions without presenting workable procudures for implementing them. He stresses that because nonstructural measures must control people through regulatory type programs it is pertinent that surveys be conducted to determine how the people view the proposed regulatory program. Only after their feelings are known, can communication techniques best be tailored to relate the merits of the program to the people, to secure their understanding and support.

Political

The two district zone might not be politically acceptable.

Restriction of development in the flood plain may result in the loss of tax revenue for the community due to new industry locating in other communities where use of the flood plain is not restricted or where structural measures allow its use.

It may also be expected that land developers who want to encroach upon the floodway as well as people who are already located in the flood plain will exert pressure against zoning measures which by their nature will alert persons to the fact that flood hazards exist, and consequently lower real estate values.

Close coordination between agencies carrying out the flood plain delineation studies and representatives of the community is imperative, especially with respect to mapping floodway and flood plain limits. Obvious errors in location of floodway and flood plain boundaries can be avoided by showing preliminary boundary locations to "old-timers" who can recall the extent of inundation of past floods. Through close coordination efforts between planning agencies and the community better public relations can be expected and embarrassing errors that might create political issues avoided.

Economics

If the flood plain is delineated into a floodway and flood fringe area,will the net benefits resulting through use of this zoning technique be greater than through use of other (or combinations of other) flood plain management alternatives?

In practice it is likely that flood plain zoning may include some activities that could have profitably located in the flood plain, as well as some for which it would not have been profitable (Lind, 1967:348).

Hence zoning may be objected to on the basis that it does not provide the most economical approach to mitigating flood loss.

Environmental

In most cases environmental aspects, especially those related to preserving open flood plain lands and wetlands for wild game, fish and other aquatic life, will not act as a constraint, but rather will reinforce the open space floodway concept of the two district approach. Nevertheless, the zoning approach must be consistent with existing or planned environmental programs.

Where possible, zoning of land areas should insure that pollution to surface and ground water will be minimized, with respect to the effects on human, animal or plant life.

In any event, a study assessing the impact of flood plain zoning measures on the environment (environmental impact statement) must be conducted prior to adoption of a zoning ordinance (National Environmental Policy Act, 1969).

Summary

Flood plain zone boundaries are determined from uncertain hydrologic, hydraulic, and topographical data which means the mapped boundaries are the expected or average boundaries for the regulatory flood. Citizen participation is important for establishing the actual boundaries that are to be enforced. The initial expected boundaries could therefore be legitimately adjusted (within calculable error bounds) to accommodate subjective information presented by any citizen (particularly "old-timers") who feels that parts of the calculated boundaries lack credibility. Suitable legal machinery must be operable to enforce the zoning boundaries so established. The plan must reflect the community's ability to administer the zoning ordinance.

While physical flood plain zoning may not result in the optimum economic use of land in the flood plain, the relative simplicity of implementation and management probably compensates for this deficiency (this is not established fact). A rigorous economic analysis recognizing net economic benefits as well as economic benefits to the region requires far more data than is needed for two district zoning. Further, the uncertainties included by the use of incomplete economic data may tend to confuse planning decision making rather than help.

ENGINEERING AND PLANNING CONSIDERATIONS--TWO DISTRICT ZONING

Three principal topics are covered in this section:

1) Data needed for determination of the expected relevant flood zone boundaries are described. These data are used in deterministic hydraulic and mapping procedures.

2) Procedures employed in delinéating the expected floodway and flood fringe are fully discussed.

3) Uncertainty associated with data, models, and mapping procedures is discussed. Recommendations are made for modifications to the boundaries obtained by average deterministic procedures to reflect the uncertainty resulting from uncertain data and procedures.

1) Data Needed

Data of principal importance for delineating the flood plain can be classified into 3 general categories:

1. Peak flow data
2. Field survey data
3. Map data

The schematic diagram in Figure 3 shows how these data are related to establishing the actual flood fringe and floodway boundaries.

Regulatory-Flood Frequency and Regulatory-Flood Discharge

It is readily apparent as illustrated in Figure 3 that the selection of a flood having a specific return period (to use as the regulatory-flood) is of paramount importance in flood plain delineation. Normally the 100 year return period flood is specified as the regulatory-flood. Estimation of this flood's magnitude nearly always

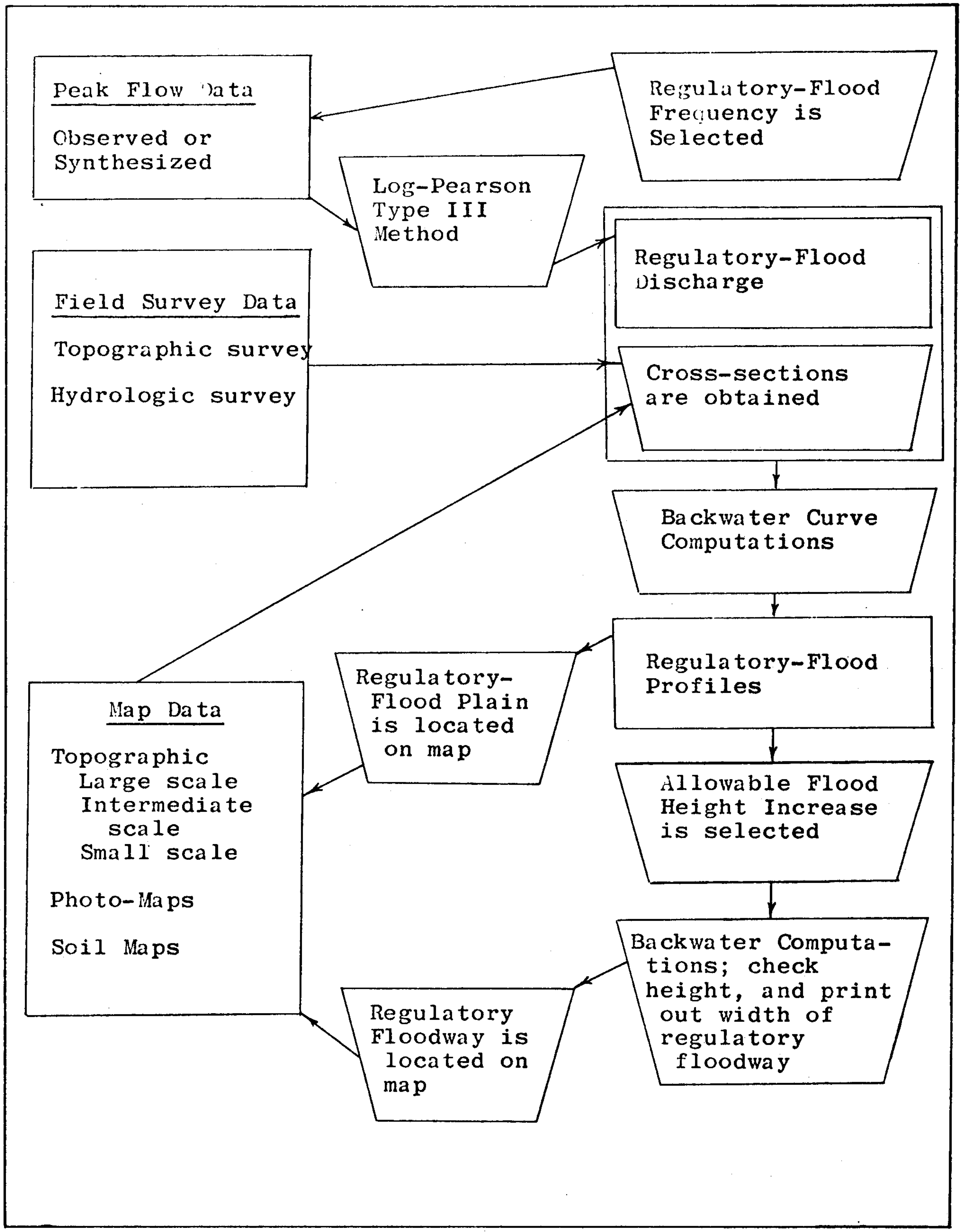


Figure 3. Data Requirements for Flood Plain Delineation.

necessitates extrapolation beyond observed peak-flood data. Therefore, there is much speculation as to which precedure is most suitable for estimation of the regulatory-flood. In addition to uncertainty resulting from the extrapolation procedure adapted,there is additional uncertainty in the estimated magnitude of the design flood resulting from small sample estimates of the properties of the probability distribution describing the peak-flood flows. Elements of this uncertainty are discussed later in this section.

Because there were a number of different probability distributions in use (by federal agencies) for determining peak-flood flow frequencies, the Water Resources Council adopted the Log-Pearson Type III method as a base method for determining flood flow frequencies. In doing so, the Hydrologic Committee of the Water Resources Council (WRC, 1967:6) recognized that while selection of the Log-Pearson Type III method was primarily to provide uniformity among federal agencies in calculating peak-flood flow frequencies, complete standardization was not possible or feasible. For that reason the committee recommended allowance for using other methods where adequate justification is presented. Discussion and an example problem in Appendix A illustrate the application of the Log-Pearson Type III method.

Federal guidelines (and some state laws) require that the flood frequency be determined by the statistical technique endorsed by the Water Resources Council. It is emphasized however, that the adoption of the Log-Pearson Type III method is primarily to encourage all agencies to use a uniform procedure to relate flood frequency to flood discharge.

Linsley and Franzini (1972:129) state that,

> Until much longer records are available, there is no absolute proof of the adequacy of which theoretical distribution fits the actual distribution of floods.

Usually flood frequency distributions are determined from a relatively long (30 years) record of recorded peak annual flow. However, if a long-term record is unavailable the planner may synthesize streamflows from other meteorological and hydrologic data. Four such methods for synthesizing flood peaks are discussed in Appendix B.

Cross-sections

Cross-sections of the channel and valley area are taken at man-made and natural locations along the river such as bridges, dams, fill areas and points where the natural valley narrows or widens. Cross-sections are generally taken at a maximum of 700 feet in urban areas and 1,500 feet in rural areas (Kusler and Lee, 1972:29). The accuracy of results is usually improved as the length of reach gets shorter.

A field survey instruction sheet used by the Seattle district office of the U.S. Army Corps of Engineers (1973b:1) specifies that overbank cross-sections are to be extended until the ground surface is approximately 25 feet higher than the elevation of the water surface. This empirical guideline insures that the ground covered by the cross-sections is adequate to contain the width of the flood plain. In addition, other factors which will influence backwater calculations, such as locations of rapid fall in water surface elevations, or a change in vegetation require that additional cross-sections be taken at those locations.

The cross-sectional information, exclusive of the channel (between points A and B in Figure 4) can also be obtained from topographic maps, providing the maps are current and at a proper scale and contour interval: in urban areas 1 inch = 100 to 200 foot scale and 2 to 4 foot contour interval; in rural areas 1 inch = 500 to 1000 foot scale with 5 foot contours (Kusler and Lee, 1972:29). It is important to recognize that topographic map contours can be substantially in error and that the map datum may differ from that in local use. Maps should always be checked for accuracy. Normally, contour maps can be expected to be in error by as much as one half the contour interval used.

When adequate up-to-date topographic maps are not available, information for the entire cross-section can be obtained by field survey or, in some cases, through aerial photo stereo-plotter techniques (Kusler and Lee, 1972:31).

2) Floodway and Flood Fringe Delineation Procedures

Floodway and flood fringe delineation involves seven principal activities that require professional analysis:

1) The regulatory flood hydrograph must be determined.

2) The regulatory flood hydrograph is routed through the river (and flood plain) reach being studied and the water surface profile determined.

3) The calculated water surface profile is transformed to a topographical map and the expected inundation region is located.

4) The regulatory floodway is computed on the basis that development in the flood fringe reduces the discharge capacity of the flood fringe to zero.

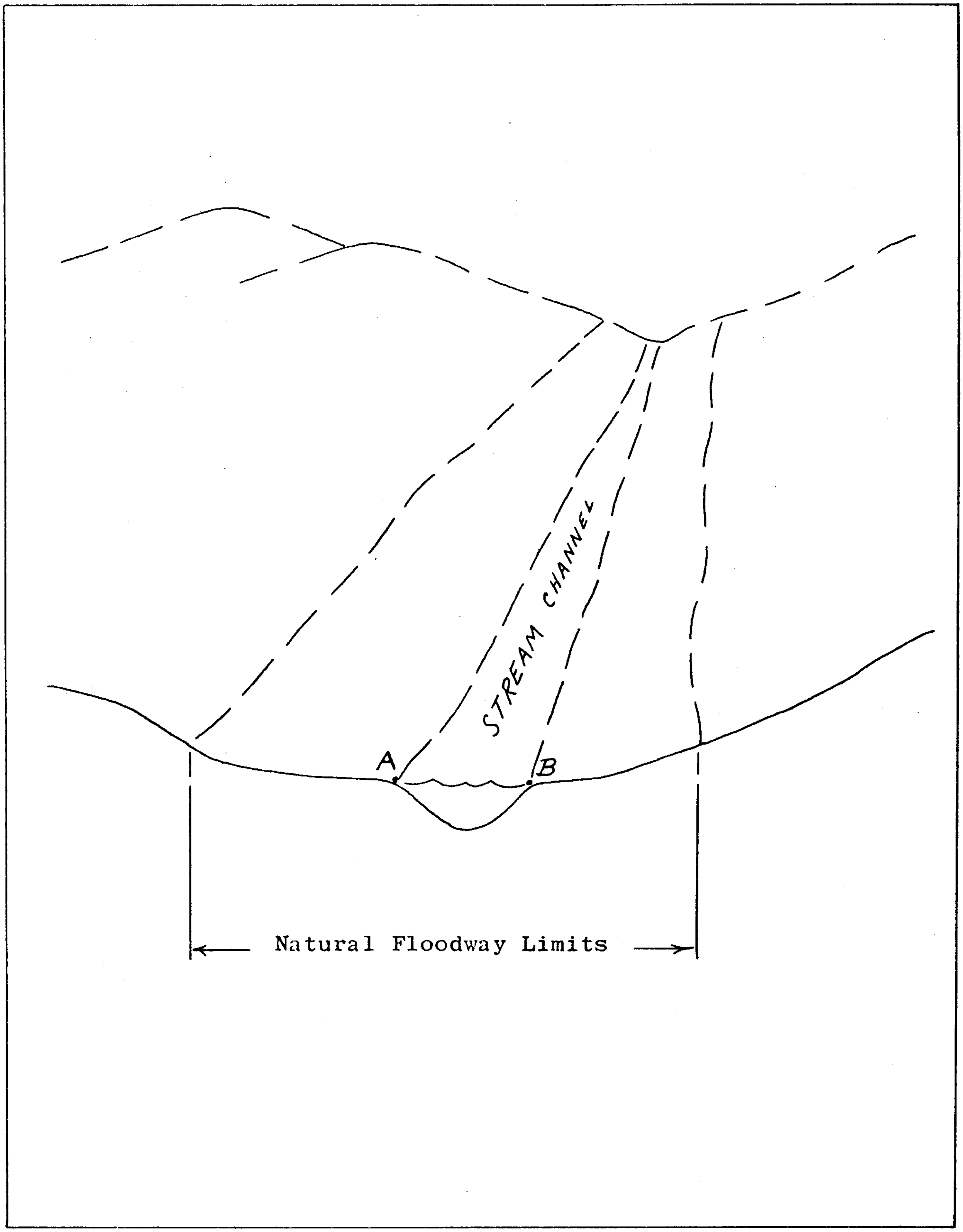


Figure 4. Valley Cross-Section.

5) Mappings of flood zones are modified to accommodate physic systems (e.g., transportation systems) and community preferences. Modifications must not violate the flood discharge requirements of the section.

6) Additional adjustments to mapped boundaries are made to reduce problems associated with drainage, groundwater tables and local ponding.

7) Depth and velocity estimates are made so that flood proofing requirements in the regulatory zones can be determined.

Details of these specific activities follow.

Backwater Curves--Water Surface Profiles

The regulatory flood discharge, channel and overbank geometric and hydraulic properties, and the topographic characteristics of the area are used to calculate the regulatory flood surface profile. Most federal agencies compute the flood surface profiles with the aid of a computer program which calculates backwater curves by solving one dimensional continuity and momentum equations. The reader is referred to Engineering Manual 1110-2-1409 (COE, 1959) (or other treatises on hydrualics) for numerous technical details.

The procedure used for computing the surface water profile requires that numerous coefficients defining frictional and other energy losses be determined by calibration techniques using flood profiles from floods other than the regulatory flood. Limited information on previous floods makes this calibration process inexact; the predicted flood profile is therefore estimated to be in error by ± 1 foot. During an actual flood, the water surface profile may vary even further from predicted values, as the result of localized debris accumulations, bank erosion or sediment deposits (COE, 1973a:9).

Flood plain boundaries are marked on topographic maps of appropriate scale using the computed regulatory flood profile. The actual floodway is located after consideration is given to allowable flood height increase.

The water profile elevations are of utmost importance in delineating the flood plain as they are used to determine the exact limits of the flood plain in the field, to solve mapping disputes and to specify flood proofing levels for construction.

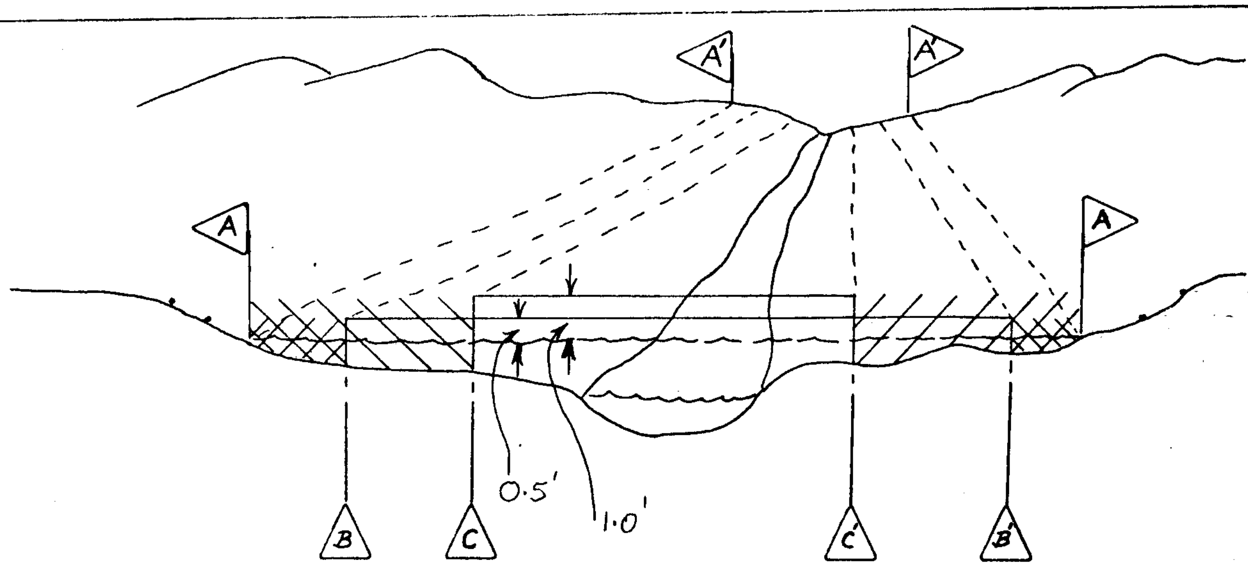
Increase in Flood Heights and Determination of Floodway Limits

In calculating the regulatory-floodway, it is assumed (COE, 1972:2) that the flood fringe will eventually be developed, filled or altered, so none of it will be available to convey or store flood water (in actuality complete loss of conveyance is unlikely). Filling or building in the flood fringe area will naturally increase flood heights over what they would have been, had nothing been filled in or built within the natural floodway boundaries. Increase in flood heights resulting from the adjustment of the natural floodway line riverward of the natural floodway are reflected in most state standards and federal guidelines (WRC, 1971:50). State standards vary but normally limit theoretical flood height increases (Figure 5) between 0.5 and 1.0 foot (WRC, 1971:235). Encroachment cannot be permitted where excessive velocities would necessitate mandatory protection of fill material. Clearly there is room for imaginative planning in determining flood plain areas suitable for filling and economic use. It should be emphasized that if flood heights do rise to the permitted increase (say 1.0 foot), then in effect the water surface elevation would be 1.0 foot above the water surface elevation of the regulatory-flood profile which was used to delineate the flood plain. However, since a new flood plain boundary is not delineated despite the 1.0 foot increase in flood height and because of the uncertainty of backwater computations depicting the exact flood surface elevation, individuals living in the flood plain and in the near vicinity just outside the flood fringe outer boundary, should insure that at least 1.0 foot of freeboard is allowed as a safety factor when floodproofing or locating new structures.

A method frequently used to determine floodway lines involves use of a computer program which allows floodway lines to be adjusted on more or less a trial and error basis until the increases for a reach of a stream having uniform hydraulic characteristics are uniformly one foot. A pamphlet from the Seattle District Corps of Engineers (1971b) refers to a computerized program that has been developed for this purpose at the Hydrologic Engineering Center, Davis, California. The program, commonly known as HEC-2, is used to determine loss of hydraulic conveyance on either side of the floodway limits and resulting water surface profiles. Figure 5, illustrates how the increases in flood stages are related to floodway determination.

Although the engineering studies assume that all of the land outside of the floodway encroachment line will be lost for hydraulic conveyance, it is unlikely in practice that all of this area would be lost for valley storage purposes unless the area was protected by a temporary or permanent levee. Lee(1971:13) points out:

> ...that most state programs however, do not as a general practice study the loss of valley storage due to potential development outside the selected floodway. Exceptions are made where particular circumstances



A-A' = Natural floodway boundaries for a flood which on the average would occur once every say 100 years.

B-B' = Regulatory floodway for 0.5 foot of acceptable increase in flood heights for the same flood. This is due to loss of hydraulic conveyance in the areas as shown by crosshatched section XXXXX which is assumed to be filled.

C-C' = Regulatory floodway for 1 foot acceptable increase in flood heights for the same flood. This is due to loss of hydraulic conveyance in the areas as shown by the crosshatched section plus the lined section XXX //// which is assumed to be filled.

It is assumed that the channel and portion of the flood plain between the encroachment lines B-B' and C-C' will convey the selected flood, the increase in flood height due to fill of the flood plain, being .5' and 1' respectively.

Figure 5. Effect That Different Permitted Increases in Flood Heights, for the Same Flood, Have on the Regulatory-Floodway Width.

> indicate that existing development patterns and land use patterns will have a significant effect on valley storage.

Floodwater depths calculated for the 100 year flood, with flood height increase limited to 1 foot due to assumed fill in the fringe area, vary from 5 - 9 feet,depending upon flood plain geometry, just outside of the floodway limits (Lee, 1971:25). Considerably lower depths of water are normally associated with the 100 year flood with flood height increase limited to 0.5 foot due to assumed fill of the fringe area, but depend on the topography. Selection of the higher 1 foot level results in more flood plain land being available for development. However, the greater use of the flood plain can cause the following problems (Lee, 1971:16):

1. The depth of the 100 year flood in the vicinity of the floodway limits (Figure 6), will normally make flood proofing of structures impractical due to depth and velocity of floodwaters which can be expected, or unreasonable due to the high cost required to flood proof structures to excessive heights.

2. "Island type" development may occur in areas near the floodway limits, if these areas are filled to heights above the regulatory-flood profile while landward areas are not. Large depths of water around the "island type" developments when flooding occurs could cause serious interior drainage problems, endanger life, and cause public burdens for rescue and relief measures. (See also Shaeffer, 1967).

The aforementioned problems can be minimized if floodway selection is based on small permitted increases (0.5 foot instead of 1.0 foot) in the regulatory-flood profile. This normally results in flood depth being less at the floodway limits due to the floodway limits being further landward from the river channel (if 0.5 foot is used rather than 1.0 foot; see Figure 6).

Generally, in highly urbanized areas no flood height increases should be permitted. This is particularly true in flood plains where the land is relatively flat and where any increase in flood heights resulting from filling could affect large areas of existing urban development. On the other hand, large increases (around 1.0 foot) in the regulatory-flood profile may be allowed in areas reserved for open space uses (such as golf courses or parks) and where there are assurances that local land use plans and controls will guarantee that the land will remain open space (Kusler and Lee, 1972:39).

Selection of the final floodway limits can be manipulated to suit the needs of a community, without compromising the established procedures for determination of the limits. For instance, coordination between community planners and the agency performing the flood plain delineation studies might allow the community planners to participate in designating where the floodway limits should be established. Then if the water profile elevations (resulting from the backwater calculations using the floodway limits recommended by the community) fall within the prescribed limited increase in flood height, the floodway limits may be so established.

The limits of the floodway at any cross-section are set on an equitable basis. Thus, where the flood plain on both sides of the river channel could be utilized by filling, the floodway limits are determined by assuming equal loss of hydraulic conveyance in both portions of the

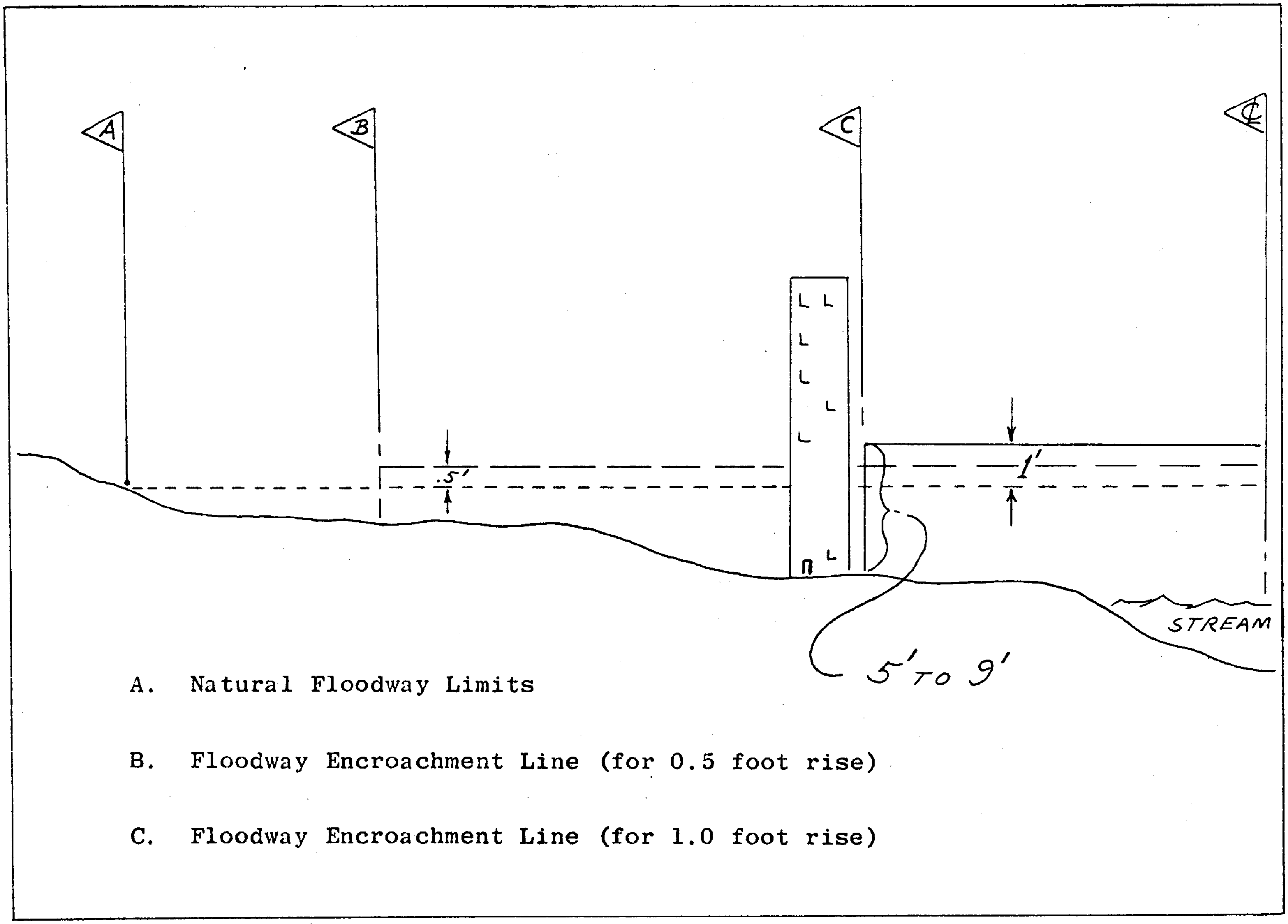


Figure 6. Relationship of Encroachment Boundary Location and Depth of Flooding to Ground Elevation.

natural flood plain farthest from the main channel.

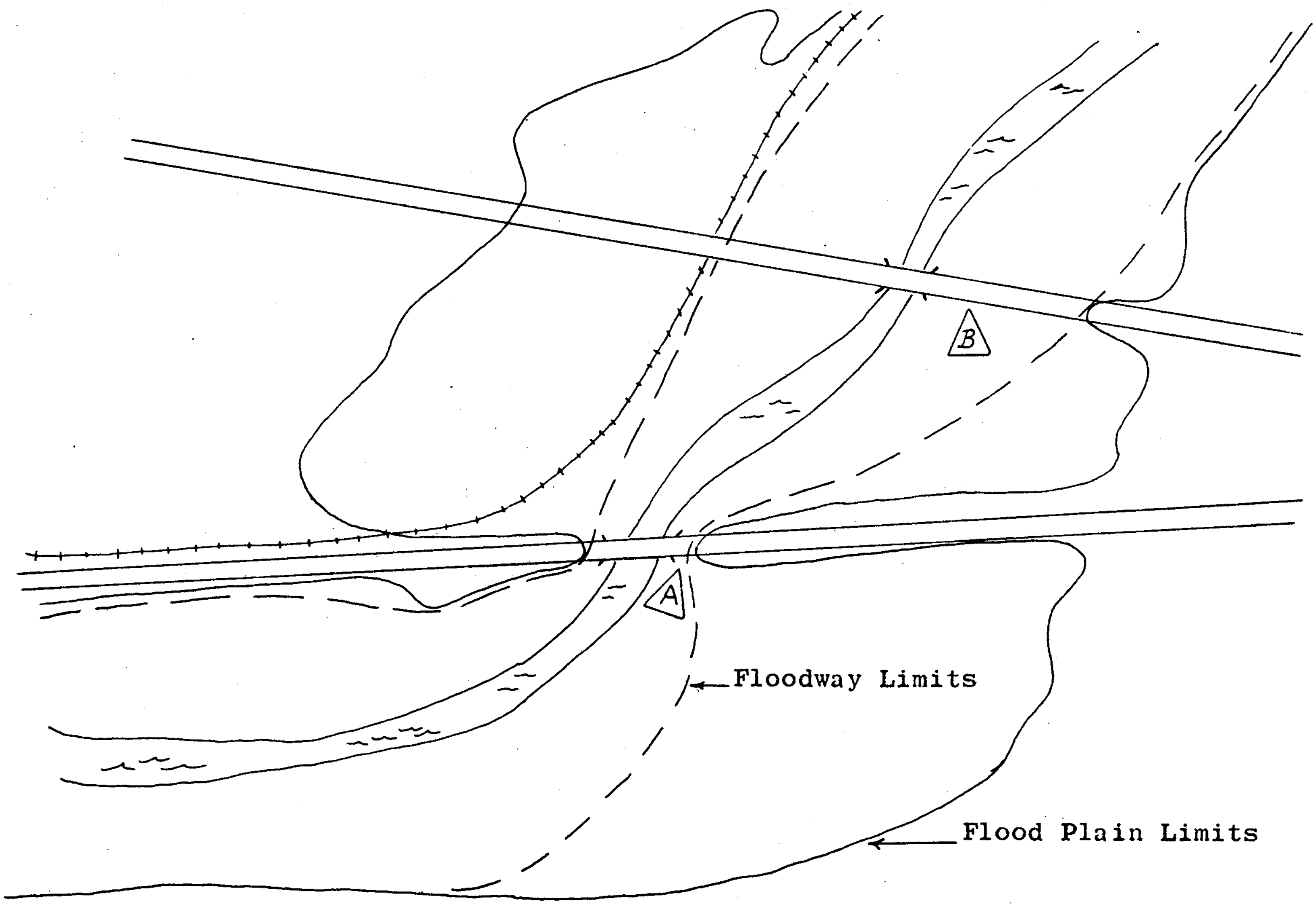
The floodway is drawn by plotting on the plan view, the calculated floodway intercepts on each valley cross-section. A smooth line is drawn between intercepts to represent the hydraulic flow configuration at the floodway limits. Flood flows ignore political boundaries and property lines and abrupt changes in the floodway line should be avoided (COE, 1972). However it may be equally difficult to enforce zoning when an owner's property is divided.

Effects of Transportation Systems

Highways and railroads particularly play an important role in influencing the final positioning of a floodway line (Lee, 1971:19). In Figure 8 a railroad parallels and a road network lies perpendicular to a stream. The railroad acts as the floodway limit, or the dividing line between moving and relatively stagnant water.

Where the regulatory-flood passes through the bridge opening without any overtopping of the road (A in Figure 7), floodway lines are transitioned into and out of the bridge opening. If the regulatory-flood overtops the road, the floodway lines are positioned so the portion of the road that is overtopped by floods will be included (B in Figure 7).

While location of existing railroad beds and road networks may adversely affect a flood situation by increasing flood heights due to restriction of flood flow, positioning of new railroad beds and road networks should be carefully planned to coincide with the location of the regulatory floodway limits and if possible constructed to at least 1 foot higher (freeboard) than the elevation of the regulatory-flood profile. In effect, a low levee would then have been constructed affording protection to development in the flood fringe.



(from: Kusler and Lee, 1972:38)

Figure 7. Influence of Transportation Systems on Floodway Boundary Location.

Interior Drainage

Attention should be paid to drainage characteristics of the flood fringe area. Once the floodway limits have been established, construction in the flood fringe may block or seriously alter drainage patterns of tributary streams that run laterally through the fringe area. Because fill in the tributary will obstruct the watercourse and cause flooding, the lateral tributary should be included within the floodway where possible, or development regulated in its vicinity (Lee, 1971:20).

Community Comprehensive Plans

Flood plain zoning regulations, like other land use controls should be related to and made part of applicable local and regional land use plans. Kusler and Lee (1972:40) state:

> Floodway selection should consider areas throughout the community planned for residential, commercial, industrial park, street and water and sewer uses.
>
> In addition, increases in flood heights attributable to a floodway section of one community should have negligible effects on adjoining communities. For acceptable floodway selection affecting more than one community it is essential that representatives from these communities actively participate in the selection.

Existing Development

Where possible floodway lines can be designed to follow the riverward side of existing building development. However, existing development areas are often ineffective in conveying flood waters since the buildings obstruct flood flows. The Water Resources Council Study (1971:4-19) states:

> A sound regulatory policy for existing uses in one area may not be a sound policy for uses in another. For an area with existing high-density and valuable development, construction of protective works, rather than regulation, may be the preferred management alternative. For scattered uses in a floodway area, regulations which require abatement of the uses may be justified. For scattered or moderate density development in floodway fringe areas, flood proofing might be required when existing uses are substantially altered or reconstructed.

Identifiable Land Features

Where the floodway parallels but does not coincide with some identifiable land feature such as a street, railroad, fence, or power line, it is desirable to establish on the floodway map the appropriate separating distance. Kusler and Lee (1972:40) point out,

> The inability of the officials and affected land-owners to locate accurately the floodway on the ground is a major problem in implementing and administering flood plain regulations.

Ground Water Table and Ponding

Where the ground water table is high, as in the case of wet lands, or in certain areas where large depressions encourage ponding, the danger of flooding may be increased after a flood or period of prolonged rainfall due to the soil becoming saturated. Subsequent rainfall or flooding will not be stored in the full ponds or be absorbed by the saturated soil but will cause flooding to be extended landward. If these conditions are severe, consideration should be given to expanding the outer flood fringe boundary and increasing flood proofing measures.

Flood Depths and Velocities

Flood depths and velocities in the flood fringe area should be small and compatible with the regulations and degree of safety required by uses in the flood fringe.

Experience in field studies has produced generally adequate "rule of thumb" criteria which state that the product of the depth of water (ft) and the velocity (fps) should not exceed seven (7) for areas associated with human occupancy or habitation (Lee, 1971:22). Higher velocities and greater depths may be permitted in other areas. Flood proofing regulations, published by the Office of the Chief of Engineers(1972:14-1) as guidelines to be used by communities in establishing building codes, assume that the maximum practical depth for which flood proofing measures are economically effective is 10 feet of free water above grade for a building or structure having a 10 foot space of basement below grade. A velocity of 10 feet per second is generally considered to be the upper limit for which flood proofing measures are economically effective.

It is emphasized that the above-mentioned standards are offered as broad guidelines and that effects of flood depth and velocity on structures are variable.

Summary

The procedures that have been outlined leave considerable room for imaginative planning within the constraints imposed. It is important to remember that at all stages of the zoning procedure limited methods and imprecise data are used. Therefore, empirical observations and engineering art cannot be ignored. Empiricism is important because one dimensional analyses are used to represent three dimensional flow phenomena.

The discussion of engineering and planning factors to be considered for delineation of the flood fringe and floodway districts specified what data are required and the criteria that those data should meet. Data requirements and criteria are summarized in Table 1.

Table 1: Data Needed for Delineation of the Expected Floodway and Flood Fringe

ITEM	METHODS	RECOMMENDED CRITERIA
1. Flood Frequency	Log-Pearson Type III frequency analysis of annual maximum floods	Design discharge is the 100 year recurrence interval flood event
2. Cross Sections a. Channel b. Overbank (1) Urban (2) Rural	Field Survey Field Survey or from topographic maps	 Scale: 1" = 100' to 200' 2' to 4' contour interval Scale: 1" = 500' to 1,000'; 5' contour interval
3. Water Surface Profile	Backwater Calculations	Water depth computations are accurate to 1 ft. at any section
4. Floodway Limits	Boundaries are plotted (through scaling) on maps meeting criteria of Item 2	
5. Allowable Flood Height Increases a. Urban b. Rural	Increase due to assumption that flood fringe will be filled	 Maximum increase = 0.5 ft. Maximum increase = 1.0 ft.
6. Flood Plain Limits	Boundaries are plotted on maps meeting criteria of Item 2	
7. Flood Velocities Residential Other areas of human occupancy	Hydraulic analysis	 Maximum of 3 fps Rule of thumb: depth of water (ft) x velocity (fps) $\leq$ 7

3) Uncertainty in Flood Plain Mapping*

Most engineering practice is associated with decision making under uncertainty. Therefore, it is important to identify and quantify elements of uncertainty to ensure realistic decision making. Thus, the importance of uncertainty, components of uncertainty, types of uncertainty, and uncertainty associated with the magnitude of the estimated regulatory flood are discussed below. Uncertainty in estimates of flood peaks is generalized and input from the generalized result is used in an example application of first order uncertainty analysis to determine uncertainty in flood fringe bounds. Some generalizations about uncertainty in locating the flood fringe boundary as well as recommendations to improve flood plain planning are made.

Uncertainty and Engineering Decision Making

There are numerous interpretations of the purposes of engineering analyses and what they could or ought to be. An analysis that provides the basis for engineering decision making should not be performed if it does not provide more appropriate information to the decision makers than could have been obtained via empirical or subjective information. When it is necessary, and possible, to conduct a technical analysis it must be remembered that the analyst is attempting to place upper and lower bounds on the estimate of the quantity being predicted. When these bounds coincide, the system is deterministic. Usually, however, we have imprecise methods and data that are combined to perform analyses yielding average expected solutions. When the variance of a particular estimate becomes large the value of the analysis rapidly diminishes. With these thoughts in mind it is appropriate to examine

*This section, p. 46-69, is of technical interest and can be omitted on a first reading.

the flood mitigation alternative known as flood plain zoning.

Because of the existence of uncertainty in methods and information used to delineate the regulatory flood plain boundaries it is unrealistic to specify only the expected (average) boundary. In fact, there will be a probability distribution representing the possible inundation boundary; there will be finite probabilities that the area inundated will be less than the anticipated (average) boundary or larger than that contained within the anticipated boundary determined by the procedures outlined in previous sections of this report.

Before examining the significance of uncertainty it is important to consider the objectives of flood mitigation planning. Numerous possible objective statements could be made. However, the basic objective is to maximize the net benefits (measured in the widest context) from land use in flood prone areas. It is therefore probable that flood plain zoning has its greatest potential in flood prone areas that have not been substantially developed.

One major problem resulting from two district flood plain zoning (i.e., one district where any obstruction to flow is prohibited while structures in the outer district are flood proofed against the regulatory flood) is that occupants of the flood fringe may be lulled into a false sense of security. Usually, zoning must be performed using the estimated 100 year flood hydrograph in order to qualify for federal flood insurance. However, flood proofing against this arbitrary flood may well be completely ineffective against larger flood magnitudes. Thus, it is important to examine every case for the consequences of a major flood, e.g., the well known Standard Project Flood (SPF) which may have a recurrence interval in the range 250 to 500 years. In situations where the floodway boundary for the regulatory flood is not substantially closer to the main river channel than that of the SPF then the wider boundary might be more appropriate for zoning purposes. It must be stressed that flood plain mapping is arbitrary and does not necessarily yield a near optimum economic use of land. Thus, it is inappropriate to make any blanket recommendations with respect to use of the SPF for delineation purposes.

Sources of Uncertainty in Flood Plain Delineation

The principal uncertainty in determining the floodway and flood fringe boundaries arises from uncertainty associated with the determination of the backwater profile for the regulatory flood. Other elements of uncertainty result from transposition of this profile to a plan view, and in the inclusion of social preference. The major physical aspects of uncertainty are associated with determination of:

i) the peak discharge,

ii) the design hydrograph characteristics,

iii) hydraulic characteristics

  a. within channel,

  b. over bank,

iv) backwater profile,

v) flood velocities,

vi) local inflow, and

vii) the effect of increase in regulatory-flood height on the outer fringe boundary location.

Additionally, errors in topographic maps used to determine flood plain boundaries can substantially contribute to uncertainty in location of boundaries.

Types of Uncertainty

There are two major types of uncertainty associated with flood plain zoning analysis. Type I uncertainty results when an incorrect representation of a fundamental process is used. This is typified by use of an incorrect theoretical flood frequency distribution to describe the observed flood peak data. Type II uncertainty results when the model of the basic process is known to be correct but the parameters are not known with certainty. Normally, both types of uncertainty are present. For example, a sample of flood peak data is used to estimate the actual flood peak population (i.e., the population contains all possible information about flood peaks) in terms of the appropriate probability distribution of flood peaks and the magnitudes of the distribution's parameters. A third type of uncertainty that might be called "ignorance" may also be present: the analysts may be completely unaware of some past event or hydraulic phenomenon that may have significant bearing on the current work.

The remainder of the discussion on uncertainty will explore the significance of Type II uncertainty. Analysis of Type II uncertainty permits lower bound estimates of the uncertainty in locating flood zones.

Uncertainty in Estimates of the Regulatory-Flood's Magnitude

Estimates of the regulatory-flood's magnitude (usually the 100 year flood) necessitates extrapolation of some theoretical probability distribution because seldom do observed records cover more than about 60 years. Thus the estimate of the magnitude of the regulatory-flood, Q_{RF}, contains both type I and type II uncertainty. For planning purposes it suffices to estimate the mean regulatory flood, Q_{RF}, and its variance S^2_{RF}.

Uncertainty in estimates of Q_{RF} is illustrated by examining and analyzing the peak annual flood data from the South Fork of the Skykomish River as recorded near Index Washington. Details of the 355 square mile watershed as well as the magnitude and date of occurrence of the largest flood discharge each year for the period 1904 to 1970 are given in Table 2. Three specific analyses of these data were performed, viz:

i) to determine if the annual flood peaks belong to more than one population,

ii) to find appropriate probability distributions to describe the observed flood data, and

iii) to estimate the 100 year recurrence interval flood event's magnitude.

It was important to conduct the first analysis because empirical observations of flood flows in Washington suggest that the very major floods, for rivers flowing west of the Cascade mountains, are caused by rapid washoff of snow by heavy warm rainfalls. These major events occur in late fall or early winter when the snowpack has not developed resistance to rapid removal. Additional floods occur during the spring snowmelt season. Thus, on an a priori basis it could be anticipated

Table 2: Annual Instantaneous Peak Flow,
South Fork Skykomish River
near Index, Washington USGS #12133000

Remarks: 355 square mile drainage area
No diversion, regulation, or reservoirs
60 years of record, Water years 1904-70
Years missing, 1906-11, 13
Records: Excellent

Year	Discharge (cfs)	Date		Year	Discharge (cfs)	Date
1904	12,400	11-30		1941	13,000	11-29
5	10,200	11-22		2	12,600	12-2
1912	26,000	11-19		3	21,200	11-23
14	24,800	1-6		4	41,900	12-3
15	15,800	11-3		5	28,200	1-7
16	14,200	10-31		6	18,400	10-25
17	14,300	11-9		7	24,700	12-11
18	54,100	12-18		8	26,900	10-19
19	26,500	12-14		9	13,800	5-13
1920	33,900	11-15		1950	33,700	11-27
1	22,100	2-11		1	33,300	2-9
2	55,000	12-12		2	7,600	10-3
3	25,400	1-6		3	25,100	1-31
4	50,500	2-12		4	17,800	12-9
5	22,400	2-2		5	18,900	2-8
6	22,400	12-23		6	27,900	11-4
7	21,500	10-16		7	31,900	12-10
8	34,300	1-12		8	8,500	5-25
9	10,500	10-9		9	24,400	11-12
1930	10,900	2-5		1960	51,800	12-15
1	19,400	12-27		1	24,200	1-15
2	50,000	2-6		2	17,800	1-3
3	46,900	11-13		3	42,400	11-20
4	53,200	12-21		4	13,800	1-1
5	35,400	10-25		5	17,900	1-30
6	11,800	5-16		6	12,200	5-6
7	14,400	12-18		7	16,800	12-13
8	27,700	4-18		8	30,100	1-20
9	17,200	1-1		9	24,000	1-5
1940	15,400	12-15		1970	11,800	10-30

Summary Statistics: mean = 24,850 cfs
standard deviation = 12,700 cfs
skew coefficient = .93

that the largest floods would fall into a "rain-snow-washoff" category and the lesser floods into a snowmelt category. Visual examination of the partial flood series, Figure 8, and the annual flood series, Figure 9, indicate clearly that the data used in the flood frequency analysis for this particular river are generated by Fall-Winter floods with the heaviest floods accurring in November and December. This relatively simple visual examination of the data indicates that there is not a significant causative deterministic differentiation of the flood peaks into more than one population. In cases where a statistical procedure might need to be followed to examine the two-population hypothesis, the procedure developed by Singh and Sinclair (1972), which requires use of the fourth moment of the data, could be employed.

The flood peaks were ranked from high to low order and plotted on extreme value probability paper, the mth largest flood being plotted at the $\frac{N+1}{m}$ recurrence interval, where N is the number of flood events contained in the sample (see Benjamin and Cornell, 1970, 449). Visual observation of the plotted data suggested that extreme value Type I (Gumbel) or Log-Pearson type III probability distributions would describe the data. Details of these probability distributions are given by Chow (1964, Chap. 8).

Figure 10 shows the 10 largest and most of the lesser peak flows in the 60 year record as well as the mean cumulative theoretical flood frequency curves that are needed for extrapolation to the 100 year flood event. The three extreme value cumulative frequency curves (these plot as straight lines in Figure 10 on the linearized reduced variate paper) result from using the first 30, the last 30 and all 60 observations respectively. It is apparent that the earlier part of the flood peak

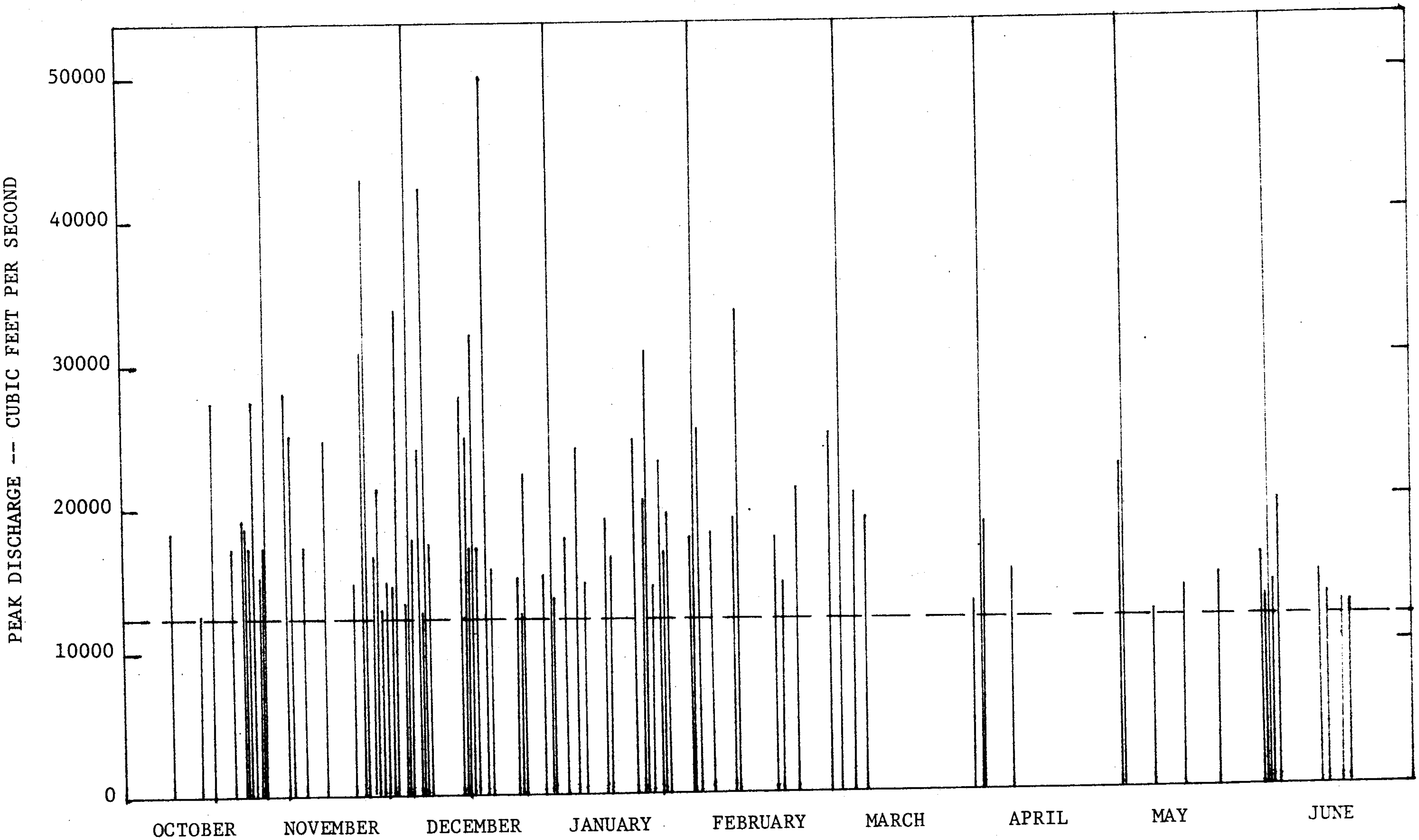


Figure 8. Distribution of Peak Floods in Excess of 12000 cfs., 1941-1970, South Fork Skykomish River, Near Index, Washington. (Partial Flood Series)

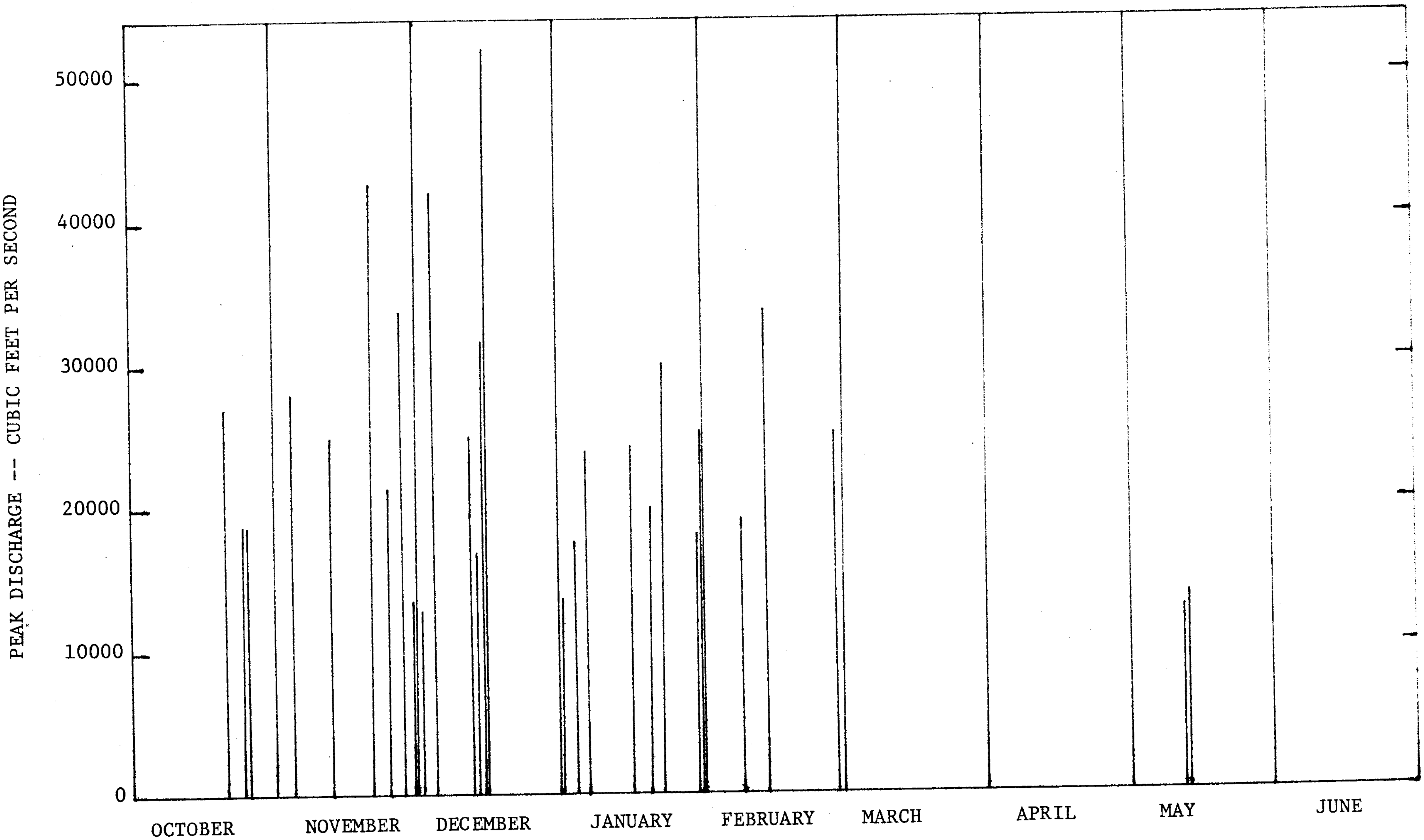


Figure 9. Distribution of Peak Annual Floods, 1941-1970, South Fork Skykomish River, Near Index, Washington. (Annual Flood Series)

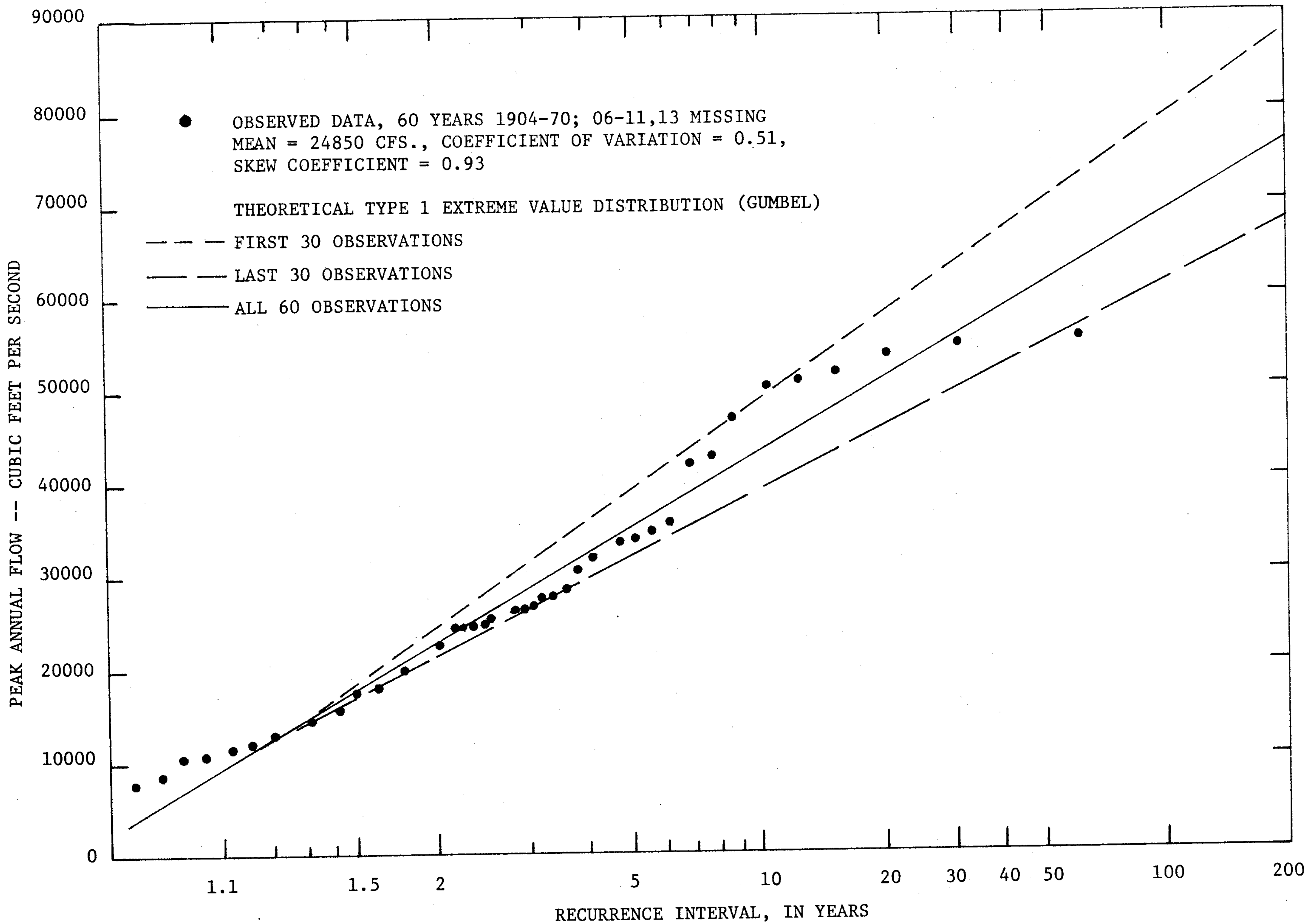


Figure 10. Cumulative Probability Distributions of Annual Peak Flows, South Fork Skykomish River, Index, Wa.

record suggests a larger mean estimate of the 100 year event than that obtained from the last 30 years.

Because substantial differences can occur in the flood frequency distributions derived from short samples it is extremely important to use as long an historical record as possible (when forced to extrapolate flood frequency curves)to estimate the magnitudes of uncommon events. In situations where only a short record exists for a particular stream, the probability distribution of the flood peaks can be compared with concurrent short records, as well as the complete records, of hydrologically similar nearby watersheds to determine if the short record yields a high or low trend. If no deterministic cause for the trend can be identified, the resulting flood frequency curve should be adjusted to comply with longer term regional trends. The literature is replete with methods for extending records or adjusting for trends.

Figure 11 shows the theoretical cumulative frequency curves for the Log-Pearson Type III analysis of the first 30 and all 60 years of record. The Gumbel curve for all 60 years is included for comparison. The Log-Pearson estimate exceeds the Gumbel estimate of the 100 year flood magnitude by 5 per cent.

Because both theoretical distributions adequately described the flood peak data, further analysis was only pursued via the Gumbel approach (principally for convenience of illustrating the importance of uncertainty). Confidence limits corresponding to approximately 68% about the theoretical Gumbel curve are plotted in Figure 12. These limits were determined by the method developed by Gumbel (see Chow, 1964, Chap. 8:32). It should be noted that both the mean frequency curve and the estimated confidence bands are extrapolated beyond the 60 year event. These

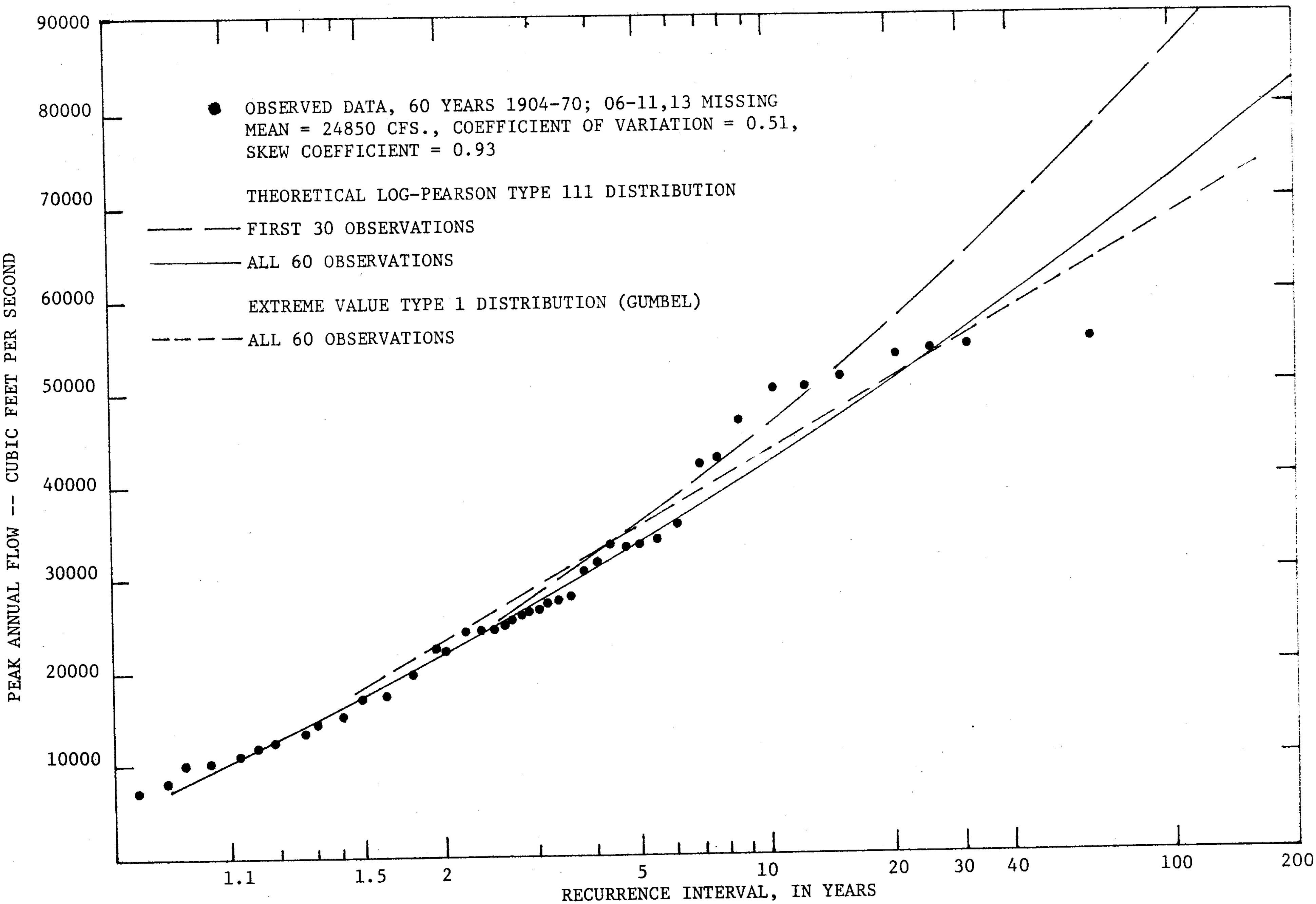


Figure 11. Comparison of Cumulative Probability Distributions of Annual Peak Flows, South Fork Skykomish River, Near Index Washington

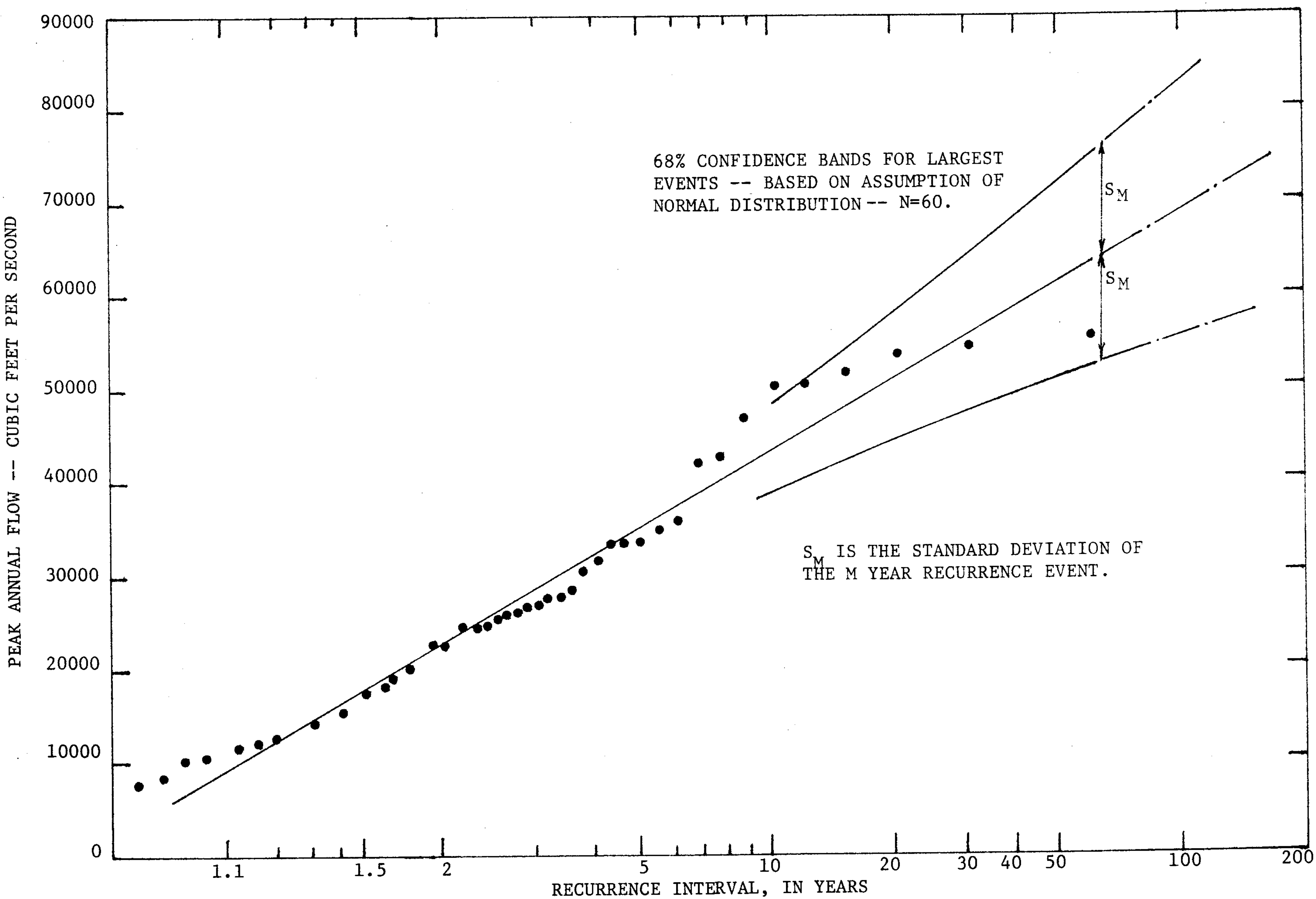


Figure 12. Extreme Value Type 1 Probability Distribution of Peak Annual Flows, South Fork Skykomish River, Near Index, Washington.

extrapolated results indicate that the 100 year flood event might have a mean value of 69,000 cfs and standard deviation of 14,000 cfs. This indicates that there is about a 70% chance that the 100 year flood is in the range 55,000 to 83,000 cfs or a 95% chance it falls within the range 41,000 to 97,000 cfs. Such uncertainty has great significance when attempting to delineate the flood plain for the 100 year event.

What generalizations about uncertainty might be made from this illustrative example? The annual flood series for this river can be conveniently summarized by three statistics and an underlying probability distribution (which is seldom known with certainty). The summary statistics are: arithmetic mean, 24,850 cfs; coefficient of variation, CV, (standard deviation of flood series/mean flood), 0.51; and skew coefficient 0.93. This large coefficient of variation is representative of an upper limit to variability of annual flood magnitudes of larger watersheds in the state of Washington. Generally, as watershed area increases, the variability in annual peak floods decreases. As the coefficient of variation decreases so does the uncertainty in estimates of flood events having large recurrence intervals.

General Examination of Uncertainty in Large Floods

The coefficient of variation is a useful normalized statistic for comparing watershed flood magnitude variability. Thus, it is possible to investigate the magnitude of uncertainty associated with floods having large recurrence intervals for many different types of watersheds. For convenience the theoretical extreme value Type I (Gumbel) distribution will be used in the following discussion of uncertainty. The distribution is a two parameter distribution which can be conveniently illustrated on reduced variate (linear) probability paper. (General representation of the Log-Pearson Type III distribution is not convenient). The extreme value distribution is used here to illustrate the general significance of uncertainty in estimates of the regulatory-flood; its use is not an advocacy for describing annual flood data. In many situations, however, the extreme value distribution faithfully represents flood peak data.

Theoretical, non-dimensional, extreme value Type I flood frequency curves having coefficients of variation of 0.6 and 0.25 (skew coefficient is fixed at 1.14) are shown in Figure 13. This range in coefficient of variation accounts for most watersheds in the State of Washington, the larger variability corresponding to smaller watersheds while the smaller variability corresponds to much larger watersheds. Uncertainty bounds (Chow, 1964, Chap. 8:32) corresponding to plus and minus one standard deviation for floods of specified recurrence interval are plotted on the basis that the population frequency curves had, in fact, been defined by only 30, 60 , or 200 annual flood events. Two important observations can be made: (i) the flood population having low coefficient of variation has significantly smaller numerical uncertainty associated with the estimate of flood magnitude corresponding to a given recurrence interval (Figure 13b) than is evidenced in watersheds whose flood populations have large coefficients of variation, and (ii) uncertainty bounds are significantly narrowed as the number of observations used to estimate the frequency curve increases from 30 to 200.

When the consequences of large uncertainty in estimates of the regulatory flood have significant impact on flood plain mapping, several

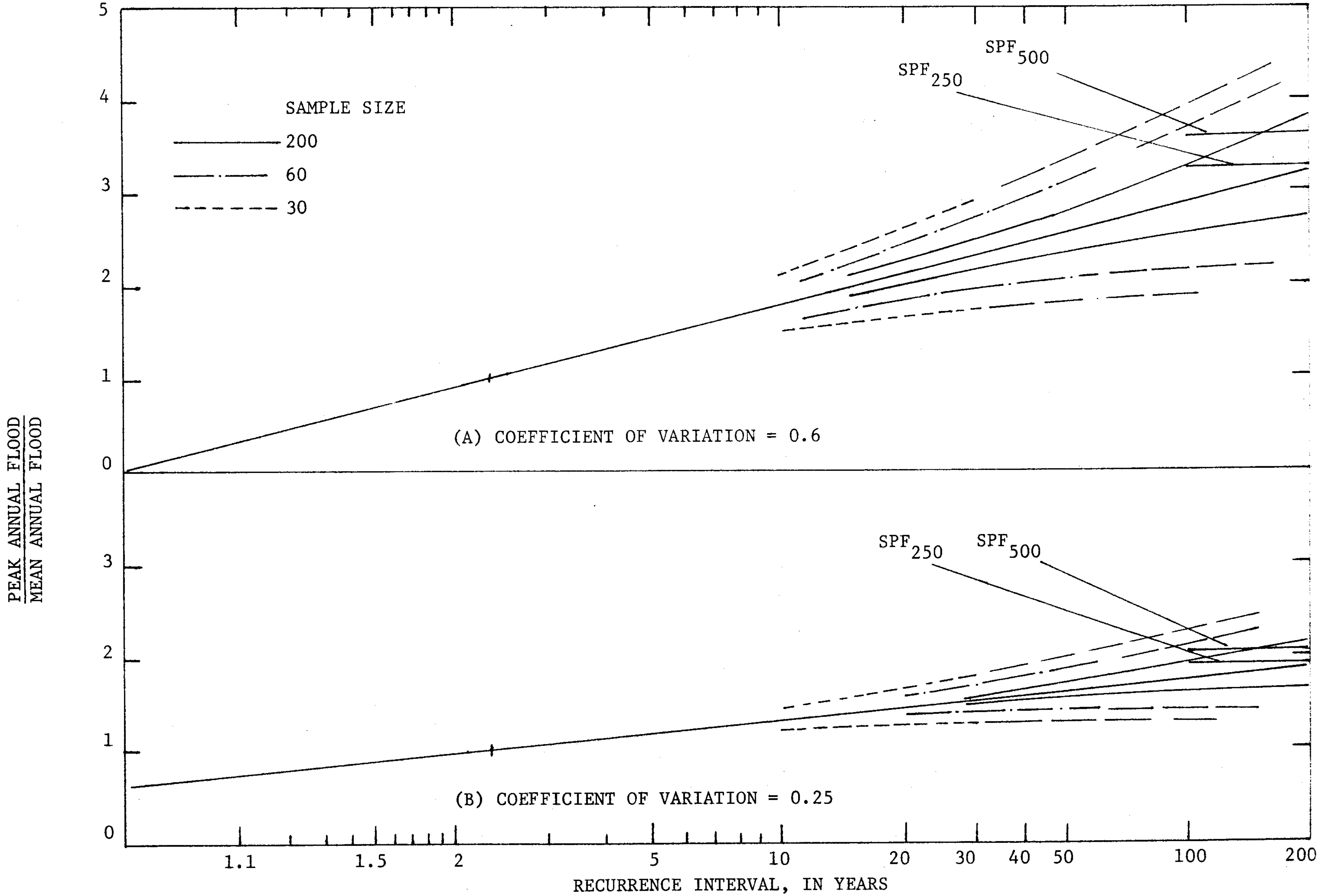


Figure 13. Nondimensional Extreme Value Type 1 Probability Distributions Showing Confidence Bands as a Function of Sample Size.

approaches may be pursued to reduce the uncertainty. Most of these approaches involve increasing the sample size used to determine the flood frequency curve. Approximate uncertainty estimates for the usual regulatory flood (100 year recurrence interval) based on samples containing 30, 60, and 200 observations (Figure 13), are given in Table 3.

Table 3 shows that increasing the sample size from 30 to 60 events reduces uncertainty in the estimated 100 year recurrence interval event by one third while increasing the sample size from 30 to 200 events reduces the magnitude of the uncertainty by two thirds.

Table 3: Approximate Uncertainty Bounds for Estimates of the Magnitude of the 100 Year Flood

Flood Population: (Gumbel) Type I Extreme Value	Sample Size		
	30	60	200
CV = 0.6; $Q_{100}/\overline{Q}$ =	2.9	2.9	2.9
(68% Confidence Bounds)/$\overline{Q}$ =	1.85-3.90	2.15-3.65	2.55-3.30
S_{100}/Q_{100} =	0.35	0.26	0.14
CV = 0.25; $Q_{100}/\overline{Q}$ =	1.75	1.75	1.75
(68% Confidence Bounds)/$\overline{Q}$ =	1.30-2.25	1.40-2.10	1.65-1.90
S_{100}/Q_{100} =	0.29	0.20	0.09

Notes: Q_{100} = 100 year flood; S_{100} = standard deviation of estimate of 100 year flood; $\overline{Q}$ = mean annual flood (2.33 year recurrence interval); CV = population standard deviation/mean annual flood.

Typically, a long flood record contains 60 annual peak flood observations. It is obvious from Table 3 that extension of short records to equivalent lengths of 60 years has some merit. However, the need to obtain long records by one means or another, to reduce uncertainty, is much less important for watersheds having low CV for annual flood peaks than for watersheds having higher CV as evidenced in Figure 13 and Table 3. It is important to note that these comments pertaining to uncertainty only include Type II parameter uncertainty. The utility of uncertainty reduction must be viewed in light of the specific situation in which the data will be employed.

The generalized discussion of Type II uncertainty indicates the significance of the coefficient of variation and sample size upon the magnitude of uncertainty. While the uncertainty bounds were not determined by more recent techniques which accommodate the asymmetry of the confidence bounds (see for example Ott, 1971, Chap. 5; Burges, 1972) the procedure used has sufficient validity to illustrate the magnitudes involved. These approximate uncertainty bounds are used in the following section which employs first-order uncertainty analysis to determine a lower bound to uncertainty in actual flood plain delineation.

Estimation of a Lower Bound to Uncertainty in Flood Plain Mapping

The design hydrograph characteristics and the flood plain condition at the time of the flood wave arrival probably will not be known with much certainty. Consequently, the backwater profile computed for the design flood may not be representative of reality. The actual area of the flood plain that is inundated depends upon the rate of rise of the input hydrograph and upon the time the discharge remains near the peak level of the design hydrograph. Fortunately, conservative estimates of the extent of inundation can be made by assuming equilibrium flow conditions (i.e., the river remains at peak discharge for a sufficiently long period of time to ensure equilibrium flow) and that unanticipated obstructions do not occur downstream (causing the area upstream of the obstructions to act as a reservoir). Obviously, emergency flood fighting tactics are needed to ensure that major obstructions do not remain at downstream locations. Thus, by considering Type II uncertainty and equilibrium flow for the estimated regulatory flood magnitude, the mean inundation area, and an appropriate uncertainty measure (standard deviation of the inundated width at a given section normal to the flow) yield sufficient information to determine a lower bound on uncertainty in flood plain delineation.

An illustrative example that shows how a simple methodology is used to determine the importance of uncertainty in flood plain delineation, at any river section, follows. For convenience the symmetric river-flood plain section of Figure 14 is used. All subsequent equations refer to this geometry. Different equations will be required for different fundamental geometries.

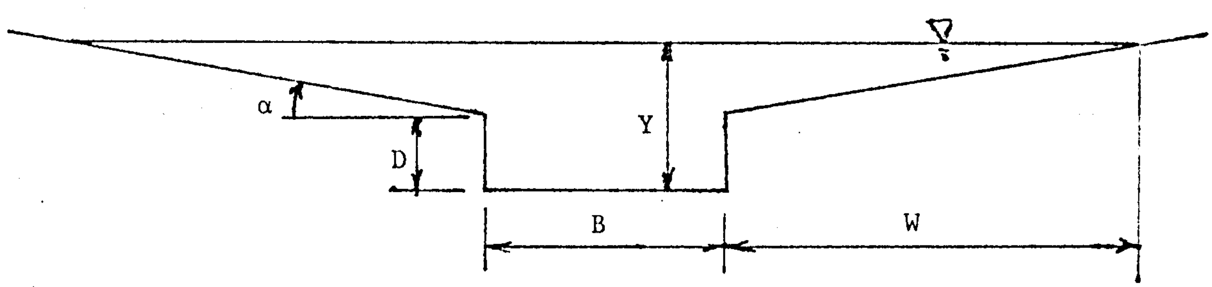


Figure 14. Idealized Flood Plain Section

The illustration involves Type II uncertainty propagation; propagation is via first order uncertainty analysis (Benjamin and Cornell, 1970:180). The basic approach requires determination of uncertainty in water depth, Y, (then uncertainty in the inundated with W) corresponding to uncertainty in the equlibrium discharge for the regulatory-flood (usually Q_{100}). Equilibrium discharge for flow normal to the section of Figure 14 is, according to the one dimensional Manning Equation:

$$Q_{TOT} = \frac{1.49 Y^{5/3} B^{5/3} SS_R^{\,1/2}}{N_R (2D + B)^{2/3}} + \frac{1.49 (Y - D)^{8/3} SS_S^{\,1/2}}{4^{1/3}\, N_S \tan(\alpha)} : \quad Y \geq D \qquad (1)$$

in which

Q_{TOT} is the total discharge normal to the section (cfs)

Y is the depth from river bed to the water surface (ft)

B, D are the river channel width and depth respectively (ft)

SS_R, SS_S are the hydraulic gradients of the river and overbank regions respectively.

N_R, N_S are Manning roughness coefficients for the river and overbank regions respectively.

$\tan(\alpha)$ is the slope of the flood plain towards the channel.

In deriving Equation 1 use was made of the fact that α is typically very small. ($\tan(\alpha) = 0.004$ corresponds to land sloping to the river at approximately 20 ft./mile.)

Most of the parameters in Equation 1 are not precisely known. However, the uncertainty in Q_{TOT} is known from the uncertainty bounds obtained during construction of the flood frequency curve. Thus, it is important to determine the amount of variance in Q_{TOT} contributed by uncertainty in the flow depth. Uncertainty is present in the estimates (determined by calibration) of N_R, N_S, SS_R, SS_S, and in the channel and flood plain geometry (measured directly). To determine how much uncertainty is associated with estimated water depth, Y, it would be desirable to express Y explicitly as

$$Y = f(Q_{TOT}, B, D, N_R, N_S, SS_R, SS_S, \alpha) \tag{2}$$

to facilitate uncertainty analysis. However, it is not readily apparent from Equation 1 how this could be done. Therefore, one way to determine the amount of uncertainty that must be associated with Y, to ensure equal total variance on both sides of Equation 1, is by iteratively incrementing the standard deviation, S_Y, of Y until the combined variance of Y, N_S, N_R, SS_S, SS_R and geometry terms equals the anticipated variance in the design flood equilibrium discharge. Details of the variance estimating equations obtained by application of first-order uncertainty analysis, as well as the solution technique employed, are given in Appendix D.

To give the illustration a semblance of reality, the geometry of Figure 14 was scaled under the assumption that overbank flow resulted from flood magnitudes exceeding Q_{BF}, the bankfull flow rate, taken conveniently to be the 5 year recurrence interval event. (Usually river channels overflow for floods having recurrence interval less than 5 years [see Dury, 1969]. Clearly, in practical situations this assumption is not needed; the geometry is readily available.) Uncertainty analyses were conducted for geometries determined from flood populations having CV equal to 0.6 and 0.25 shown in Figure 13 a,b respectively. The regulatory-flood was taken as Q_{100}, the 100 year flood. Uncertainty bounds were computed for sample sizes of 60 events in both cases. A limited range of parameter values was tested, the combinations of parameter magnitudes and associated uncertainty, as well as the computed uncertainty in depth and flood plain inundation width, are shown in Tables 4 and 5.

Table 4: Representative Results of Uncertainty in the Location of the Regulatory-Flood Plain Boundary at a Section -- Sample Size = 60 Extreme Value Type I Flood Population, CV = 0.6

$\bar{Q}$ = 10,000 cfs; Q_{100} = 29,000 cfs; S_{100} = 7,500 cfs

$\frac{Q_{BF}}{\bar{Q}}$ = 1.45; $\frac{Q_{100}}{\bar{Q}}$ = 2.9; B = 200 Ft; D = 8 Ft (Figure 14)

Quantity	α**	N_S	SS_S	N_R	SS_R	Y	$\bar{W}$(Ft)	S_W(Ft)
Mean	0.002	0.25	0.002	0.03	0.002	11.84	1920	
Coef. of Variation		0	0	0	0	0.110		650*
"		0.05	0.05	0.05	0.05	0.110		650
"		0.15	0.05	0.15	0.05	0.095		560
"		0.25	0.05	0.25	0.05	0.060		350
Mean	0.002	0.10	0.002	0.03	0.002	11.28	1640	
Coef. of Variation		0	0	0	0	0.095		510*
"		0.05	0.05	0.05	0.05	0.092		505
"		0.15	0.05	0.15	0.05	0.077		435
"		0.25	0.05	0.25	0.05	0.049		280
Mean	0.004	0.25	0.002	0.03	0.002	12.16	1040	
Coef. of Variation		0	0	0	0	0.126		380*
"		0.05	0.05	0.05	0.05	0.123		376
"		0.15	0.05	0.15	0.05	0.105		320
"		0.25	0.05	0.25	0.05	0.052		155

** Symbols are defined in Figure 14.
* This value of S_W represents an upper bound to Type II uncertainty which becomes a lower bound to total uncertainty in locating the regulatory-flood plain boundary.

Tables 4 and 5 contain similar information. The differences result from changed geometries and flood populations. In both cases the mean annual flood was taken to be 10,000 cfs. The parameters tested were for a flow hydraulic gradient of approximately 10 feet per mile; a flood plain slope, α, to the channel ranging from approximately 10 to 20 feet per mile; Manning's roughness coefficient, N_R, 0.03 for the river channel and N_S, ranging from 0.10 to 0.25 for the flood plain. The largest 100 year recurrence interval event was taken from an extreme value Type I population having CV = 0.6 (Table 4), while the smallest design peak flood was taken from a population having CV = 0.25. The standard deviation, S_{100}, representing uncertainty in the 100 year recurrence interval flood event was determined on the basis of a sample size of 60 observations.

The information in Tables 4 and 5 is summarized so that parameter changes occur only for α and N_S. The mean values as well as the standard deviations of α, N_S, SS_S, N_R, SS_R are used as input to the equations of Appendix D. The mean flood depth is computed from the mean parameter inputs. Different standard deviations of water depth, S_Y, are computed for different standard deviations of parameter inputs. Hydraulic parameter and depth uncertainty are expressed non-dimensionally as coefficients of variation. A representative result for the mean inundation width, $\overline{W}$, corresponding to the mean depth, $\overline{Y}$, is 1920 feet when Y is 11.84 feet (Table 4). Similarly when there is 5% uncertainty in N_S, SS_S, N_R and SS_R and Y = 11.84 feet the value of S_W is 650 feet.

In all instances the parameters were assumed to be independent. This is not necessarily valid for SS_S and SS_R; however, the contribution to uncertainty from these terms (assuming low levels of uncertainty) was not significant.

Table 5: Representative Results of Uncertainty in the Location of the Regulatory-Flood Plain Boundary at a Section -- Sample Size = 60; Extreme Value Type I Flood Population, CV = 0.25

$\bar{Q}$ = 10,000 cfs; Q_{100} = 17,500 cfs; S_{100} = 3,500 cfs

$Q_{BF}/\bar{Q}$ = 1.19; $Q_{100}/\bar{Q}$ = 1.75; B = 160 Ft; D = 8 Ft

Quantity	α**	N_S	SS_S	N_R	SS_R	Y	$\bar{W}$(Ft)	S_W(Ft)
Mean	0.002	0.25	0.002	0.03	0.002	10.43	1215	
Coef. of Variation		0	0	0	0	0.092		480*
"		0.05	0.05	0.05	0.05	0.090		465
"		0.15	0.05	0.15	0.05	0.063		335
"		0.20	0.05	0.20	0.05	0.026		135
Mean	0.002	0.10	0.002	0.03	0.002	10.15	1075	
Coef. of Variation		0	0	0	0	0.075		380*
"		0.05	0.05	0.05	0.05	0.072		365
"		0.15	0.05	0.15	0.05	0.052		265
"		0.20	0.05	0.20	0.05	0.030		150
Mean	0.004	0.25	0.002	0.03	0.002	10.57	640	
Coef. of Variation		0	0	0	0	0.102		270*
"		0.05	0.05	0.05	0.05	0.100		262
"		0.15	0.05	0.15	0.05	0.070		185
"		0.20	0.05	0.20	0.05	0.022		58

** Symbols are defined in Figure 14.

* This value of S_W represents an upper bound to Type II uncertainty which becomes a lower bound to total uncertainty in locating the regulatory-flood plain boundary.

General Observations

Although desirable, it may not be necessary to attempt extensive generalizations about the extent of uncertainty in flood plain inundation. Generally, flood plain inundation limits are influenced by the magnitude and shape of the design hydrograph, the geometry and hydraulic characteristics of the channel and flood plain. Because of the numerous factors involved (only a few are covered in Tables 4 and 5) it is probably not worth the effort to generalize the results in terms of dimensionless ratios. It suffices at this time for planners to recognize the combination of factors that are likely to cause most uncertainty in flood plain zone delineation.

Generally, the most extensive inundation occurs for channel-flood plain combinations having Q_{100}/Q_{BF}* large, flood plain slope to the river small and roughness coefficient for the flood plain large. Improvement in the discharge capacity of the flood plain significantly reduces the inundation zone's width. For the conditions summarized in Table 4, changing N_S from 0.25 to 0.10 caused a reduction in the average inundation width, $\overline{W}$, from 1920 to 1640 feet.

A very noticable result is contained in both Tables 4 and 5. For all cases investigated, the lower bound estimate of the standard deviation of the inundated width, S_W, was approximately one third of the magnitude of $\overline{W}$. For the largest inundation width $\overline{W}$ was 1920 feet while S_W was 650 feet. This can be interpreted as approximately a 70% chance that the regulatory flood fringe could be located between 1270 and 2570 feet from the river. (These figures correspond to $\overline{W} \pm S_W$.)

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*Q_{BF} was assumed to be Q_5.

This magnitude of uncertainty provides considerable room to accommodate disputes as to where the outer fringe should be located. Further, economic opportunity costs associated with an uncertain zone about one quarter of a mile in width must be seriously considered in planning.

What steps must the planner take to ensure that the amount of uncertainty in flood plain delineation is appropriately determined and incorporated into planning decision making? These points are addressed in the recommendations that follow.

Summary and Recommendations for Accommodating Uncertainty

Whenever flood plain delineation is being attempted, it is important to determine if the uncertainty in the width of inundation at particular sections is significant. Generally, it is most likely to be significant when:

(i) the main channel is relatively flat (on the order of 1 to 10 feet per mile)

(ii) the flood plain slope to the river is small (less than 20 feet per mile)

(iii) the coefficient of variation of the largest annual floods is large (exceeding about 0.2)

(iv) the length of record used to determine the flood frequency curve is short (anything less than about 60 years) and

(v) when large overbank floods have not been sufficiently documented to facilitate determination of the hydraulic roughness characteristics of the flood plain.

These approximate guidelines are not independent and must not be literally and blindly followed. Generally, the magnitude of uncertainty is larger for flood populations having high coefficients of variation than for populations having small coefficients of variation, particularly when the skew coefficient is approximately equal to unity.

Preliminary investigation of uncertainty can be undertaken before doing detailed backwater computations. If the magnitude of uncertainty, computed via the method outlined in Appendix D, is comparable to the estimated average inundation width at a section, then there is very little to be gained by conducting the analytical delineation procedure outlined earlier in this report. Such is likely to be the case when only short records are obtainable (or synthesizable), the channel and flood plain slopes very flat, coefficient of variation of the annual flood peaks large, and flood plain slope to the river very flat. When uncertainty is large it is probable that the best strategy to follow is that of subjective (and objective) physical delineation of boundaries. These will be dictated by soil types, vegetation patterns, historical indications of inundation and the geomorphology of the river. It is important to differentiate glacial and fluvial "inundation" boundaries. Boundaries located in this manner ought to be wider than those computed via the regulatory-flood (if it was available) and are thus conservative. As more information is collected that reduces uncertainty, then it will be practical to undertake an analytical delineation of the flood fringe.

The preceding arguments have only addressed the importance of uncertainty in the areal extent of flood plain inundation. Inundation depth has not been specifically addressed. However, inundation uncertainty, of one standard deviation of inundation width at a section, corresponded to approximately 1 foot at the average inundation boundary in the examples of Tables 4 and 5. Thus, it is important to trade off the utility of flood proofing structures, for an arbitrary distance beyond the anticipated regulatory flood fringe limit, against the utility of physical boundaries, on the order of a few feet high and located in the vicinity of the anticipated flood fringe, to accommodate uncertainty.

Whatever criteria are adopted to accommodate uncertainty they should be based on economic analysis. Unfortunately, the uncertainty introduced by the data needed for such analyses may only compound the problem (Linsley, et al., 1969). Thus, there is a need for arbitrary criteria (the regulatory-flood mapping criteria are arbitrary) to make planning practical and feasible. The criteria must have provisions for accommodating modification if an affected party can conclusively show, for a particular location, that use of such arbitrary criteria foster economic waste.

Before some criteria are suggested, it is useful to return to Figures 13 and 14 and Tables 4 and 5. In Figures 13A and B, two flood magnitudes are used to depict hypothetical large floods refered to as "Standard Project Floods" (SPF). The magnitude of the SPF for a given watershed usually has a recurrence interval in the range 250 to 500 years on an extrapolated extreme value Type I flood frequency curve. This flood is the largest flood (though considerably smaller than the probable maximum flood) that might reasonably be expected to occur in the watershed. Figure 13 shows that the SPF magnitude is less than Q_{100} plus S_{100} (i.e., less than plus one standard deviation of uncertainty about the usual regulatory flood). Therefore, one way to allow for uncertainty caused by incomplete hydrological data would be to delineate the flood fringe on the basis of the SPF. This may prove to be uneconomic for the area but it truly reflects the magnitude of lower bound uncertainty involved in the delineation process.

Whatever criteria are adopted they should reflect the likely magnitude of uncertainty. They should particularly incorporate the losses that may result if inundation does in fact exceed the anticipated flood fringe boundary. Some possible criteria are listed below.

(i) Require flood proofing for all structures located one standard deviation beyond the average flood fringe boundary.

(ii) Build a physical boundary at the average flood inundation limit capable of withstanding a depth rise comparable to two standard deviations in inundation depth uncertainty. This will typically be about two feet.

(iii) Use the so called Standard Project Flood to delineate inundation areas. Require at least minimal flood proofing of structures in the extended zone between the limits of Q_{100} and Q_{SPF}.

(iv) Use building codes to prohibit slab construction or basements in areas where uncertainty computations suggest inundation depths greater than 1 foot could occur.

Social acceptance of the above suggested criteria has not been investigated. It is the responsibility of the regulatory agency to adopt appropriate delineation criteria.

CRITERIA: FOR EVALUATING ALTERNATIVE ZONING METHODS

Determination of the magnitude of the regulatory-flood requires that a specific flood frequency be selected, e.g., 100 year, 50 year, or of some other recurrence interval. Selection of the 100 year flood will result in a larger area being allocated for the regulatory-flood plain than for a 50 year flood. While appropriate data and procedures required to delineate the flood plain into flood fringe and floodway districts have been discussed, an important question is: on what basis is the selection of the regulatory-flood frequency made? Arbitrary criteria follow.

Federal Criteria

Because of the uncertainty inherent in extrapolating frequency curves beyond the limits dictated by sample size and in determining which frequency should be chosen as the regulatory-flood frequency, the federal government has adopted the Log-Pearson Type III probability distribution for determining flood flow frequencies. Federal guidelines (WRC, 1972a:11) require that all federal agencies use the 100 year flood as the basic flood in evaluating flood hazards.[4] The National Flood Insurance Program administered by the U.S. Department of Housing and Urban Development requires that in order to qualify for insurance based on actuarial rates, the delineation of the outer fringe boundary be based on the 100 year flood, and that encroachment in the fringe area will not raise the 100 year flood level more than 1 foot (HUD, 1971a : 1910.3c)

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[4]The magnitude of the 100 year flood relative to floods of other magnitudes and the rationale for its choice as the regulatory-flood magnitude are discussed in Appendix C.

These arbitrary decisions will have a significant effect in standardizing the delineation of flood plains and have been accepted as the criteria on which to base flood plain delineation in evaluating alternative zoning methods in this report.

Legal Aspects

As floodway regulations stringently restrict development, it is essential that they be carefully conceived to meet federal and state constitutional requirements. Equal degree of protection under the laws (equal treatment) and reasonable uses (development and uses consistent with degree of flood hazard) must be allowed. Generally, courts may disapprove of severe restrictions which prohibit all structures in low hazard areas. However, severe restrictions against fill, structures and other nuisance-like obstructions in floodway areas may be sustained (WRC, 1971:34).

Two District Zoning Considerations

A strong case for adopting a two district flood plain zoning ordinance can be made on the basis that regulatory restrictions on flood plain land uses and development in low hazard areas (flood fringe) are less severe than those applying to high hazard areas (floodway). Any regulations that are adopted must treat individuals who are similarly situated without discrimination (WRC, 1971:340).

> Unless there are good reasons for acting otherwise, a State agency or local unit establishing building or floodway lines may have to assume that each similarly situated portion of floodway land with equal development potential and equal potential for passing floodflows must provide a proportionate share of flood-flow capacity. This does not suggest that the lines would always need to be drawn at equal distances from the stream, since elevations of the adjacent sides may vary with one area having a limited role in passing floodflows and another naturally discharging a greater volume of water (WRC, 1971:341)

In general, a sound regulatory scheme for floodway and flood fringe areas must recognize the right of private citizens to use lands as well as the right of the state to guide and regulate land uses and development to insure that public health, safety, and welfare objectives are met (Liebman, 1973:22).

THE NATIONAL FLOOD INSURANCE PROGRAM

A compelling reason for states and local communities to adopt the federal criteria for flood plain zoning is that these criteria fulfill one of the requirements for participation in the regular National Flood Insurance Program. The two district zoning ordinance discussed in this report satisfies these criteria[5] which follow:

(i) Federal and state legal requirements.

(ii) Federal standards.

a. Log-Pearson Type III method used for determining flood flow frequencies.

b. Regulatory-flood plain limits determined from the 100 year flood.

c. Regulatory floodway limits determined by limiting increase in floodwater height[6] caused by assuming total loss of conveyance in the flood fringe area.

Emergency and Regular Flood Insurance Programs

To become eligible for flood insurance a flood prone community must submit to the Federal Insurance Administrator a written request to participate in the National Flood Insurance Program for the entire area under its jurisdiction. If the community satisfied the land use control criteria for initial acceptance under the emergency program, it may receive flood insurance at government subsidized rates[7]. The differences between emergency and regular programs are as follows:

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[5] Reasons for adoption of the criteria are given in the "Engineering and Planning" and "Criteria" sections of this report.

[6] Normally 1 foot for rural areas and .5 foot for urban areas.

[7] The emergency program operated through an insurance industry pool under the auspices of the National Flood Insurers Association, by means of a Federal subsidy to make up the difference between actuarial rates and the rates actually charged to property owners for the protection provided. In many cases the Federal subsidy amounted to more than ninety per cent of the cost of the insurance (HUD, 1971a:1909.2a).

> The Federal Insurance Administration has been authorized to provide subsidized flood insurance until December 31, 1973, without first determining the individual community's actuarial premium rates, which is a prerequisite for coverage under the regular program. The emergency program is intended primarily as an interim program to provide earlier coverage for potential flood victims pending the completion of actuarial studies. The Federal Insurance Administration has no authority under the emergency program either to offer the higher limits of coverage or to offer subsidized premium rates to new construction. New construction cannot be covered under the emergency program but must wait until actuarial premium rates have been established. The emergency program does not affect the requirement that a community must have adequate land use and control measures in effect in order to participate in the flood insurance program (HUD, 1972b:18).

Once a community is accepted into the flood insurance program, the community must adopt more precise land use and flood mitigation measures based on new technical data as furnished by the Federal Insurance Administrator. The Administrator is responsible for identifying the special flood hazard areas and for supplying the community with the technical data necessary for the development of a sound flood plain management program (HUD, 1971a:1910.3).

> The Administrator may initiate technical studies through other Federal agencies, State or local agencies, or through private engineering firms, or he may utilize existing data. In any event, no expense will accrue to the community (HUD, 1972b:20).

By meeting and enforcing the criteria of the National Insurance program, the community can eventually become eligible for flood insurance based on actuarial rates. The actuarial rate studies are based on analysis of flood frequency damage curves, with the results associating damage with flood water elevations[8]. Generally, premiums are based on the difference in elevation between the lower floor of a structure and the 100 year flood level.

Before a community becomes elegible for actuarial rates it must in effect delineate the flood plain on the basis of the 100 year flood and establish a floodway which will carry the waters of the 100 year flood without increasing the water surface elevation of that flood more than 1 foot (HUD, 1972a:1910.3d). Modifications of this criteron based on exceptional local conditions must be approved by the Federal Insurance Administrator (HUD, 1971a:1910.5).

<u>Flood Disaster Protection Act of 1973</u>

Recent legislation requires communities in flood prone areas to participate in the National Flood Insurance Program. The bill[9], entitled the "Flood Disaster Protection Act of 1973", ensures stringent regulation of flood plain uses (HUD, 1973). The purpose of the Act is to:

(i) Increase the limits of flood insurance coverage.

(ii) Accelerate identification and information concerning flood prone areas.

(iii) Require states and local communities, as a condition for receiving future federal financial assistance, to participate in the flood insurance program and to adopt

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[8]The uncertainty in estimating flood damages with respect to flood surface elevations includes errors in assessment of flood damages as well as errors in estimation of flood frequency, depths, velocities, and duration. Linsley, *et al*. (1969:33) show that variations in the estimate of mean annual damage made in a "typical" flood project investigation might be as great as 18% of the true value in two cases out of three.

[9]Senate Bill SB495; House of Representatives Bill HR 6524.

adequate flood plain ordinances consistent with federal standards (HUD, 1973:Sec. 2b.3).

(iv) A significant purpose is to:

> Require the purchase of flood insurance by property owners who are being assisted by Federal programs or by Federally supervised, regulated, or insured agencies[10] in the acquisition or improvement of land or facilities to be located in identified areas having special flood hazards (HUD, 1973:Sec. 2b.4).

Two general provisions of the Act include:

(i) Known flood prone communities not already participating in the National Flood Insurance Program would be notified of their tentative identification as a community containing one or more areas having special flood hazards (HUD, 1973:Sec. 201a).

(ii) After such notification, each tentatively identified community would have to apply to participate in the National Flood Insurance Program or within Six (6) months submit technical data sufficient to establish to the satisfaction of the Secretary of the Department of Housing and Urban Development (HUD) that the community is either not seriously flood prone or that such hazards as may have existed have been corrected by floodwarks or other flood mitigation methods (HUD, 1973:Sec. 201b).

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[10] Includes banks, savings and loan associations and other lending institutions.

Four specific provisions of the bill have been stated as:

102a. No Federal officer or agency shall approve any financial assistance for acquisition or construction purposes on and after July 1, 1973 for use in any area that has been identified by the Secretary as an area having special flood hazards and in which the sale of flood insurance has been made available under the Act, unless the building or mobile home and any personal property to which such financial assistance relates is, during the anticipated economic or useful life of the project, covered by flood insurance in an amount at least equal to its development or project cost...(HUD, 1973:Sec. 102a).

102b. Each Federal instrumentality responsible for the supervision, approval, regulation, or insuring of banks, savings and loan associations, or similar institutions shall by regulation direct such institutions on and after July 1, 1973, not to make, increase, extend, or renew any loan secured by improved real estate or a mobile home...unless the building or mobile home and any personal property securing such loan is covered for the term of the loan by flood insurance in an amount at least equal to the outstanding principal balance of the loan or the maximum limit of coverage made available with respect to the particular type of property under the Act, whichever is less (HUD, 1973: Sec. 102b).

202a. No Federal officer or agency shall approve any financial assistance for acquisition or construction purposes on and after July 1, 1975, for use in any area that has been identified by the Secretary as an area having special flood hazards unless the community in which such area is situated is then participating in the National Flood Insurance Program (HUD, 1973:Sec. 202a).

202b. Each Federal instrumentality responsible for the supervision, approval, regulation, or insuring of banks, savings and loan associations, or similar institutions shall by regulation prohibit such institutions on and after July 1, 1975 from making, increasing, extending, or renewing any loan secured by improved real estate or a mobile home located or to be located in an area that has been identified by the Secretary as an area having special flood hazards, unless the community in which such area is situated is then participating in the National Flodd Insurance Program (HUD, 1973: Sec. 202b).

The Act's provisions prohibiting federally supervised, regulated, or insured agencies from making, extending, or renewing loans to owners of flood plain real estate unless the community is participating in the National Flood Insurance Program will provide a strong incentive for communities to participate in the program. Furthermore, it will publicize the fact that the community is in a flood prone area in the sense that anyone desiring a loan from a federally insured bank or savings and loan association for a development within the flood plain will be denied the loan if he doesn't have flood insurance or if appropriate land use and flood control measures are not in effect. He may be granted the loan if he has flood insurance and his proposed development is in accordance with land use and control measures meeting the National Insurance Program criteria.

The National Insurance Program offers a community the chance to eventually adopt a two district zoning ordinance with technical data and expertise made available through federal agencies at little or no direct cost to the community. As communities adopt stringent land use and flood mitigation regulations, meeting the National Insurance Program requirements for flood insurance, at premiums based on non-subsidized actuarial rates, new occupants entering the zoned flood plain fringe cease to be a tax burden as the government subsidy is not required.

A COMPARISON OF SOME ALTERNATIVE ZONING METHODS

Although federal guidelines and criteria exist for delineation of flood plains into flood fringe and floodway districts, many states delineate the flood plain and employ zoning methods based on other criteria (WRC, 1971:148-174).

Several of the Northeastern states use a multiple of the mean annual flood for delineation of the regulatory-flood plain limits and a lower multiple of the mean annual flood for delineation of the regulatory floodway limits (Lee, 1971:8).

In some cases, the 100 year natural floodway is used to delineate the regulatory-flood plain limits and the 10 year flood plain is used to delineate the regulatory floodway limits (Lee, 1971:9).

Another alternative would be to determine which magnitude of flooding to use to delineate the flood plain through economic analysis of the flood prone land (James, 1972). In essence, the portion of the land flooded to certain shallow depths by the design flood would be floodproofed and the remainder of the flood plain (which cannot be economically floodproofed) zoned to exclude development.

Variations of the Two District Approach

A possible range of two district zoning approaches is illustrated by the cases shown in Table 6. The five cases of Table 6 are amplified below.

Case I. This case illustrates the criteria which are endorsed and utilized by federal agencies in delineating the floodway and flood fringe areas and meets the criteria of the regular National Flood

Table 6: Alternative Two District Zoning Methods

Case	Regulatory-Flood Plain Limits Determined by:	Regulatory Floodway Limits Determined by:
I.	100 year flood	Permitted flood height increase, assuming flood fringe cannot convey water
II.	*Multiple of mean annual flood	Lower multiple of mean annual flood
III.	*Multiple of mean annual flood	Permitted flood height increase, assuming flood fringe will be filled
IV.	100 year flood**	Flood magnitude less than for flood plain, (e.g., 10 year flood plain)
V.	Regulatory-flood discharge to be used for establishing regulatory-flood plain limits is determined through economic analysis	Location of use within the flood plain determined by economic analysis

* (but less than 100 year flood)

** Topography changeable

Insurance Program with regard to delineation of the regulatory-flood plain and regulatory floodway limits.

Case II. Because the regulatory-flood magnitude is less than the 100 year flood, the regulatory-flood plain is not as large as would be the case if the 100 year flood had been selected. The regulatory floodway limits will depend on what multiple is chosen and could be greater or less than that of Case I.

Case III. Both regulatory-flood plain limits and regulatory floodway limits will be less than those of Case I, as the regulatory-flood magnitude is less than the 100 year flood.

Case IV. This case illustrates use of the 100 year natural floodway for delineation of the regulatory-flood plain limits and use of the 10 year flood plain for delineation of the regulatory floodway limits. This means that the outer boundary of the regulatory-flood plain is delineated with the smooth (hydraulic transition) 100 year natural floodway lines and the regulatory floodway with the irregular 10 year flood plain lines.[11] Since the irregular 10 year flood plain limits seldom coincide with the smooth 100 year natural floodway lines, problems might frequently occur where large portions of the 10 year flood plain lie outside the 100 year natural floodway. In a case cited by Lee (1971:9) fill and structures are prohibited in this area (A in Figure 15) on the basis that the area is needed to convey flood flows. However, if a building permit for a structure

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[11] The irregular boundaries can result from modified geometries, stream characteristics or from hydrographs having peak flows equal to Q_{10} but different shapes.

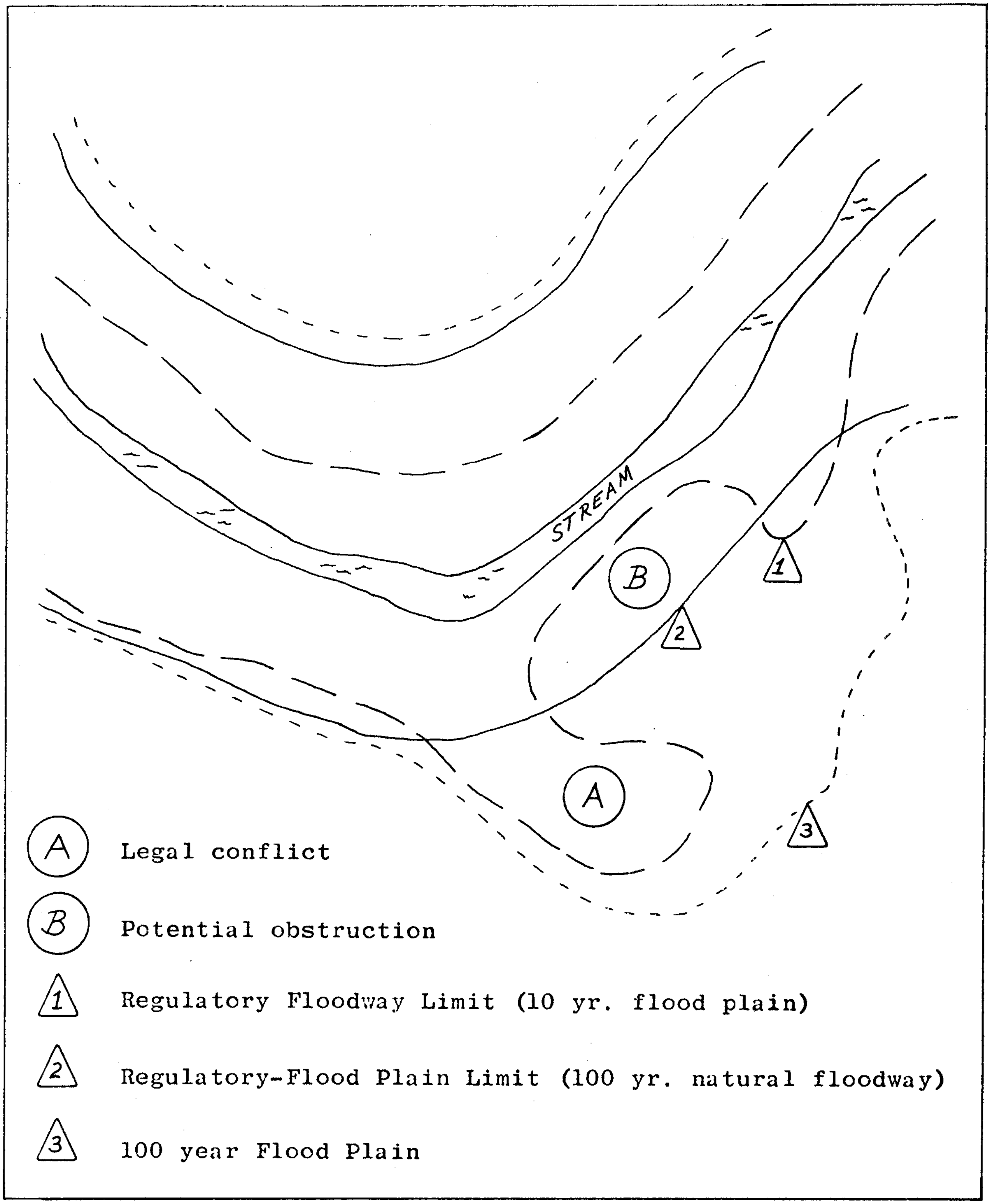

Figure 15. Variations in Two District Zoning Methods, Case III.

to be placed in this area was denied, the legality of such regulation would be questionable since the legal test of restricting development to preserve the carrying capacity of the floodway is not valid for structures outside the 100 year natural floodway (Lee, 1971:10).

Another conflict is illustrated (B in Figure 15) where construction could be permitted in an area which would be within the 100 year natural floodway (but not within the 10 year flood plain) yet still exist as a potential obstruction to 100 year flood flow.

Case V. This case is based on using economic criteria to evaluate the benefits and costs associated with locating in the flood plain. James (1972) emphasizes that economic criteria should be used in planning nonstructural flood control measures.

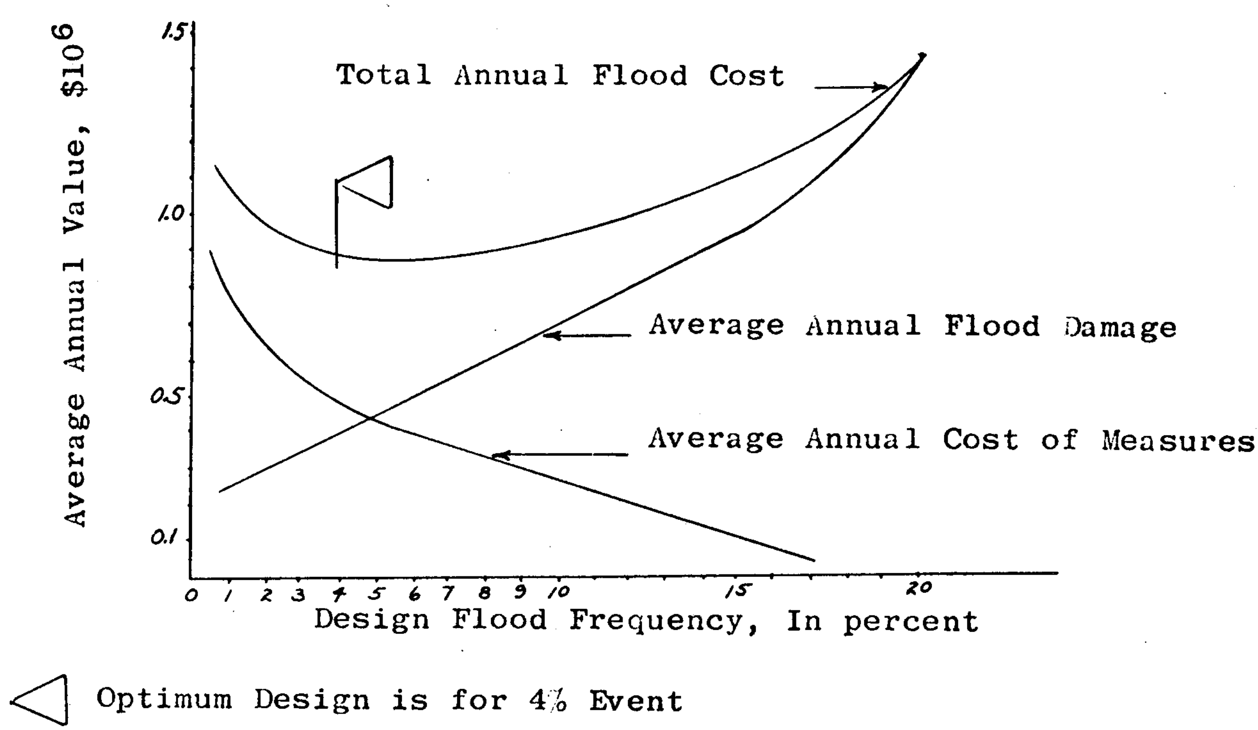

Figure 16. Determination of Optimum Design Flood Magnitude, Based on Economic Analysis, for Delineating a Flood Plain.

James (1972) presented an example problem wherein elements of land use zoning and flood proofing were combined to maximize the net benefit with regard to uses of the flood plain. In the hypothetical example James presented (Figure 16) a project optimization curve was derived which indicated that a 4% frequency flood (25 year recurrence interval) should be used as the regulatory-flood discharge. The total annual flood cost curve (Figure 16) indicated that a very satisfactory design would result even if a flood having 10% chance of occurrence (in any year) was used as the regulatory-flood.

Economic analysis shows that the least cost of a non-structural flood mitigation program, based primarily on a combination of zoning and floodproofing methods, is to exclude development via zoning in areas flooded to a greater depth than it is economical to floodproof against. In essence, the floodway is separated from the flood fringe on the basis of an economic analysis. The additional parameters introduced into flood plain zoning decision making, when an economic analysis is attempted, could introduce considerable uncertainty, which, when added to the uncertainty associated with estimates of water depths and velocity might obfuscate rather than help the decision making process. If zoning is to be done using an economic analysis, considerable effort may be required to reduce parameter uncertainty. The usefulness of this approach would have to be estimated in preliminary evaluations of individual flood plains to determine its applicability.

Single District Approach

The basic alternative to a two district zoning ordinance is that of a single district ordinance, which is characterized by a general flood plain district. The flood plain delineation boundary is normally roughly located on a topographic map and is based on interpretation of soil maps, air photos, or historical flood records (Kusler and Lee, 1972:34).

In the sense that applications for alteration resulting from developement within the flood plain area are considered on a case-by-case basis to determine whether the proposed or existing development is in a high hazard area (floodway) or low hazard area (flood fringe) the distinction between the floodway and flood fringe areas is made. Normally the case-by-case evaluation is based on a detailed hydraulic analysis when suitable data are obtainable. The single district features are outlines in Table 7.

Table 7: Single District Flood Plain Zoning Features

Case	Regulatory-Flood Plain	Regulatory Floodway Limits Determined by:
VI.	Interpretation of soil maps, air photos, or historical flood records. (Roughly delineated)	Hydraulic analysis on a case-by-case basis

The single district approach is most useful when it will neither be warranted nor possible to employ a two district approach. For instance in rural areas where potential for development is small, flood plain zoning may not be feasible. In other areas where data and expertise required to adopt a two district zone are not immediately available, it will not be possible to immediately institute a two district flood plain zoning ordinance. In the latter case a single district approach may be decided on, but should be regarded as an expedient and interim measure to meet the initial eligibility requirements of the National Flood Insurance Program and to serve the community well until a more stringent two district approach can be adopted from data that will be eventually furnished by the Federal Insurance Administrator.

Additional Zoning Alternatives

Other zoning methods include:

(i) No districts.

(ii) A single floodway district delineated by encroachment lines established by statutes.

(iii) Multiple zoning.

The first two methods do not meet established federal criteria and do not embrace the floodway-flood fringe concept of flood plain regulation.

Multiple zoning, wherein floodway limits are established and the flood fringe area is divided into a number of zones, according to degree of flood hazard, is basically a viable modification of the floodway-flood fringe concept and is considered to be in the same category as a two district zoning approach in this report. In fact, flood insurance rate maps indicate actuarial rate zones applicable to the flood plain and may consist of multiple zones (HUD, 1971a:1914.2).

IMPLEMENTATION OF A TWO DISTRICT ZONING ORDINANCE

Flood Plain and Land Use Zoning Ordinances

Two basic zoning approaches have been discussed, with the practicality of implementing each depending on a variety of circumstances. These approaches may be implemented in zoning ordinances in the following form:

1. Single district general flood plain ordinance.
2. Two district (floodway and flood fringe) ordinance.

A third approach combining single and two district zoning for different reaches of a river within one general locality is often necessary. Implementation of any zoning approach requires a separate zoning ordinance (or separate considerations) to be incorporated into a more comprehensive land use zoning ordinance for the area.

When flood loss mitigation zoning regulations are used in conjunction with existing land use zoning ordinances, the flood loss mitigation zoning regulations may be adopted as an overlay district, affecting the original zoning of the area only with respect to flood loss mitigation regulations. In the event that future structural measures eliminate the need for, or necessitate the modification of, the flood loss mitigation regulations, the regulations may be rescinded or modified. The area will still be covered by the original zoning ordinance with respect to whether the area is restricted to residential, commercial, or some other use. Slight modifications of the terminology used in the two district ordinance format, suggested by the Water Resources Council (1971:552), would facilitate adoption of the single district, combination district, or overlay district methods into an acceptable form of zoning ordinance.

Flood Plain Zoning Requirements for Issuance of Permits

An important aspect of implementation of the two district approach is the establishment of a suitable management structure to ensure that the zoning objectives are being achieved. Thus, any changes in land use or structural modification in the zoned areas must satisfy several broad categories of constraints. A permit system is employed to ensure compliance with these zoning objectives. An outline (WRC, 1971:520) of the general procedure to be followed to obtain a zoning permit under the two district zoning ordinance is illustrated in Figure 17. The numerous criteria and constraints of Figure 17 are amplified below. Permitted and special uses for floodway districts are discussed, followed by a discussion of permitted uses in the flood fringe zone.

Floodway District

Permitted uses. (A)[12] Uses that might be permitted in the floodway district are those having a low flood damage potential and which will not obstruct flood flows (WRC, 1971:524) and include:

1. Agricultural uses such as general farming, pasture lands, and grazing ranges.

2. Industrial-commercial uses such as parking areas, loading areas, and airport landing strips.

3. Private and public recreational uses such as golf courses, tennis courts, wildlife and nature preserves, swimming areas, picnic grounds and parks.

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[12] This refers to Figure 17.

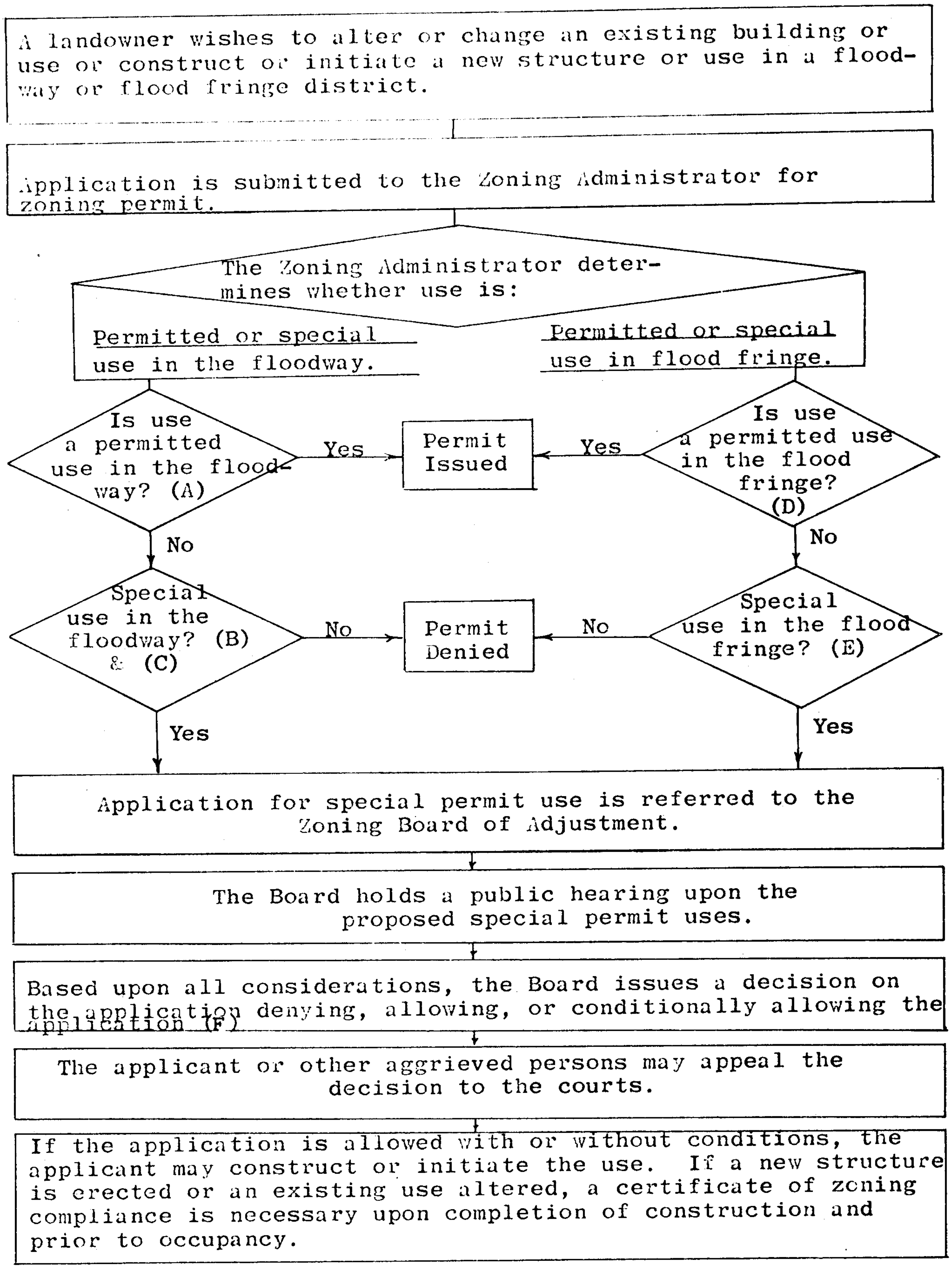

Figure 17. Zoning Permit Application Procedure For Construction or Change of Land Use Within the Floodway or Flood Fringe.

4. Residential uses for lawns, gardens, parking areas, and play grounds.

In general, the permitted uses listed above would be allowed as a matter of right whereby the Zoning Administrator must issue a permit if the applicant meets the stated requirements.

Special permit use standards. (B) Some special permit uses which involve structures (temporary or permanent), fill, or storage of materials or equipment may be permitted only upon application to the Zoning Administrator and the issuance of a special permit by the Board of Adjustment. The permit is issued only after a public hearing by the Board of Adjustment which determines that the conditions set down in the ordinance do exist.

An important objective with regard to issuance of special permits is the establishment of a procedure whereby flood plain uses can be evaluated on a case-by-case basis. If the flood plain is used as open space (not involving structures) then a specific evaluation may not be required. Otherwise, technical engineering assistance will be required to evaluate the effects of the proposed use, in causing increases in fill heights, before action on the permit is taken.

Special permit uses. (C) Examples of special permit uses, which may be permitted only upon application to the Zoning Administrator and the issuance of a special permit by the Board of Adjustment are (Kusler and Lee, 1972:48) as follows:

1. Drive-in theaters, roadside stands, new and used car lots.
2. Gravel pits and sand washing operations.
3. Docks, piers, wharves and marinas.
4. Railroads, road networks, utility transmission lines.

Evaluative Standards for Floodway Uses

Recommended evaluative standards for floodway uses (Kusler and Lee, 1972:49) are as follows:

1. All uses. Cumulative effects of all likely encroachments on the floodway causing increases in flood heights must be considered. If one landowner is allowed to encroach on the floodway it may be reasonable to assume that other landowners within the same hydraulic reach must be treated equitably and allowed to develop within the floodway to an equal extent.

2. Fill. Filling in the floodway should be minimized to preserve the flow capacity of the floodway, but if allowed must be protected against erosion.

3. Structures. Both temporary and permanent structures designed for human habitation are prohibited from being placed in the floodway. Those structures permitted as special-exception uses must be situated where they will not greatly obstruct flood flow.

4. Storage of material. Materials and equipment which won't be damaged by flooding or can be removed before flooding occurs, may be stored. Buoyant, flammable and toxic materials are prohibited.

Flood Fringe District

Permitted uses. (D) Almost all uses are permitted since flood flows generally have low depths and velocities in the fringe area. Most open space uses will not need to be placed at the regulatory-flood protection level. Permitted uses are:

1. Any use permitted in Section (A) (i.e., as in the floodway)

2. Structures constructed on fill so that the first floor and basement floor are above the regulatory-flood protection elevation. The fill shall be at a point no lower than [1] foot below the regulatory-flood protection elevation for the particular area and shall extend at such elevation at least [15] feet beyond the limits of any structure or building erected thereon. However, no use shall be constructed which will adversely affect the capacity of channels or floodways or any tributary to the main stream, drainage ditch, or any other drainage facility or system (Kusler and Lee, 1972;50).

By meeting standards suggested by the numerical values in the brackets, fill should be sufficient to prevent excessive damage due to scouring.

Non-conforming uses. (E) The Task Force on Federal Flood Control Policy recognized the troublesome issue caused by enactment of a zoning ordinance that renders the location or use of a building to violate the provisions of the zoning ordinance. The Task Force (WRC, 1971:447) stressed the differences between existing and potential uses, viz:

> Public policy should distinguish between the problem of minimizing damage to existing flood plain developments and the problem of achieving optimum future use of flood plains. The first problem centers on protecting an investment already made. The second is concerned with choosing the best investment alternative from the myriad possibilities available.

Some of the major techniques (WRC, 1971:450) for dealing with pre-existing uses are as follows:

Nonregulatory alternatives:

Condemnation or purchase
Flood insurance
Construction of protective works or
Provision for allied programs

Regulations for existing uses

Abatement of existing uses as public nuisances;
Nonconforming use provisions in zoning ordinances to:
- require uses be brought into conformity when reestablished after destruction or abandonment,
- require existing uses be elevated or floodproofed when major repairs, structural alterations, or extensions are undertaken,
- require existing structures in continued use to be elevated or floodproofed,
- require elemination or modification of uses through amortization procedures.

The nonconforming use provisions presented in the two district zoning ordinance (WRC, 1971:533) are designed for flood hazard situations and basically allow the nonconforming use to continue subject to the conditions under the above-mentioned category of "Regulations for existing uses."

Zoning Application Decision by the Board of Adjustment (F) The Board issues a decision on the application denying, allowing, or conditionally allowing the application. In addition to the specific requirements for floodway uses and flood fringe uses already mentioned, some of the general requirements (WRC, 1971:531) the Board should consider are:

1. The danger to life and property due to increased flood heights or velocities caused by encroachments.

2. The danger that materials may be swept on to other lands or downstream to the injury of others.

3. The proposed water supply and sanitation systems and the ability of these systems to prevent disease, contamination and unsanitary conditions.

4. The susceptibility of the proposed facility and its contents to flood damage and the effect of such damage on the individual owner.

5. The importance of the services provided by the proposed facility to the community.

6. The requirements of the facility for a waterfront location.

7. The availability of alternative locations, not subject to flooding, for the proposed use.

8. The compatibility of the proposed use with existing development and development anticipated in the foreseeable future.

9. The relationship of the proposed use to the comprehensive plan and flood plain management program for the area.

10. The safety of access to the property in times of flood for ordinary and emergency vehicles.

11. The expected heights, velocity, duration, rate of rise and sediment transport of the floodwaters expected at the site.

Follow-up Management

After the two district zoning ordinance has been adopted and implemented, it still will be necessary to enforce the ordinance, insuring that regulations and proper land use in each zone are being adhered to. Changes over time, which affect the stream and valley cross-sections and cause an increase in the flood heights above regulatory limits, may necessitate adjusting delineation boundaries. Alternatively, prompt initiation of plans for structural measures, such as construction of levees or dredging and cleaning of sediment from the channel bottom may, be more appropriate.

A two district zoning ordinance for a region does permit detailed control over the type of land use and building development; however, the zoning ordinance is usually most effective when used in conjunction with building codes, sanitary codes, subdivision regulations, and other special regulations.

CHAPTER 4

SUMMARY AND CONCLUSIONS

Summary

Flood plain zoning is one of many alternatives that can be employed by planners to mitigate flood damage losses in flood plain regions. When this alternative is chosen it is important that the planners recognize the need to establish management capable of enforcing the ordinances. Additionally, the zoned district must have emergency flood fighting capabilities. Otherwise adequate provision for contingencies such as a flood of catastrophic proportions (in excess of the regulatory-flood) will not be possible. The two district zoning approach is a viable alternative for regulating flood hazard areas and is fully in concert with federal land use control policy and flood plain management criteria. Federal involvement in two district flood plain zoning, data required for delineation, and the expected impact of zoning are summarized below.

Federal Involvement in Two District Flood Plain Zoning

The benefits which may be expected from employment of the two district approach are derived both from federally sponsored programs and directly from the provisions of the two district flood plain zoning ordinance. The federal government has taken and continues to take strong administrative actions to aid state and local governments in establishing flood plain management programs and to encourage the adoption of the two district zoning ordinance. These actions (establishing guidelines or criteria) help standardize methods by which flood plains are delineated and zoning measures implemented. The two district flood plain approach accommodates the following federal guidelines, criteria, and proposed actions.

1. Regulatory-Flood Magnitude:

The Log-Pearson Type III probability distribution is used to describe the annual flood peak magnitudes. The regulatory-flood plain is delineated using the flood having a 100 year recurrence interval.

2. National Flood Insurance Program:

By participating in the National Flood Insurance Program a community can receive the technical data and expertise required for delineation of the flood fringe and floodway districts at little or no direct cost accrued to the community. As communities adopt stringent land use and flood control measures, and actuarial rate studies are completed, flood insurance is made available only at actuarial rates within the flood plain with respect to any property which is thereafter constructed or substantially improved. Hence, flood plain landowners who qualify for actuarial rates cease to be a tax burden.

3. Flood Disaster Protection Act of 1973:

Participation in the National Flood Insurance Program by flood prone communities will in effect be mandatory. Non-compliance by July 1, 1975 will mean that flood plain landowners will be denied loans (from federally insured institutions) for construction projects within the flood plain.

4. Federal Land Use Policy Act 1972 (SB-268):

Federal dollars will go to states and local communities for development of land use plans and programs which are likely to embrace flood plain lands and management programs.

5. Water Resources Council Statutes and Flood Plain Zoning Ordinances 1971:

The "draft" statutes, ordinances, and commentary will provide many states and local communities with the necessary tools to begin a sound flood plain management program, with emphasis placed on establishing a two district flood plain zoning ordinance as the preferred land use regulatory technique for reducing flood losses.

Data Required for Two District Flood Plain Delineation

Two district flood plain mapping is a data intensive procedure. Hydraulic, hydrologic and geometric data are required for backwater profile computations from which the floodway and flood fringe boundaries are delineated. The specific data required includes: The N largest annual floods in an N year period (gauged or simulated); channel and flood plain geometries normal to the flow direction (field survey and topographic map interpretation); inundation boundaries resulting from large historical floods (visual and other records); and hydraulic parameters (estimated and refined by calibration computations). Few of these data are obtainable with precision. Therefore, considerable uncertainty may exist as to where the actual regulatory-flood plain boundaries should be located.

Preliminary computations, as outlined in the body of this report, should be undertaken to ensure that the data required for mapping purposes are sufficient to justify the expense of the analytical procedures used in mapping. Further, the data must permit the boundaries to be established with sufficient accuracy to avoid over or under design with respect to flood proofing measures in the flood fringe zone. When preliminary computations indicate large uncertainty in the mean location of the flood fringe boundary, there may be insufficient data to delineate the flood plain into two zones. In such cases, single district zoning (with no construction in the estimated regulatory-flood plain) is all that can be justified. Single district zoning, based upon physical flood plain features, can be modified to two district zoning as sufficient data are collected to permit reduction in uncertainty bounds to prescribed limits.

Generally, the largest component of flood plain delineation uncertainty results from insufficient flood peak information to accurately estimate the magnitude of the regulatory flood. This uncertainty is largest for flood peak data samples having large coefficient of variation and few observations in the sample.

Expected Impact of Two District Flood Plain Zoning

In accordance with federal criteria, and in accordance with federal and state legal requirements, a two district zoning ordinance for an area will provide the means to prohibit obstructions in floodways, and guide economic development of floodway fringe areas by permitting only those uses that are compatible with the estimated degree of flood hazard.

A two district flood zoning ordinance includes provisions designed to:

1. Provide regulatory controls for preventing filling or encroachment of buildings and structures having large damage potential or that are designed for human habitation in the floodway.

2. Encourage floodway use for recreation, open space and conservation.

3. Require protection for structures and service facilities in the flood fringe.

4. Protect individuals from buying lands and structures which are unsuited for intended purposes because of flood hazards.

5. Provide for public awareness of the flooding potential.

6. Minimize public and private property damage.

7. Protect human life and health.

Conclusions

When uncertainty in hydrologic and hydraulic data is large only single district flood plain zoning can be attempted. The magnitude of mapping uncertainty can be determined in each area by preliminary computations employing first order uncertainty analysis using approximate channel-flood plain sections normal to the main flow and estimates of the mean and variance of the regulatory-flood magnitude.

A two district zoning approach offers an acceptable method for regulating flood hazard areas to reduce flood losses. Two district zoning,satisfying federal criteria, can be implemented in flood plain areas provided that the necessary data are sufficiently accurate to clearly establish the expected inundation boundaries.

There exists a need to establish criteria for incorporating the uncertainty associated with estimated flood plain inundation boundaries into the zoning process. Some possible criteria are suggested in the body of this report.

Further work on uncertainty is important to determine the degree of over or under design associated with boundaries established in accordance with federal criteria for two district zoning. We have only addressed Type II uncertainty in this report. It is necessary to quantify the magnitude of Type I error associated with the design hydrograph shape and with the assumption that the flood peaks are distributed as a Log-Pearson Type III probability distribution.

As information is gathered about the usefulness of two district zoning, it will be necessary to examine the economic viability of the approach. Guidelines will need to be developed that translate the subtleties of economic analysis into practical zoning considerations.

APPENDIX A

USE OF THE LOG-PEARSON TYPE III PROBABILITY DISTRIBUTION TO ESTIMATE THE MAGNITUDES OF UNCOMMON FLOODS

While several different types of statistical distributions might be used, in order to promote greater consistency in project formulation, the Water Resources Council recommended use of the Log-Pearson Type III distribution, as a uniform technique for determining flood frequencies. This does not imply that this distribution should be used unthinkingly. (WRC, 1967)

The Pearson Type III probability distribution is quite general and its density function is

$$f_x(X) = \alpha^{\lambda} e^{-\alpha(x-m)} (x-m)^{\lambda-1} dx$$

$$m \leq x < \infty \qquad \bar{x} = \frac{\lambda}{\alpha+m}$$

$$\alpha > 0 \qquad \text{and} \qquad S_x = \frac{\lambda}{\alpha^2} \qquad \text{A-1}$$

$$\lambda > 0 \qquad G_x = \frac{2}{\sqrt{\lambda}}$$

in which x is the measured quantity or variable being described; $\bar{x}$, is its arithmetic average; S_x, the standard deviation; and G_x, is the skew doefficient of the variable x. The Log-Pearson[1] distribution results when $Y = \log(x)$ is substituted for x in equations A-1.

[1] Confidence intervals are more difficult to obtain than for the Extreme Value (Gumbel) distribution. See for example: B. Bobee and G. Morin. 1973. "Determination of Confidence Intervals for Pearson Type III Distribution Using Order Statistics," *Journal of Hydrology*, Vol. 20, No. 2, pp. 137-154, October.

Equation A-1 is not in convenient form for common usage. Thus a generalized relationship between the logarithm of flood flow and corresponding recurrence interval

$$Y = \overline{Y} + KS_y \qquad \text{A-2}$$

in which Y is the logarithm (base 10) of a flood having recurrence interval factor K; $\overline{Y}$ is the arithmetic average; S_y is the standard deviation; and K is a multiplier uniquely determined by the specified recurrence interval of Y and the skew coefficient of the logarithms of flood flows, is used. Values of K are shown in Table A-1; the table was taken from James and Lee (1971:232). Equation A-2 simply states that the log-transform of any flood is the mean plus or minus a multiple of the standard deviation. A numerical example using the annual flood series for the South Fork Skykomish River, near Index Washington (Table 2) follows.

Example

Compute the estimated 100 year recurrence interval flood using N = 60 years of data for the South Fork Skykomish River. All logarithms are to base 10.

i) Compute $\overline{Y}$ the mean of the logarithms of the flows.

$$\overline{Y} = \sum_{i=1}^{n} \frac{Yi}{N}$$

$$= 4.34$$

ii) Compute S_y the standard deviation of the logarithms of

Table A-1: *K* **Values for Pearson Type III Distribution***

RETURN PERIOD, YEARS

*G**	2	5	10	25	50	100	200
3.0	−0.396	0.420	1.180	2.278	3.152	4.051	4.970
2.8	−0.384	0.460	1.210	2.275	3.114	3.973	4.847
2.6	−0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.4	−0.351	0.537	1.262	2.256	3.023	3.800	4.584
2.2	−0.330	0.574	1.284	2.240	2.970	3.705	4.444
2.0	−0.307	0.609	1.302	2.219	2.912	3.605	4.298
1.8	−0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.6	−0.254	0.675	1.329	2.163	2.780	3.388	3.990
1.4	−0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.2	−0.195	0.732	1.340	2.087	2.626	3.149	3.661
1.0	−0.164	0.758	1.340	2.043	2.542	3.022	3.489
0.8	−0.132	0.780	1.336	1.993	2.453	2.891	3.312
0.6	−0.099	0.800	1.328	1.939	2.359	2.755	3.132
0.4	−0.066	0.816	1.317	1.880	2.261	2.615	2.949
0.2	−0.033	0.830	1.301	1.818	2.159	2.472	2.763
0.0	0.000	0.842	1.282	1.751	2.054	2.326	2.576
−0.2	0.033	0.850	1.258	1.680	1.945	2.178	2.388
−0.4	0.066	0.855	1.231	1.606	1.834	2.029	2.201
−0.6	0.099	0.857	1.200	1.528	1.720	1.880	2.016
−0.8	0.132	0.856	1.166	1.448	1.606	1.733	1.837
−1.0	0.164	0.852	1.128	1.366	1.492	1.588	1.664
−1.2	0.195	0.844	1.086	1.282	1.379	1.449	1.501
−1.4	0.225	0.832	1.041	1.198	1.270	1.318	1.351
−1.6	0.254	0.817	0.994	1.116	1.166	1.197	1.216
−1.8	0.282	0.799	0.945	1.035	1.069	1.087	1.097
−2.0	0.307	0.777	0.895	0.959	0.980	0.990	0.995
−2.2	0.330	0.752	0.844	0.888	0.900	0.905	0.907
−2.4	0.351	0.725	0.795	0.823	0.830	0.832	0.833
−2.6	0.368	0.696	0.747	0.764	0.768	0.769	0.769
−2.8	0.384	0.666	0.702	0.712	0.714	0.714	0.714
−3.0	0.396	0.636	0.660	0.666	0.666	0.667	0.667

* **Values calculated by Central Technical Unit, Soil Conservation Service, "New Tables of Percentage Points of the Pearson Type III Distribution" (January, 1968).**

*G is the coefficient of skewness

(James and Lee, 1971:232)

the annual floods.

$$S_y = \sqrt{\frac{\sum_{i=1}^{n} (Y_i - \overline{Y})^2}{N - 1}}$$

$$= 0.22$$

iii) Compute G_y, the coefficient of skewness of the sequence Y_i .

$$G_y = \frac{N \sum_{i=1}^{n} (Y_i - \overline{Y})^3}{(N-1)(N-2)\, S_y^{\,3}}$$

$$= 0.07$$

iv) From Table A-1 interpolating between G = 0 and G = 0.2 the appropriate multiplier K is

$$K_{(0.07,\ 100)} = \frac{0.07}{0.2} (2.472 - 2.326) + 2.326$$

$$= 2.377$$

Hence

$$Y_{100} = 4.34 + 2.377 * 0.22$$

$$= 4.86$$

$$Q_{100} = \text{Antilog } (Y_{100}) = 72{,}300 \text{ cfs}$$

APPENDIX B

ESTIMATION OF PEAK FLOODS

James and Lee (1971:234) list methods[1] and data sources which may be utilized to estimate streamflows if long term runoff records are not available.

1. For smaller drainage basins, a unit hydrograph may be derived and then applied to rainfall excess estimated for the major storms of each year to determine each annual flood for the frequency analysis.[2]

2. Direct application of the unit hydrograph gives unsatisfactory results for large heterogeneous drainage basins (over 3,000 sq. miles). Individual unit hydrographs must be developed for each small, homogeneous component basin from which the flood hydrographs may be routed and combined to find the flood peak.

3. Flood hydrograph peaks do not really vary linearly with storm-runoff volume as is assumed by the unit hydrograph. More refined methods of hydrograph reconstruction use digital computer models with moisture balance accounting. The Stanford watershed model synthesizes the entire annual hydrograph from hourly rainfall records and watershed parameters developed from 3 or 4 years of stream records.[3]

4. An alternative method is to develop long-term flow sequences having statistical parameters derived from the historical record but not representing historical flow sequences. This method is not well understood at present and should be used with caution.

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[1] Additional discussion is found in J. Amorocho and W.E. Hart, "A Critique of Current Methods in Hydrologic Systems Investigation", Trans. Am. Geophys. Union, Vol. 45 (June, 1964) pp. 309-321.

[2] Ray K. Linsley, Jr., Max A. Kohler, and Joseph L.H. Paulhus, Applied Hydrology (New York: McGraw-Hill Book Co., 1949), pp. 194-203.

[3] N.H. Crawford and Ray K. Linsley, "Digital Simulation in Hydrology: Stanford Watershed Model IV", Standord University, Department of Civil Engineering (Tech. Rept. 39), 1966.

APPENDIX C

THE 100 YEAR FLOOD IN PERSPECTIVE

Generally the maximum probable flood of an area is determined from the effects of the physical limit of rainfall over the drainage basin (Linsley and Franzini, 1972:137). Usually the spillways of many major dams are designed to discharge this flow, especially where the failure of a dam,followed by rapid release of the reservoir's contents, would result in heavy loss of life downstream.

By comparison, peak discharges for the Standard Project Flood (SPF) used by the Corps of Engineers are generally 40 to 60 per cent of the probable maximum flood for the same basins (COE, 1969: 33). The Standard Project Flood[1] is defined as,

> ...the flood that may be expected from the most severe combination of meteorological and hydrological conditions that is considered reasonably characteristic of the geographical area in which the drainage basin is located, excluding extremely rare combinations. (COE, 1969:33)

Flood plain information studies prepared by the Corps of Engineers typically provide water surface profiles and location of the outer boundaries of the flood plain for both the Standard Project Flood and the 100 year flood (COE, 1969). Typically, flood heights resulting from the Standard Project Flood are 1 to 3 feet higher than that of the 100 year flood[2] (COE, 1973:35).

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[1]The Standard Project Flood has been used in the past to determine the physical capacity of flood mitigation reservoirs.

[2]It is instructive to compare this observation with the recommendations for accommodating uncertainty given earlier in this report.

It is important to realize that the 100 year flood has a 1% chance of occurring in any year. This does not mean that it will occur in any particular year or that it will occur in a 100 year time span. What then is the risk of flood inundation for a flood plain zone, mapped on the basis of a particular recurrence interval flood over a large number of years? Table C-1, extracted from Linsley and Franzini (1972:125) illustrates different risks for different design floods.

Table C-1: Probability (J) That an Event Having Specified Recurrence Interval Will be Equalled or Exceeded at Least Once During Various Time Periods.

Flood Recurrence Interval (Years)	Number of Years Area is Exposed to Flood Hazard							
	1	5	10	25	50	100	200	500
	Probability (J)							
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	0.5	0.97	0.999	*	*	*	*	*
5	0.2	0.67	0.89	0.996	*	*	*	*
10	0.1	0.41	0.65	0.93	0.995	*	*	*
50	0.02	0.10	0.18	0.40	0.64	0.87	0.98	*
100	0.01	0.05	0.10	0.22	0.40	0.63	0.87	0.993
200	0.005	0.02	0.05	0.12	0.22	0.39	0.63	0.92

*In these cases J can never be exactly 1, but for all practical purposes its value may be taken as unity.

The information in Table C-1 illustrates, for example, that a flood magnitude having a recurrence interval of 10 years has a 41%

chance of being equalled or exceeded at least once in a period of 5 successive years or a 93% chance of being equalled or exceeded at least once in a continuous 25 year period some time in the future. To an individual, who plans to construct a house on a flood plain which has been zoned on the basis of a 100 year flood, these probabilities mean that his chance of being flooded at least once in 50 years is 40%. If this same flood plain had been zoned on the basis of a 50 year flood, however, the probability that the house owner will be flooded at least once in a 50 year period is 64%. These probabilities do not reflect the magnitude of damage to be expected.

A Water Resources Council Study (WRC, 1971) refers to the 100 year flood as a

> ...commonly used regulatory flood..., and cites an unpublished statement submitted to the Bureau of the Budget (by representatives of 25 Federal agencies, July 26, 1967, p. 3) for consideration in drawing up the document published as, "Flood Hazard Evaluation Guidelines for Federal Executive Agencies."

The statement read:

> ...(I)t is not practical to establish a particular flood magnitude which is applicable for determining safe elevations for all uses or all sites. However, a sampling of Federal, State and local program administrators indicated that although floods of other magnitudes are sometimes used, there is general agreement that the one per cent probability line (100 year flood) more readily represents a reasonable balance between excessive flood losses and excessive conservatism for most uses.

APPENDIX D

RELATIONSHIP BETWEEN UNCERTAINTY IN FLOOD PEAK MAGNITUDE AND UNCERTAINTY IN FLOOD INUNDATION BOUNDARIES

Consider the total discharge, Q_{TOT}, normal to the idealized section of Figure D.1.

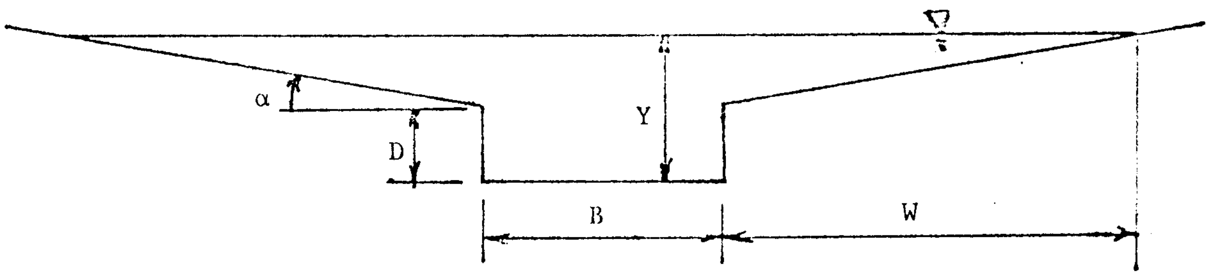

Figure D.1. Idealized Flood Plain Section

The discharge normal to this section can be approximated with one dimensional flow analysis. At equilibrium flow, Manning's equation, applied to the channel and flood plain, yields:

$$Q_{TOT} = Y^{5/3} \frac{(1.49B^{5/3}}{N_R(2D + B)^{2/3}} + \frac{(Y - D)^{8/3}(1.49S}{4^{1/3} N_S \tan(\alpha)} \; ; \; Y > D \qquad \text{(D1)}$$

in which

Q_{TOT} is the discharge normal to the section (cfs)

Y is the depth from river bed to the water surface (ft)

B, D are river channel width and depth respectively (ft)

N_R, N_S are Manning roughness coefficients for the river and overbank regions respectively.

SS_R, SS_S are the hydraulic gradients of the river channel and overbank regions respectively.

Tan(α) is the slope of the flood plain towards the channel.

In deriving Eq. D1 use was made of the fact that α is typically very small. ($\tan(\alpha) = 0.004$ corresponds to land sloping to the river at approximately 20 ft./mile.)

If the notation $\overline{X}$ and S_X is used to represent the mean and standard deviation respectively of a parameter X then application of first order uncertainty analysis to Eq. D1 yields

$$\overline{Q}_{TOT} = \overline{Y}^{5/3}\frac{(1.49B^{5/3}\overline{SS}_R{}^{1/2}}{\overline{N}_R(2D + B)^{2/3}} + \frac{(\overline{Y} - D)^{8/3}(1.49\ \overline{SS}_S{}^{1/2}}{4^{1/3}\overline{N}_S \tan(\alpha)} \qquad \text{(D2)}$$

Variance estimates for Q_{TOT} can be determined through a first order analysis using uncertainty in S_R, S_S, N_R, N_S, and Y. However, in the flood plain mapping situation $\overline{Q}_{TOT}$ and $S_{Q_{TOT}}$ are determined by frequency analysis of flood peaks. Thus uncertainty in Y can be determined from the total uncertainty $S_{Q_{TOT}}$ and the other uncertain parameters. This necessitates a suitable implicit solution scheme to determine $\overline{Y}$ and S_Y.

The uncertainty in estimated peak discharge for the ith uncertain parameter, P_i, of Eq. D1, C_i is given by

$$C_i = \left|\frac{\partial Q_{TOT}}{\partial P_i}\right| \cdot S_{P_i} \qquad \text{(D3)}$$

Total uncertainty is given by

$$S_{Q_{TOT}} = [\sum_{i=1}^{n} C_i^{\,2}]^{1/2} \tag{D4}$$

Consider only uncertainty in Y, N_R, N_S, SS_R, SS_S. Then n equals 5 in Eq. D4. The respective C_i for these parameters are, assuming independence of parameters:

(i) Uncertainty in Y

$$C_1 = 1.49[\frac{5\bar{Y}^{2/3}\ B^{5/3}\ \overline{SS}_R^{\,1/2}}{3\bar{N}_R(2D + B)^{2/3}} + \frac{8(\bar{Y} - D)^{5/3}\ \overline{SS}_S^{\,1/2}}{3(4)^{1/3}\ \bar{N}_S\ \tan(\alpha)}]\ S_Y \tag{D5}$$

(ii) Uncertainty in N_R

$$C_2 = \frac{1.49\bar{Y}^{5/3}\ B^{5/3}\ \overline{SS}_R^{\,1/2}}{\bar{N}_R^{\,2}\ (2D + B)^{2/3}} \cdot S_{N_R} \tag{D6}$$

(iii) Uncertainty in SS_R

$$C_3 = \frac{1.49\bar{Y}^{5/3}\ B^{5/3}\overline{SS}_R^{\,-1/2}}{2\bar{N}_R(2D + B)^{2/3}} \cdot S_{SS_R} \tag{D7}$$

(iv) Uncertainty in SS_S

$$C_4 = \frac{1.49(\bar{Y} - D)^{8/3}\overline{SS}_S^{\,-1/2}}{2^{5/3}\ \bar{N}_S\ \tan(\alpha)} \cdot S_{SS_S} \tag{D8}$$

(v) Uncertainty in N_S

$$C_5 = \frac{1.49(\bar{y} - D)^{8/3}\overline{SS}_S^{\,-1/2}}{4^{1/3}\ \bar{N}_S\ \tan(\alpha)} \cdot S_{N_S} \tag{D9}$$

Solution Procedure -- Determination of $\overline{Y}$ and S_Y.

The following steps were conducted using a digital computer.

1. Read section geometry, Q_{TOT}, $S_{Q_{TOT}}$ and mean parameter values.
2. Solve iteratively (Eq. D2) for $\overline{Y}$.
3. Read coefficients of variation for N_R, N_S, SS_R, SS_S.
4. Increment estimated value of S_Y until $S_{Q_{TOT}}$ (Eq. D4) is approximately equal to the value of $S_{Q_{TOT}}$ read in step 1 above.
5. Print out relevant values of parameters, $\overline{Y}$ and S_Y.
6. Repeat steps 3, 4, and 5 for as many cases as desired.
7. Compute mean and variance of flood plain boundary, W.
8. Repeat steps 1 through 7 for different combinations of geometries and floods.

Generalization of Procedure.

When particular geometries, that differ from that of Figure D.1, are being investigated, they can be approximated by suitable geometric shapes and a new set of equations showing the relationship between geometry, hydraulic parameters and flood flow magnitude can be readily derived. Usually at equilibrium flow SS_S and SS_R should be approximately equal; it must be remembered that the analysis assumes the validity of a one dimensional formulation for the flow normal to the flow section area.

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