DEVELOPMENT OF A DRAINAGE AND FLOOD CONTROL MANAGEMENT PROGRAM FOR URBANIZING COMMUNITIES — PART II

by

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Completion Report

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ABSTRACT

Urbanization causes an alteration of the stormwater runoff response of the urbanizing watershed which, in turn, increases stormwater damages downstream. Few communities have successfully implemented programs for managing these development induced drainage impacts due in part to the uncertainties associated with any drainage management program. Which rainfall-runoff model should be used, how sensitive is project analysis to poor discharge prediction, how should project cost be allocated, and so on.

The objective of this research is to clarify these uncertainties and develop a readily implementable drainage and flood control management program for the mitigation of development-induced drainage impacts. These objectives are realized through a detailed examination of and recommendation on the three major elements of a drainage management program: the Technical element which establishes the method of flood hydrology calculation, the Financial element which establishes the methods for drainage and flood control cost calculation and cost allocation, and the Regulatory element which establishes the enforcement mechanism of the drainage management program.

The recommended Technical element is based on the sensitivity of project analysis to poor runoff prediction, and on the predictive capability of various rainfall-runoff models. This predictive capability was evaluated for some of the more popular rainfall-runoff models through a statistical analysis of published results from those models.

The recommended Financial element is based on a thorough review of the legal issues regarding: 1) municipal and developer liability

with respect to development-induced drainage impacts, 2) project cost calculation, and 3) project cost apportionment. A new approach for apportioning drainage and flood control facility costs between developers and the municipal government is presented. The approach utilizes existing engineering analysis techniques to divide project costs in proportion to the reduced liability attributable to the developers and to the municipal government.

Two Regulatory elements are proposed for the drainage management program. The changes to existing legislation that are necessary to enforce the drainage management program under the proposed regulatory component are discussed and sample legislation is included for each.

The report is divided into two parts. Part II is the complete project report with detailed discussions of the methods and data used, and of the research findings. Part I is written as a user publication. It summarizes the research methods and results, and discusses the recommended drainage management program.

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Chapter I

INTRODUCTION TO THE STUDY

Summary of the Drainage Problem in Urbanizing Communities

Urbanization transforms agricultural and natural environments into residential and commercial developments. This transformation alters the stormwater runoff response of the urbanizing watershed which, in turn, increases stormwater damages downstream. The municipal engineers of some 2,000 rapidly growing communities across the country are beginning to recognize the severity of these changes, and their responsibility to accommodate them. Unfortunately, they have had limited success in implementing programs to manage these development-induced drainage impacts.

More than just a few communities have found themselves studying and restudying the same drainage basins without ever establishing any kind of drainage management program. The appropriation of money for drainage studies indicates that these communities recognize the existence of drainage and flood control problems. Why does the community stall at the study phase? What is causing the delay in implementing a program for managing the drainage impacts of community growth? In the writers' opinion, the delay stems from the uncertainties in the three principal elements of any drainage management program: 1) the Technical element which establishes the method of flood hydrology calculation, 2) the Financial element which establishes the methods for drainage and flood control cost calculation and cost allocation, and 3) the Regulatory element which establishes the enforcement mechanism of the drainage management program. The prevalent uncertainties in these areas are as follows:

Technical - There are numerous published techniques -- rainfall-runoff models -- that are "suitable" for computing watershed discharge in an urbanizing environment (17, 24, 33, 36, 89). Unfortunately, they all yield different discharges. These differences can be quite large; in one instance the 100 year discharge for a basin in Colorado using one method was twice the value computed using another.[1] These differences in discharge result, in turn, in different designs and different economic analyses. In developing a drainage management program, the municipal engineer must decide which technique offers his community the "best" flood hydrology prediction capability.

The literature in this area will not help the municipal engineer make this decision. He will find reports of demonstrated uses of, and problems associated with the various rainfall-runoff models (17, 63, 75, 109). However, his real concern -- the predictive capability of these models -- will not be answered. The reports of model comparisons (8) are far from conclusive and offer little assistance in selecting an appropriate rainfall-runoff model.

Financial - Drainage management is not cheap. The limited budgeting for the drainage sector must be augmented with other funds. The municipal engineer must first estimate the cost of needed drainage and flood control facilities. He then has to devise a method for equitably and legally collecting money to pay for these facilities.

The literature in this area is helpful but not complete. The municipal engineer will find reports on project evaluation methods (40), drainage facility financing alternatives (12), cost allocation

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[1] Endnotes begin on page 160.

formulae (23), and legal issues of financing urban infrastructure through cost sharing programs such as assessment districts (85) or development charges (3). Besides being disjointed, this research in the financial area has not satisfactorily answered the equity and legality questions of financing drainage and flood control facilities. The municipal engineer is still faced with the problem of determining the legal and equitable amount to charge the various beneficiaries of a particular flood control facility.

Regulatory - To be effective, the drainage management program must be packaged within an effective regulatory mechanism. The municipal engineer in concert with the municipal attorney and the local decision makers must determine how to implement the drainage management program. The implementation must be within the limits of the local government's grant of authority and, more importantly, it must be politically workable.

The literature in this area provides little practical guidance for selecting a Regulatory element. The majority of the literature addresses new and innovative regulatory approaches to land management such as land banking (1), timed development (11), and transfer of development rights (34). These techniques are interesting concepts in growth management but are not generally politically favorable at the present time.

Although the research in each of the three drainage program elements is important, it presents only pieces of the solution to the municipal engineer. In order to solve the problems of development-induced drainage impacts, the municipal engineer needs all three drainage program elements clarified and then combined into an implementable drainage management program. Without guidelines in these area, each municipal engineer will continue to waste precious time and scarce money as he searches for a program to effectively mitigate development-induced drainage impacts.

Objective

In this report, the writers' objective is to develop a readily implementable drainage and flood control management program for the mitigation of development-induced drainage impacts. The writers accomplish this objective by 1) analyzing the engineering, legal, and socio-political factors involved with each of the program elements, 2) recommending appropriate elements for small to medium size communities based on this combined analysis, and 3) presenting the advantages and disadvantages of the recommended elements.

Scope and Limitations

In this report, the writers bring together the research efforts in the technical, financial, and regulatory areas to develop a program for managing development-induced drainage impacts. The management program does not address the actual design and construction of drainage and flood control facilities, nor does it rely on a newly developed flood hydrology model. The program is developed for the appropriate allocation of costs for drainage and flood control facilities using existing cost effective rainfall-runoff models, abbreviated yet reasonable planning procedures, and effective regulatory mechanisms.

The program is converted into sample legislation that can be incorporated within local subdivision regulations or state subdivision enabling legislation. This research clarifies those uncertainties in the three element areas of drainage management listed earlier. It represents a comprehensive effort to develop a drainage management program that is legal, equitable, and most importantly, implementable within the resource and sociopolitical constraints of small to medium sized communities.

Definitions

In order to clarify many points in this paper, the following definitions and explanations are presented:

1) Drainage basin/subbasin - A community can be divided into major drainage basins ranging from 10 to 100 square miles. These major basins are composed of individual drainage subbasins ranging from 1 to 5 square miles as illustrated in Figure I-1. The writers feel this division creates logical drainage units for planning and management at the local level. The division separates the overall basin planning process from the detailed subbasin planning process, yet provides for coordination between these planning efforts. The major basins are studied to plan central drainage and flood control facilities, such as major channels and retention ponds. The individual subbasins are then studied to plan the trunk drainage facilities (minimum size of 36" to 54" pipe or channel equivalent) from the major channel to the upper reaches of the subbasin. Each property within the community is overlain by at least one basin and one subbasin and subject to the requirements of each.

2) Drainage and flood control - Control of surface and subsurface stormwater runoff. In this paper, the writers will use "drainage" or "flood control" alone to mean the same thing. The writers are not referring to drainage of marshy lands for reclamation purposes, nor to the hydraulic flow processes per se.

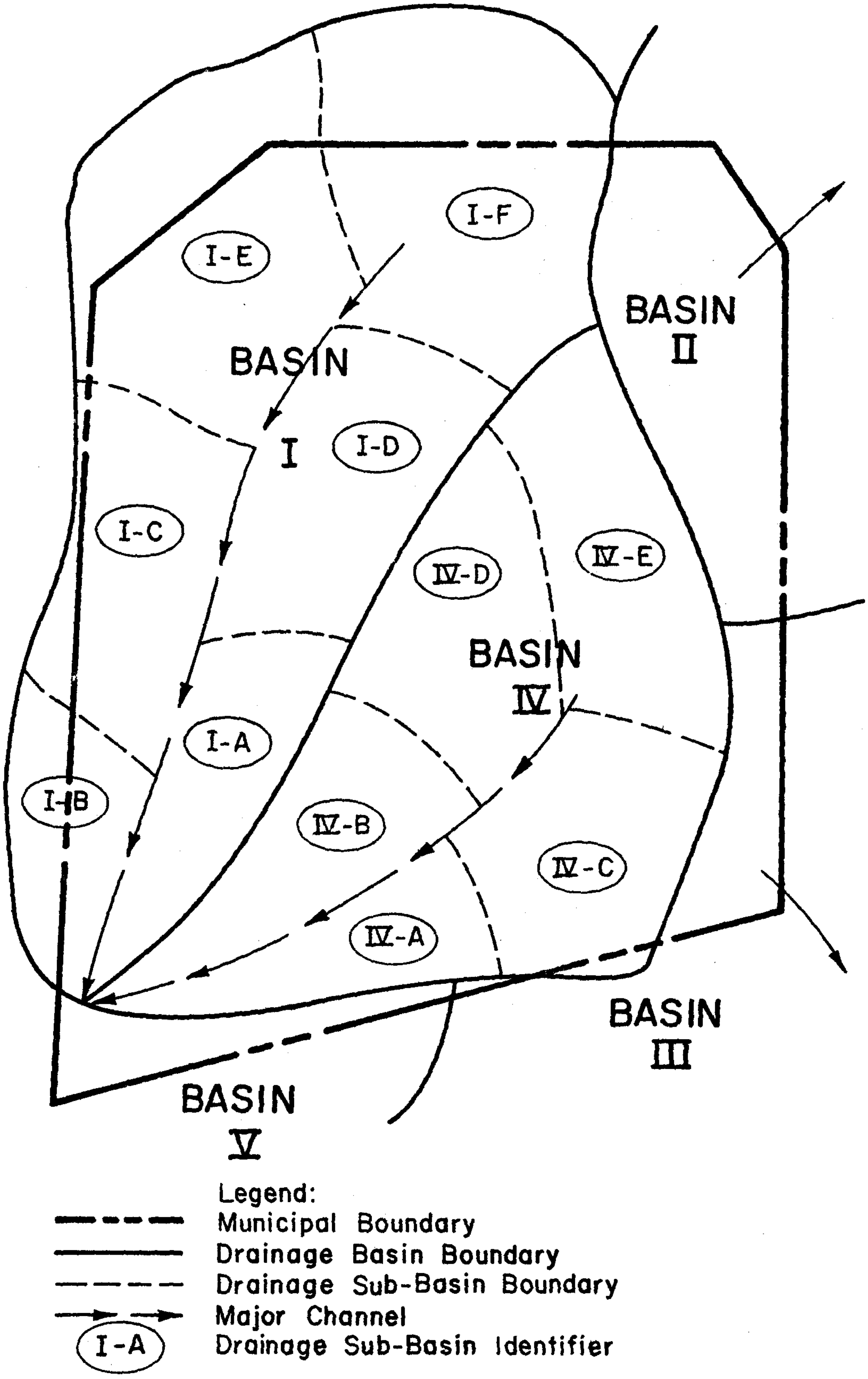


Figure I-1. Drainage Basin/Sub-basin Configuration.

3) Drainage and flood control management program - A management program enforced under some regulatory scheme for the equitable financing of drainage and flood control facilities. The system consists of:

a) a Technical element which establishes the method to be used for calculating flood hydrology, and

b) a Financial element which establishes the method to be used for calculating the costs of urban drainage and flood control facilities, and for allocating those costs among the beneficiaries of the facility.

4) Medium-size community - Throughout this paper, the writers are addressing drainage management for small to medium-sized rapidly growing communities with populations under 200,000 persons.

Chapter Review

The proposed management system is developed from a review of the three major component areas of drainage regulation.

In Chapter II, the writers examine various hydrologic prediction techniques that can be used to evaluate development-induced drainage impacts. They compare the predictive capability of some of the more popular rainfall-runoff models through a statistical analysis of published results from those models. In addition, they evaluate the sensitivity of project analysis -- cost estimate, benefit computation, benefit cost ratio, and minimum cost analysis -- to poor runoff prediction. From the results of this comparison and evaluation, they recommend a technical component for the drainage management system.

In Chapter III, the writers develop the financial element of the drainage management system. They review the legal issues regarding municipal and developer liability, cost calculation, and cost apportionment. They review existing cost calculation and cost apportionment methods and develop a new engineering approach for apportioning drainage and flood control facility costs between developers and the municipal government.

In Chapter IV, the writers develop two regulatory packages for the drainage management system. The regulatory elements are developed from a review of pertinent legal issues, and a review of existing U.S. Drainage Ordinances. The writers discuss the necessary changes to existing legislation that must occur in order to enforce the drainage management system under the proposed regulatory element. They include sample legislation in Appendix C.

Chapter II

TECHNICAL ELEMENT OF THE DRAINAGE MANAGEMENT PROGRAM

Techniques for Evaluating Changes in Hydrologic Response

Review of past work - Statistical analysis of historic runoff records is used to determine the expected frequency of various discharge events. The runoff data is "fitted" to a predetermined frequency distribution and peak discharges of any frequency are estimated from the parameters of the "fitted" distribution. This type of analysis has been presented by a number of authors (24, 89). It works well for rural areas that have experienced little physiographic change throughout the period of recorded runoff.

Unfortunately, small basins in urban areas generally do not have long records of homogeneous runoff data. Some kind of model or representation of the rainfall-runoff process must be used to estimate expected discharge events. The model takes the place of historic runoff data and must be capable of accurately representing the rainfall-runoff process for various rainfall events. Extensive work has been done in developing these urban rainfall-runoff models (46, 92, 93). The expressions were developed to estimate the design discharge for urban flood control structures and are generally limited to predicting only the peak runoff rate in a totally urban environment.

The limitations of these "rural" and "urban" hydrologic techniques restrict their use. Drainage and flood control management of an urbanizing basin requires an estimate of the growth-induced changes to all aspects of runoff response (peak discharge, volume of discharge, and time to peak). These changes are illustrated in Figure II-1 and

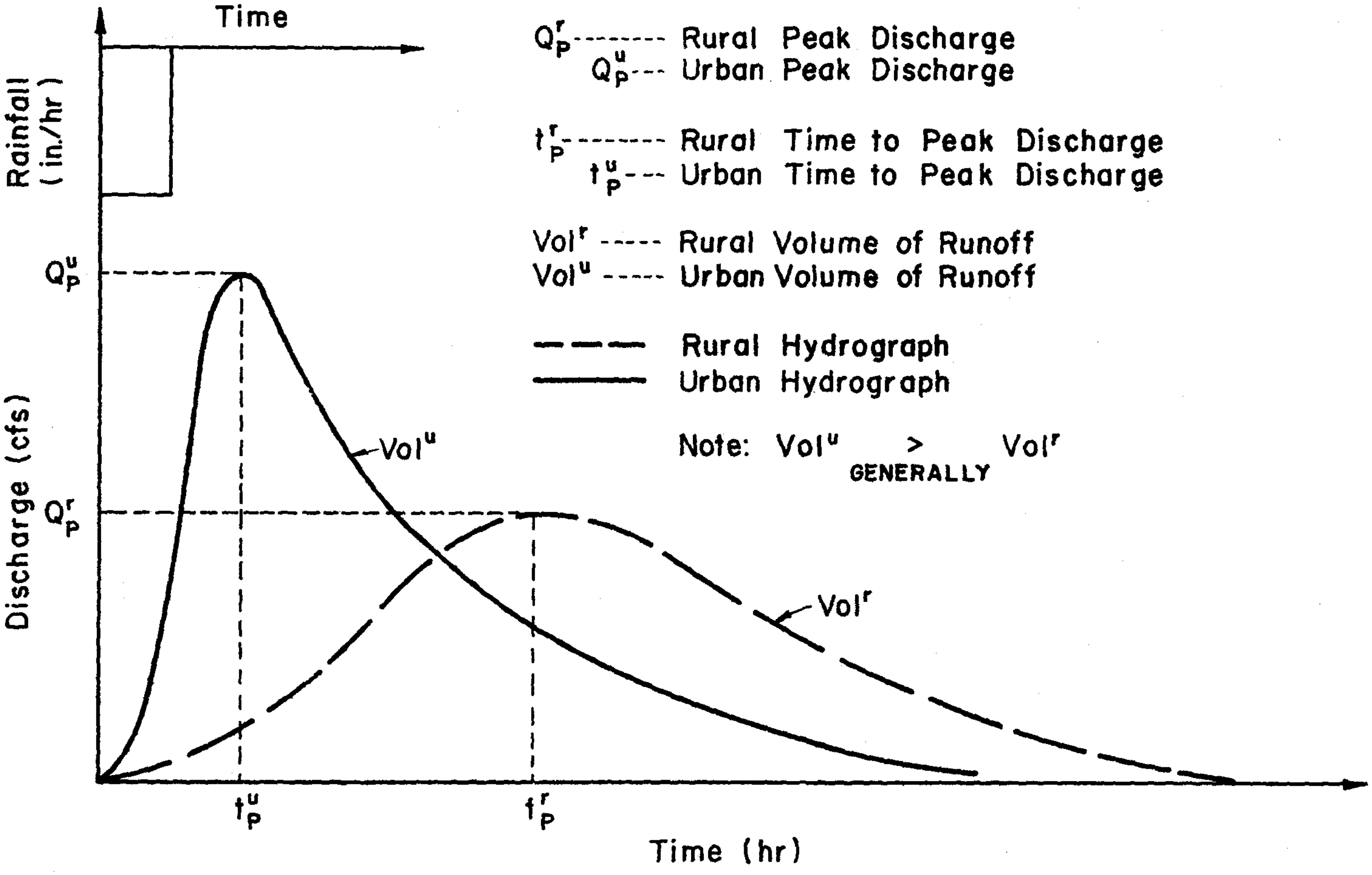


Figure II-1. Urbanization Impacts on Basin Hydrologic Response Without Increased Detention Storage.

II-2. Figure II-1 illustrates the frequently observed increase in peak discharge that accompanies watershed development. The development increases the stormwater carrying capacity of upstream channels resulting in a quicker and higher peak discharge rate. Figure II-2 illustrates the hydrologic response when the development provides for natural or man-made detention of stormwater. The volume of stormwater and the discharge duration are increased, but the peak discharge rate remains relatively unchanged.

Regardless of the response, an estimate of the change is required to identify flood control benefits and liabilities. All aspects of the response are necessary to allow flexibility in design. With all aspects of the runoff response, an engineer can design storage facilities (detention ponds) as well as discharge facilities (open channels, culverts, pipes). Another set of predictive models and expressions, or adaptations of the current ones, is required for satisfactorily representing urbanizing watersheds. These new models would be capable of predicting the <u>changes</u> in peak runoff rate, volume of runoff, and time distribution of runoff attributable to urban development.

Since the mid-1950's a number of studies have addressed the measurement of these particular changes in hydrologic response. The results of these studies are compiled in Appendix A. The results are expressed in common terms for easier comparison. The interpolation of published expressions (equations and graphs) required by this manipulation were confined within the limits of those expressions. Although the table in Appendix A is informative, the variability of the results provides little, if any, help to municipal governments attempting

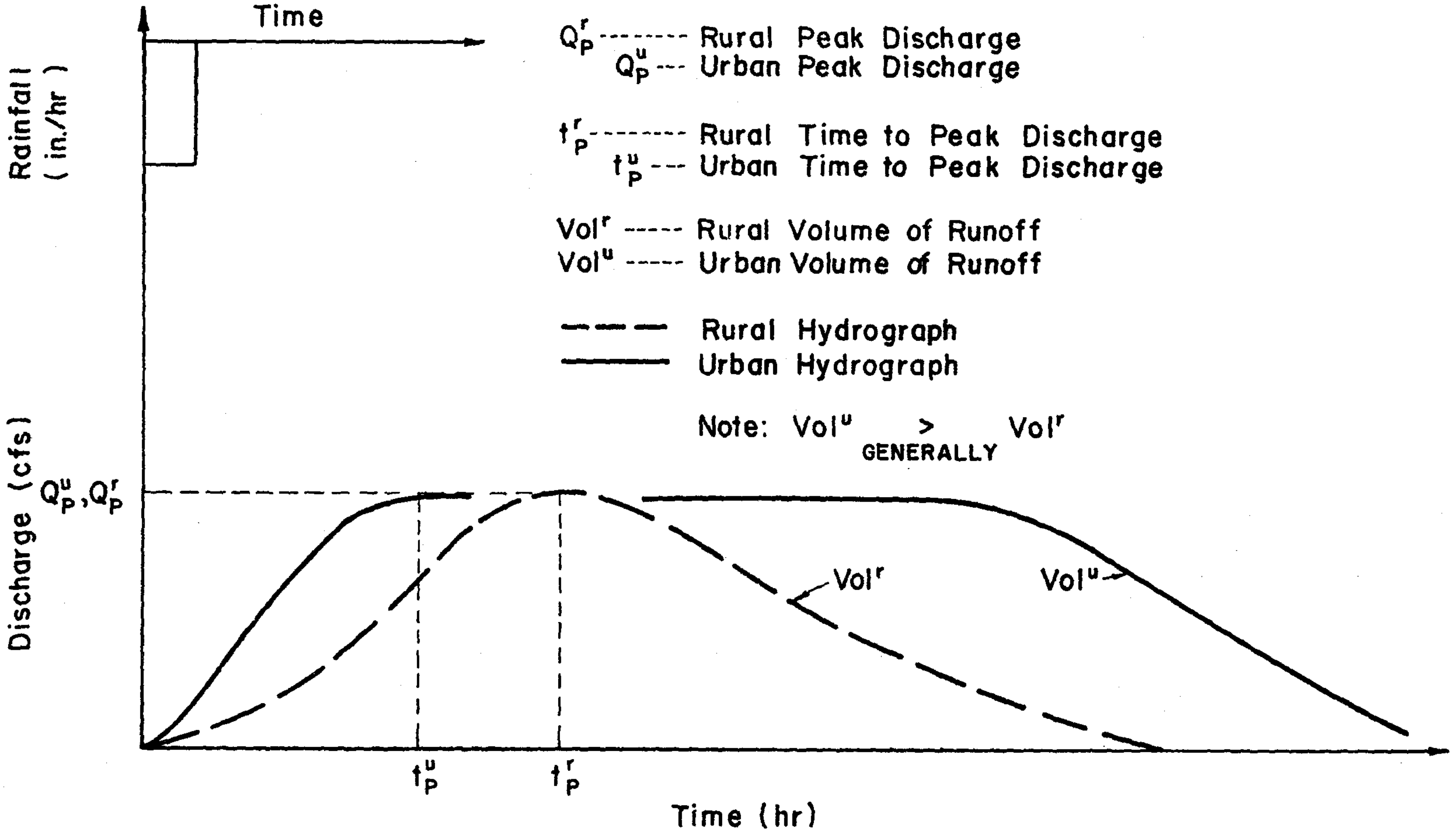


Figure II-2. Urbanization Impacts on Basin Hydrologic Response With Increased Detention Storage.

to identify the hydrologic consequences of a specific development. The table reveals that there is no universal hydrologic response formula for estimating the effects of urbanization on stormwater runoff characteristics.

The listed works are not without merit, however. They all substantiate the notion of increasing peak discharge with increasing urbanization. The peak discharge for urbanized conditions ranges from 1.8 to 8 times that for natural conditions for frequent events (mean annual flood), and from 1.8 to 3.8 times for the rare events (100 year flood). With the exception of Doehring's investigation (32), the studies further indicate that the effects of urbanization on rare events are significantly less than on frequent events. In addition, each of the studies presents a method for evaluating the effects of urbanization and identifies the data requirements for that method. In the absence of universal applicability of the results, the real value of the studies becomes the methods and the data requirements they suggest.

A number of the techniques presented by the investigators listed in Appendix A could satisfactorily be used as prediction models for urbanizing basins. The techniques fall into one of two categories: "Conceptual" rainfall-runoff models and "physically-based" rainfall-runoff models. This categorization is not sacred and at least one author (105) has questioned the existence of two separate categories due to the numerous natural phenomenon approximations and parameter estimations (i.e., conceptualization) required for physically-based models. The writers feel, however, that in addition to the different data requirements, the philosophy of approximating the physical processes of a watershed is sufficiently different from the philosophy of conceptual modeling to warrant separate classifications.

Conceptual rainfall-runoff models - Conceptual rainfall-runoff models are single transform functions that convert rainfall events into watershed runoff responses. The watershed runoff phenomenon is simply viewed as a "black-box" response ignoring all of the complex interdependent mechanisms of stormwater flow. These models can be classified according to the form of the transform function as linear, quasi-linear, and non-linear. Measured success has been attained with the first two models but at the present time the non-linear models do not appear to provide significantly improved accuracy of runoff prediction for urbanizing basins to warrant their added computational difficulties.

The application of linear conceptual rainfall-runoff models is perhaps best illustrated by Espey's unit hydrograph studies (35, 36). He developed regression equations that relate the characteristics of unit hydrographs for watersheds with different percentages of development to the physiographic features of those watersheds (percent imperviousness, channelization character, drainage area, and length and slope of main channel). Runoff hydrographs of various return intervals for urbanizing watersheds (changing percentages of imperviousness and channelization) can then be calculated by applying a rainfall event with the same return interval to the unit hydrograph derived from these equations. The major assumptions of this linear transformation is that the derived watershed unit hydrograph is unique for all rainfall events and the recurrence interval of the rainfall event is exactly equal to the recurrence interval of the runoff event.

Similar regression equations can be developed for other regions provided the requirements for Conceptual models listed in Table II-1 are available. The development procedure consists of extracting unit hydrographs from regional rainfall-runoff records for watersheds with various percentages of development. The unit hydrograph characteristics (peak runoff rate, time-to-peak, base width, etc.) are then equated to watershed physiography by multiple regression analysis.

As an alternative to this regression approach, the urbanization-induced changes of watershed response can be evaluated by a novel utilization of the n-linear reservoir conceptual model reported by Wittenburg (108). He proposed two conceptual linear reservoirs in parallel -- one that accounts for the impervious area of the watershed and one that accounts for the pervious areas. Once the parameter for each of these conceptual reservoirs has been determined, the runoff hydrograph from watersheds with various percentages of development can be determined by dividing it into pervious and impervious areas and then routing the proportionate amount of rainfall excess, for a specific recurrence interval, through the respective reservoirs. The concept appears viable but the parameter estimation for each of the conceptual reservoirs is considerably more difficult than the parameter estimation of single linear reservoir theory.

Unlike the linear conceptual models, the quasi-linear conceptual rainfall-runoff model uses characteristics of the input rainfall event to define the response transformation. That is, the quasi-linear model regression equation is a non-linear function that relates the characteristic(s) of the linear transform function (Nash model, linear reservoir model, etc.) to the rainfall characteristics (rainfall

Table II-1

Minimum Data, Technology, and Expertise Requirements for Conceptual and Physically-based Rainfall-Runoff Models

	DATA REQUIREMENTS					TECHNOLOGY REQ.			EXPERTISE REQ.				
MODEL	REGIONAL RAINFALL-RUNOFF DATA (2-5YR)	WATERSHED PHYSIOGRAPHIC CHARACTERISTICS	EXTENDED RAINFALL PERIOD	INFILTRATION, EVAPOTRANSPIRATION, DETENTION STORAGE DATA	INITIAL PARAMETER ESTIMATION	CALCULATOR	COMPUTER FACILITIES	MODEL COMPUTER PROGRAM	UNIT HYDROGRAPH ANALYSIS	CONCEPTUAL MODEL FAMILIARITY	REGRESSION ANALYSIS	FLOOD FREQUENCY ANALYSIS	MODELING & MODEL FAMILIARITY
1. Conceptual Rainfall-Runoff Models	*	*	*			*	o		*	*	*	*	
2. Physically-based Rainfall-Runoff models	*	*	*	*	*	o	*	*			o	*	*

LEGEND

* Mandatory Requirements
o Secondary Requirements

excess, storm duration, etc.) as well as the watershed physiographic features. This formulation relaxes the transform uniqueness assumption of the linear conceptual models.

The data requirements for developing similar regression equations are the same as the linear conceptual model requirements; the development procedure, however, is different. The parameter(s) of the transform function (K, or K and n) for watersheds with various percentages of development are evaluated by minimizing the deviation between the observed runoff hydrograph and the runoff hydrograph generated by the linear transformation of the associated rainfall event. These parameters are then related to the characteristics of the rainfall event as well as the watershed's physiographic features by multiple regression analysis.

There is a good chance that the regional data required to generate the regression equations of these conceptual rainfall-runoff models will simply not be available. An alternative approach has been reported in the literature (35, 88) which suggests the testing of already developed unit hydrograph formulae (such as Espey's equations) on any available data within the study region. If the tests yield satisfactory regeneration of observed hydrographs, then the full range of these equations could be used (with caution) for the basin in question.

Physically-based rainfall-runoff models - Unlike the "black-box" approach to conceptual modeling, physically-based rainfall-runoff models attempt to approximate the physical processes occurring within a watershed -- interception, evapotranspiration, infiltration, overland flow, and channel flow -- that convert rainfall into stormwater runoff. The watershed under study is divided into hydraulically similar drainage units (pervious flow planes, impervious flow planes, channel segments, etc.) for which satisfactory mathematical representation of the physical processes exist. The time distribution of storm water runoff for each drainage unit, and ultimately for the entire watershed, is then generated by applying the rainfall event and any upstream runoff to these drainage units for each time step. It should be noted that the extent to which the watershed is divided requires experience and modeling judgement; the increased accuracy of a very detailed representation of the watershed may not be worth the increased cost of simulation (9).

Dempster's (29) development of regional flood-frequency-urbanization equations is a good example of how physically-based rainfall-runoff models can be utilized. Although he does not address the time distribution of runoff, the writers feel that the development of general relationships for the runoff hydrograph (defining dimensionless runoff hydrographs for various frequency flood events) could have easily been included in the work. Dempster also illustrates that the use of physically-based models relaxes the assumption that the recurrence interval of the rainfall event must equal the recurrence interval of the runoff event. Unfortunately, the models do not account for the errors that are introduced when approximating the antecedent moisture conditions of the watershed.

Regional flood-frequency-urbanization equations similar to Dempster's can be developed for other study regions given the availability of the data listed in Table II-1. The development procedure begins with the verification and calibration (parameter estimation) of some (available) physically-based rainfall-runoff model using regional rainfall-runoff data for watersheds at various stages of development. Storm runoff events from each of these watersheds are then simulated by inputing selected rainfall events (from the extended regional rainfall record) to the calibrated model. A flood frequency analysis of the storm runoff events from each watershed is performed, and finally, the storm runoff characteristics (peak storm runoff rate, dimensionless runoff hydrograph, etc.) for a particular recurrence interval are related to the physiographic features of these watersheds by regression analysis.

One of the major complaints regarding physically-based rainfall-runoff models is their poor estimation of antecedent moisture conditions. The empirical equations used with some of these models to approximate watershed moisture conditions are simply not satisfactory. Continuous hydrologic simulation models are physically-based models that solve this problem by continuously accounting for all of the water (subsurface as well as surface) within a particular watershed. This modeling approach insures that the "exact" antecedent moisture conditions are simulated when particular storm events occur. This "exactness" is not obtained without cost, however; continuous simulation models require more and significantly better input data than the non-continuous physically-based rainfall-runoff models.

The most widely used continuous hydrologic simulation model is the Stanford Watershed Model (or versions of the Stanford Model). James (48) illustrates the application of this model. Like Dempster, he develops regional flood-frequency-urbanization relationships (graphical format) and ignores the development of relationships for the time distribution of runoff -- relationships that could be generated with the output from the continuous simulation model.

Similar flood peak relationships could be developed for other study regions provided the data listed in Table II-1 is available. The procedures for developing these relationships are essentially identical to those discussed earlier. However, instead of applying selected rainfall events, the entire extended rainfall record is applied to the calibrated model to generate a continuous runoff hydrograph. The flood frequency analysis is then performed on some series (partial duration or annual) of flood peaks extracted from this hydrograph.

An alternative continuous hydrologic simulation approach has been reported by Lumb and James (63). Instead of developing general flood-frequency-urbanization regression relationships, they develop four series of runoff responses and store them in computer files. Each file consists of the runoff response (as a function of area) from four typical "sub-units" within a watershed (impervious, high infiltration, medium infiltration, and low infiltration soils) for various recurrence intervals. The total runoff hydrograph from a particular watershed and recurrence interval can then be computed by dividing the watershed into subareas whose soil characteristics match one of the defined "subunits", and routing the appropriate runoff response (adjusted for area) through the entire watershed.

The modeling of watershed hydrologic response with either continuous or non-continuous physically-based rainfall-runoff models is indeed a tremendous advancement in the field of hydrology. Modeling should not, however, be viewed as the hydrologist's panacea. Data generated from simulation models can only be as accurate as the input data available. That is, the generation of extended runoff hydrograph records from long term point rainfall records (a major use of hydrologic models) does not necessarily increase the accuracy of flood frequency estimation. Other shortcomings of physically-based models include the difficulties of model calibration (63), the inadequacy of current data collection methods (17), and as illustrated in Table II-1 the need for special modeling expertise (9).

Comparison of the Predictive Capabilities of Physically-based and Conceptual Rainfall-Runoff Models

An urbanizing community must choose a rainfall-runoff model for hydrologic prediction. There are two criteria that must be satisfied by this choice. First, the model must be applicable to the intended use; and second, the model must be cost effective for the community.

All analytical or empirical representations of real world systems are developed for a specific purpose. This specificity usually allows certain approximations and assumptions to be made rendering an otherwise intractable problem solvable. This model should not then be used for other than its intended purpose without appropriate caution. One must insure that the inherent assumptions of the model are not violated. Rainfall-runoff models are no exception. The available models have been developed for a variety of purposes, including:

1) The simulation of the quantity aspects of rural rainfall-runoff phenomenon (general unit hydrograph) (15).

2) The simulation of the quantity aspects of urban rainfall-runoff phenomenon (Colorado Urban Hydrograph Precedures, CUHP) (110).

3) The simulation of the quantity and quality aspects of the rainfall-runoff phenomenon from combined urban sewer systems (Storm Water Management Model, SWMM) (8).

Before selecting a model, the urbanizing community must thoroughly analyze the model documentation to insure against violating model limitations. A good starting reference is Brandstetter (8). He has reviewed a number of the more popular rainfall-runoff models, and has compiled a table that lists the features and capabilities of each.

A number of rainfall-runoff models from the Conceptual and Physically-based categories will satisfy the first criteria. Which of these models will be the most cost effective prediction tool for the community? This is a tough question.

It has been suggested that physically-based rainfall-runoff models yield more accurate results (17). This accuracy translates into better utilization of funds due to the better information available for project analysis. However, these same models are more expensive to initiate than the conceptual rainfall-runoff models. The higher cost stems from the longer initiation time, the higher expertise requirements, and the greater data requirements associated with the physically-based models. The cost effectiveness question must, therefore, be addressed in two parts: First, "To what degree are physically-based models more accurate than conceptual models?" and second, "How sensitive is cost effectiveness to increased accuracy?" This section will address the first part and the next section will address the economic sensitivity question.

Data used for comparison - The writers compared predictive accuracy of the two model categories by examining the published results for models within each category. Using the results published in scientific journals is justified since they presumably represent results that an urbanizing community could expect from its staff or from an engineering consultant. One weakness of this approach is that it presumes the published work to be relatively unbiased. This presumption may not always be justified since some of the published studies compare existing models with a model developed by the author of the study.

The writers found eight published papers with sufficient prediction information to examine. Table II-2 lists the authors of the eight papers, the rainfall-runoff models tested, and information on the basins used in the tests. These basins represent a full range of typical urbanizing sub-basins. They vary from 13 acres to 2 square miles in area with 20% to 55% of that area being developed.

The writers grouped the tested models as follows:

1) Physically-based models.
    a) Stormwater Management Model (SWMM).
    b) University of Cincinnati Urban Runoff Model (UCUR).
2) Conceptual Models.
    a) Colorado Urban Hydrograph Procedure (CUHP).
    b) Soil Conservation Service Hydrograph (SCS).
    c) Road Research Laboratory Method (RRLM).
    d) Queens University Urban Runoff Model (QUURM).
    e) Battelle Urban Wastewater Management Model (BNW).
    f) Unit Hydrograph (UH).

This model classification scheme is not absolute but generally separates the models into groups with:

1) Similar data requirements.
2) Similar basin segmentation requirements.
3) Similar algorithm complexity.
4) Equal numbers of calibration parameters.

Table II-2. Reports Used for Comparison of Rainfall-Runoff Model Predictive Capability.

Investigator	Basin Information			Models Tested (no. of storms)
	Name	Area (Ac)	% Development	
Papadakis (1973)	Oakdale	12.9	46	SWMM(1)/UCUR(2)/RRLM(2)
Heeps (1974)	Vine St.	173	36	SWMM(2)/UCUR(2)/RRLM(2)
	Yarralumla	1240	20	SWMM(2)/UCUR(2)/RRLM(2)
Watt (1975)	Calvin Park	89.4	27	SWMM(10)/QUURM(10)
Marsalek (1975)	Oakdale	12.9	46	SWMM(17)/UCUR(14)/RRLM(17)
	Calvin Park	89.4	27	SWMM(13)/UCUR(13)/RRLM(12)
	Gray Haven	23.3	52	SWMM(14)/RRLM(14)
Haan (1975)	Clays Mill	890	32	CUHP(7)/SCS(7)
	Lansdowne	646	30	CUHP(5)/SCS(5)
Chow (1976)	Oakdale	12.9	46	SWMM(3)/UCUR(4)/RRLM(4)/UH(4)
Jennings (1976)	Manitou Way	141	20	SWMM(18)
	Crane Creek	287	19	SWMM(15)
Brandstetter (1976)	Oakdale	12.9	46	SWMM(8)/BNW(8)

Measures of fit - In the published studies, the various models were usually qualitatively analyzed. If the simulated hydrograph "looked" like the observed hydrograph then the model was said to predict the real world event "fairly well." No precise measure was used to establish "goodness of fit." In this examination, the writers used hydrograph "goodness of fit" measures suggested by Sarma (79) and modified by McCuen (67), together with the peak discharge measure presented by Marsalek (64). These measures of predictive capability are:

1) The Ratio (Q_pRATIO) of Simulated Peak Runoff Rate (Q_{ps}) to the Observed Peak Runoff Rate (Q_{po}). This ratio has the following properties:

a) If Q_p RATIO is greater than 1.0, the model overpredicts the peak runoff rate.

b) If Q_p RATIO equals 1.0, the model accurately predicts the peak runoff rate.

c) If Q_pRATIO is less than 1.0, the model underpredicts the peak runoff rate.

2) The Modified Correlation Coefficient (RMOD) as defined by McCuen (67). This coefficient is the linear correlation coefficient between the simulated and the observed hydrograph (as described by Sarma) adjusted for hydrograph size. It is defined by:

$$\text{RMOD} = (af) \times (R)$$

where af is the adjustment factor defined by:

$$af = \left[\frac{\sum_{i=1}^{n} (O_i - \overline{O})^2}{\sum_{i=1}^{n} (S_i - \overline{S})^2} \right]^{1/2} \qquad \text{when} \quad \Sigma(O_i-\overline{O})^2 \leq \Sigma\,(S_i-\overline{S})^2$$

$$af = \left[\frac{\sum_{i=1}^{n} (S_i - \overline{S})^2}{\sum_{i=1}^{n} (O_i - \overline{O})^2} \right]^{1/2} \qquad \text{otherwise.}$$

where S_i = simulated hydrograph ordinate at time i

O_i = observed hydrograph ordinate at time i

$\overline{O}$, $\overline{S}$ = mean values of the observed and simulated hydrograph ordinate

And, R is the linear correlation coefficient between the simulated and observed hydrographs and defined as:

$$R = \frac{N \sum_{i=1}^{n} O_i S_i - (\sum_{i=1}^{n} O_i)(\sum_{i=1}^{n} S_i)}{\{[N \sum_{i=1}^{n} O_i^2 - (\sum_{i=1}^{n} O_i)^2][N \sum_{i=1}^{n} S_i^2 - (\sum_{i=1}^{n} S_i)^2]\}^{1/2}}$$

Ratings for this statistic were suggested by Sarma and are given in Table II-3.

3) The Special Correlation Coefficient (RS) as defined by Sarma (79). This coefficient is developed from the sum of the squared deviations of the simulated and observed values. It is defined as:

$$RS = \frac{2 \sum_{i=1}^{n} O_i S_i - \sum_{i=1}^{n} S_i^2}{\sum_{i=1}^{n} O_i^2}$$

Table II-3. Descriptive Ratings for the Correlation Coefficients RMOD and RS*

RATINGS FOR THE MODIFIED CORRELATION COEFFICIENT (RMOD):

$0.99 \leq \text{RMOD} < 1.00$	Excellent
$0.95 \leq \text{RMOD} < 0.99$	Very Good
$0.90 \leq \text{RMOD} < 0.95$	Good
$0.85 \leq \text{RMOD} < 0.90$	Fair
$\text{RMOD} < 0.85$	Poor

RATINGS FOR THE SPECIAL CORRELATION COEFFICIENT (RS):

$0.99 \leq \text{RS} < 1.00$	Excellent
$0.95 \leq \text{RS} < 0.99$	Very Good
$0.90 \leq \text{RS} < 0.95$	Good
$0.85 \leq \text{RS} < 0.90$	Fair
$\text{RS} < 0.85$	Poor

*Taken from Reference (79).

This coefficient is always less than or equal to one and equals unity when the simulated hydrograph perfectly corresponds to the observed hydrograph. Sarma's ratings for this measure are given in Table II-3.

These three "goodness of fit" measures were computed for the simulated and observed storm events reported in the eight papers. A listing is presented in Appendix B. The tables in Appendix B are separated by model category. Table B-1 consists of the "goodness of fit" measures for physically-based models and Table B-2 consists of the measures for the conceptual models. These "goodness of fit" measures provide useful comparative information. They illustrate precisely how well each model predicts all aspects of the observed runoff response -- the peak discharge and the time distribution of storm water runoff.

Comparison tests and results - It is difficult to directly compare the tabulated "goodness of fit" measures; there are just too many. For this reason, composite measures -- the mean and standard deviations -- were computed for various groupings of the data as described below. These composite "goodness of fit" measures were then used to compare the predictive capability of the two model categories. The statistical validity of using these composite measures rests upon the assumption that the data in each grouping is a representative sample of the total population of "goodness of fit" measures. While this may not be entirely true for all the tests described below, the composite measures allow a precise comparison of an otherwise unwieldy amount of data.

The predictive capability of the two model categories was compared in three tests -- the one basin test, the overall test, and the consistency test.

1) <u>One basin test</u> - This test compares the predictive capabilities of the two model categories in a particular basin. The writers use the published results of the authors who evaluated both a conceptual model and a physically-based model in the same basin. The results for the six subtests are listed in Table II-4. Examination of the table reveals the following about the subtests:

a) The physically-based models generally overestimate the peak runoff rate, while the conceptual models equally over- and under-estimate the peak runoff rate.

b) The physically-based models are slightly more accurate (the mean peak discharge ratio is closer to 1.00) than the conceptual models in most of the subtests.

c) The modified correlation coefficient (RMOD) for the physically-based models ranges from poor to fair for the subtests, and for the conceptual models it is poor for all subtests.

d) The special correlation coefficient (RS) for the physically-based models as well as the conceptual models ranges from poor to good for the subtests.

e) Neither category of models predicts the runoff hydrograph more accurately (RMOD, nor RS closer to 1.0) than the other.

f) The standard deviations of the peak discharge ratio, the modified correlation coefficient, and the special correlation coefficient for the two model categories are similar. That is, the variance about the mean values is similar for both physically-based and conceptual models.

Table II-4. Results of the One-Basin Test

Sub-Test	Basin (Investigator)	Model	Q_p Ratio		No. of peak discharge events	Hydrograph Measures				No. of storm hydrographs
						RMOD		RS		
			Mean	Std. Dev.		Mean	Std. Dev.	Mean	Std. Dev.	
A	Calvin Park (Watt)	SWMM	1.078	.159	10	.786	.248	.840	.227	3
		QUURM	1.103	.115	10	.843	.219	.885	.165	3
B	Oakdale (Marsalek)	SWMM	1.084	.204	17	-	-	.884	.094	12
		RRLM	.938	.209	17	-	-	.851	.086	10
C	Calvin Park (Marsalek)	SWMM	1.196	.240	13	-	-	.480	.402	10
		RRLM	1.306	.175	12	-	-	.643	.359	10
D	Gray Haven (Marsalek)	SWMM	1.084	.227	14	-	-	.915	.069	10
		RRLM	1.071	.225	14	-	-	.828	.139	10
E	Oakdale (Chow)	SWMM	.933	.112	3	.933	.023	.962	.030	3
		UCUR	1.135	.214	4	.803	.107	.911	.060	4
		UH	.960	.107	4	.875	.064	.941	.020	4
		RRLM	.920	.235	4	.798	.145	.932	.035	4
F	Oakdale (Brandstetter)	SWMM	.909	.161	8	.813	.098	.940	.018	4
		BNW	.893	.237	8	.802	.071	.922	.031	4

These findings indicate that in particular basins the physically-based models would, on the average, predict the runoff response more accurately than the conceptual models. The prediction of peak discharge would be higher than actual and the prediction of the hydrograph shape would range from poor to good.

2) <u>Overall test</u> - This test compares the overall predictive capability of the two model categories for all basins. The writers use all the published data listed in Appendix B. The results of this test are listed in Table II-5. Examination of the table reveals the following:

a) Both physically-based and conceptual models generally overestimate the actual peak runoff rate. The mean value of peak discharge ratios for the physically-based models is 1.10, and the mean value of the peak discharge ratios for the conceptual models is 1.04.

b) The standard deviations or variances from the peak discharge ratio mean are generally higher for physically-based models than for conceptual models. The average standard deviation of the physically-based models is 0.40, and the average standard deviation of the conceptual models is 0.30.

c) The modified correlation coefficient (RMOD) for both the physically-based and conceptual models are poor (see Figure II-3).

d) The special correlation coefficient (RS) for both of the physically-based models is poor. For the conceptual models, the coefficient ranges from poor to good (see Figure II-3).

Table II-5. Results of the Overall Test.

		1. Q_p Ratio Measure 2. RMOD Measure 3. RS Measure					
Model		Mean	Std. Dev.	Median	90% Confidence interval	No. of basins	No. of Storms
Physically-Based:							
SWMM	1.	1.109	.419	1.07	1.042- 1.177	8	106
	2.	.700	.291	.829	.577- .823	5	18
	3.	.776	.303	.912	.704- .848	6	50
UCUR	1.	1.188	.369	1.12	1.084- 1.292	5	36
	2.	.695	.179	.734	.603- .786	4	13
	3.	.541	.615	.748	.360- .722	4	33
Conceptual:							
RRLM	1.	1.063	.292	1.12	.993- 1.133	5	49
	2.	.675	.199	.702	.553- .796	4	10
	3.	.786	.228	.855	.727- .845	5	42
BNW	1.	.893	.237	.78	.722- 1.063	1	8
	2.	.802	.072	.831	.705- .899	1	4
	3.	.922	.031	.913	.880- .964	1	4
QUURM	1.	1.103	.115	1.07	1.033- 1.173	1	10
	2.	.843	.219	.962	.390- 1.0	1	3
	3.	.885	.165	.979	.543- 1.0	1	3
CUHP	1.	1.050	.475	.91	.792- 1.308	2	12
	2.	.607				1	1
	3.	.765				1	1
SCS	1.	1.062	.440	.94	.823- 1.300	2	12
	2.	.539				1	1
	3.	.599				1	1
UH	1.	.96	.107	.93	.815- 1.105	1	4
	2.	.875	.064	.853	.788- .961	1	4
	3.	.941	.020	.939	.915- .968	1	4

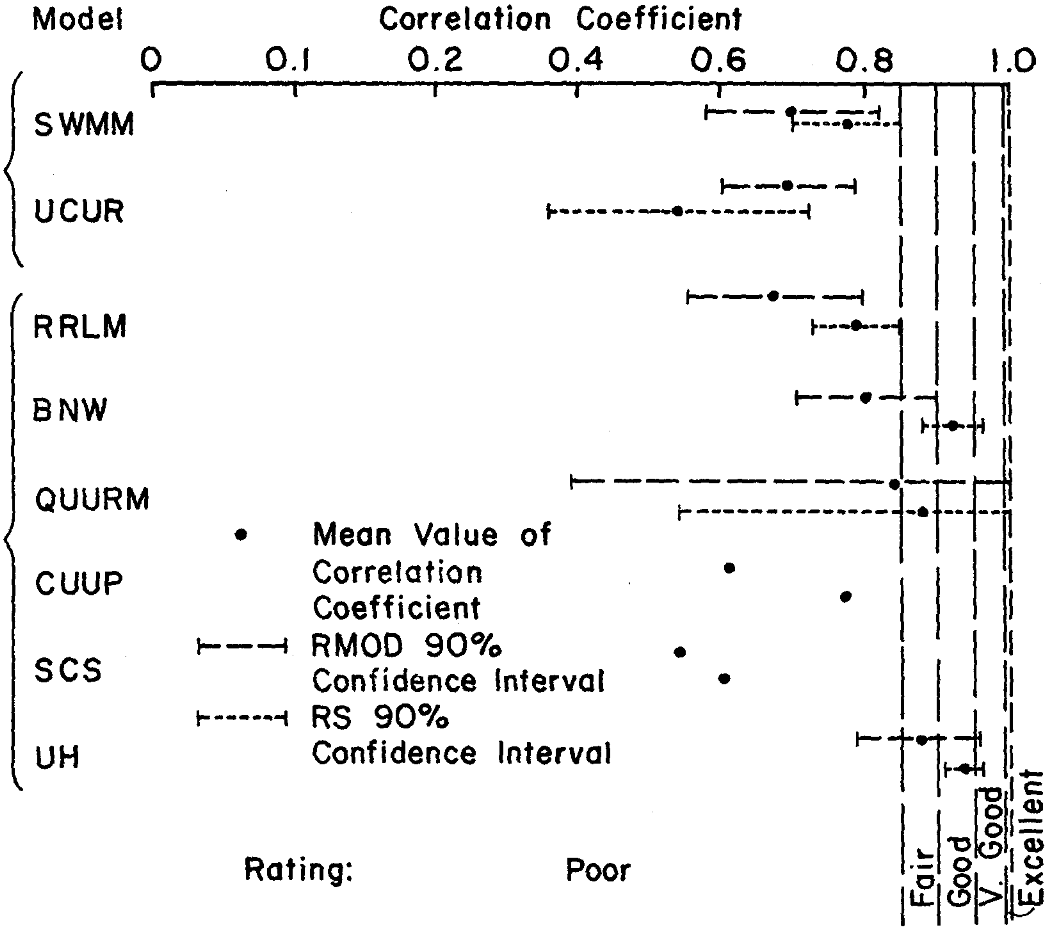


Figure II-3. 90 Percent Confidence Intervals for the Correlation Coefficients of the Overall Test.

These findings indicate that, on the average, the conceptual models will better predict the actual runoff response. The conceptual models' mean overprediction of the actual peak discharge is 4% with 90% of the prediction being within ±30% of this value. The physically-based models' mean overprediction of actual peak discharge is 10% with 90% of the predictions being within 35% of this value.

3) Consistency test - This test evaluated the ability of different modelers to get similar predictions with the same rainfall-runoff model. The writers use the published results of several modelers who were using the same rainfall-runoff model to predict the runoff response of the same storm event in the same basin. Table II-6 lists the results.

Any conclusions drawn from this test are questionable due to the relatively few published results available for the test. Notwithstanding these limitations, Table II-6 indicates an understandable trend. The results from the conceptual models are more consistent (have a smaller spread) than the results from the physically-based models. This trend is not surprising when one considers the calibration process. During calibration of a model, various calibration parameters are adjusted to shift the model-generated runoff response into closer agreement with the actual runoff response. Thus, prediction of future runoff responses with this "calibrated" model becomes a function of the parameter adjustments. If the runoff response is very sensitive to a certain calibration parameter, a slight difference in calibration will result in a significant change in predicted runoff response. With this in mind, the consistency trend found in Table II-6 is expected. It is more likely that several modelers will assign a similar value to the few

Table II-6. Results of the Consistency Test.

Model		Storm event	Q_p Ratio				Event Spread	Model Spread	
			Papadakis	Marsalek	Chow	Brandstetter		Mean	Std. Dev.
Physically-Based:									
SWMM	1.	5/19/59		1.26	1.06	1.07	.20		
	2.	7/2/60-1		1.02		.85	.17		
	3.	7/26/60-1		1.27		.80	.47		
	4.	7/26/60-2		.73		.70	.03	.174	.153
	5.	4/29/63-1		1.03	.85		.18		
	6.	8/2/63-1		1.19		.91	.28		
	7.	8/2/63-2		1.27		1.21	.06		
	8.	7/2/60-2	.89		.89	.89	0		
UCUR	1.	5/19/59		1.12	1.42		.30		
	2.	7/2/60-2	1.04		1.04		0	.09	.141
	3.	4/29/63-1		1.12	1.16		.04		
	4.	7/7/64	.94		.92		.02		
Conceptual:									
RRLM	1.	5/19/59		1.10	1.01		.09		
	2.	7/2/60-2	.82		.81		.01	.058	.050
	3.	4/29/63-1		.77	.66		.11		
	4.	7/7/64	1.18		1.20		.02		

calibration parameters of the conceptual models, than to the many calibration parameters of the physically-based models.

In addition to these three predictive capability tests, the published results were subjected to a correlation test. The writers postulated that the predictive capability of a particular model might be some function of certain basin or event characteristics. For example, the storm water management model (SWMM) might predict the 5 year event in a 1 square mile basin that is 40% developed perfectly; but its predictive ability might decrease for other events, other basin sizes, or different percentages of development.

In the correlation test, the writers evaluate the correlation of the peak discharge ratio (Q_pRATIO) to the basin area, the percent imperviousness, and the recurrence interval of the storm event. The highest correlation coefficient is less than 0.5 as shown in Table II-7. This low correlation indicates that either the limited amounts of data preclude a strong showing of correlation, or no significant correlation exists between the prediction measure and the three independent variables chosen.

<u>Summary of test results</u> - The results of these comparison tests produce two significant findings: first, the physically-based models (as a group) do not provide significantly better runoff response predictions; and second, the predictive capability of conceptual models is less sensitive to the model user than is the predictive capability of the physically-based models. These findings suggest that, at the present time, the cost effective rainfall-runoff models for local governments are the conceptual models. Their predictive ability is as good as the physically-based models, yet they are generally less

Table II-7. Results of the Correlation Test

Model	Linear Correlation Coefficient Between Q_p Ratio and:			No. of basins	No. of storms
	Basin Area	Return Interval	% Impervious		
Physically-Based:					
SWMM	-.040	-.109	-.142	8	106
UCUR	-.214	.083	-.215	5	36
Conceptual:					
RRLM	-.383	-.484	-.173	5	49
CUUP	.167	.102	.167	2	12
SCS	.180	.094	.180	2	12

expensive to initiate. Just as important, the conceptual models are more likely to yield consistent runoff response predictions regardless of the model user. This consistency is extremely important when the chosen model will be accessed by the various model users in the community such as municipal staff personnel and engineering consultants.

These findings must, of course, be tempered with the limitations of this analysis. One must remember the following:

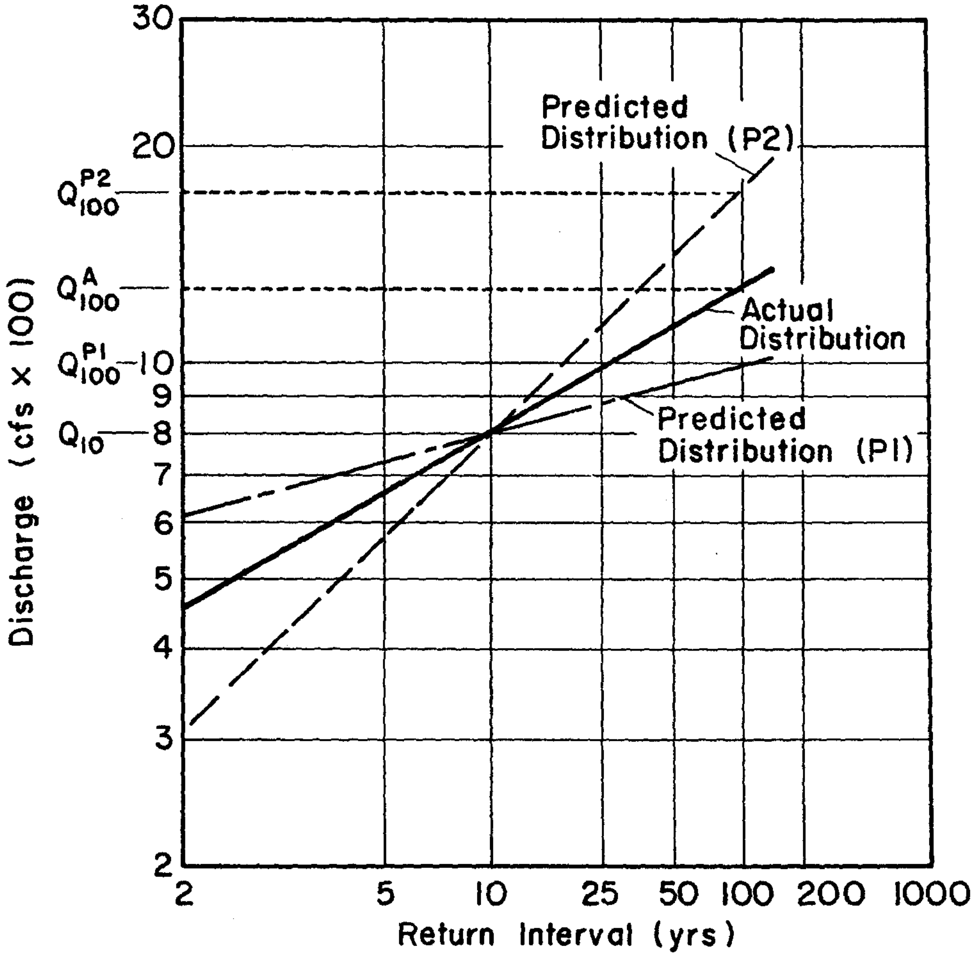
1) The statistical inferences are based on the assumption that the predictive information used is representative of the entire "population" of such information.

2) The storm events used were generally the more frequent events; consequently, the mean values of the "goodness of fit" measures represent the mean values for frequent storms and not the whole range of storm events. Thus, models with perfect prediction for the 10-year storm event may predict any one of the runoff distributions shown in Figure II-4. The consequences of this distribution variability are significant when calculating damage-frequency curves.

3) The published prediction results are from basins with adequate verification and calibration data. Such data generally does not exist in urbanizing basins.

Economic Sensitivity of Errors in Predicting Runoff Responses

One of the findings reported in the previous section states that the predictive ability of physically-based rainfall-runoff models is not significantly better than the predictive ability of conceptual models. This condition may change with the availability of better data and improved simulation algorithms. The writers note that the high cost of collecting proper model data for every urbanizing basin



Legend:

Q_{10} = 10 Year Storm Discharge (Actual and Predicted)

Q_{100}^{A} = Actual 100 Year Storm Discharge

Q_{100}^{P1} = Predicted (P1) 100 Year Storm Discharge

Q_{100}^{P2} = Predicted (P2) 100 Year Storm Discharge

Figure II-4. Runoff Distributions With Identical 10-Year Storm Events.

may preclude it from ever being available. However, with adequate verification and calibration data, the detailed physically-based models should, intuitively, be able to better simulate the runoff response.

The advantage of this better prediction has been taken for granted. People believe that drainage facility analysis will improve as the accuracy of the response prediction increases. Just how important is the prediction accuracy? It would be embarrassing if hydrologists were struggling to get perfect prediction of runoff response when an accuracy of ±25% is sufficient. "Sufficient" here means that the cost of the project, the calculated benefits of the project, and the economic analysis of the project change very little within that accuracy range.

The writers tested the sensitivity of predicted peak discharge to costs, benefits, benefit cost ratio, and optimal design. These four characteristics were chosen because they are the prevalent criteria for evaluating proposed urban drainage and flood control facilities. The sensitivity was related to predicted peak discharge because of analysis convenience and because peak discharge is still a major design characteristic of flood control facilities.

Costs - The cost of typical urban drainage and flood control facilities such as pipes and open channels is a function of the peak discharge rate (Q). However, a large portion of the construction cost consists of "move-on" or "job-location" costs, overhead, and project work needed regardless of design discharge. If the design discharge value is changed slightly, the total project cost remains relatively constant. This relative insensitivity can be illustrated for installed storm drain pipe.

Grigg (41) suggested the following relationship for the cost of installed pipe (plus manholes and laterals) as a function of pipe diameter:

$$C_p = \alpha D^x \tag{1}$$

where

C_p = installed pipe cost per foot of pipe,
D = diameter of pipe, in feet, and
α, x= regression parameters.

Using a basin in the Denver, Colorado area and 1975 prices, he found the regression power parameter (x) to be 1.663.

If we assume full pipe flow (not under pressure) we can use Mannings' equation to rewrite equation 1 in terms of the discharge (Q). That is:

$$Q = \frac{1.49}{n} AR^{2/3}S^{1/2} \tag{2}$$

where

Q = peak discharge (cfs),
n = Manning's friction factor,
A = cross-sectional area of flow (ft^2),
R = hydraulic radius (ft),
S = friction slope (ft/ft),
= pipe invert slope at full pipe flow but not pressure flow.

For full circular pipe flow (not under pressure):

$$A = \pi D^2/4 \quad , \quad R = D/4 \quad , \quad n,S = \text{constants}.$$

So, equation 2 becomes:

$$Q = \alpha_1 D^{8/3}$$

or

$$D = \alpha_2 Q^{3/8} \tag{3}$$

Substituting equation 3 into equation 1 yields:

$$C_p = \alpha(\alpha_2 Q^{3/8})^{1.663}$$

or

$$C_p = \alpha_3 Q^{0.624} \tag{4}$$

We can examine the effect of poor discharge prediction on pipe cost (C_p) by differentiating equation 4 with respect to discharge (Q).

$$\frac{dC_p}{dQ} = \alpha_3 \frac{d}{dQ} Q^{0.624} = \frac{0.624\ \alpha_3}{Q^{0.376}} \tag{5}$$

Dividing equation 5 by C_p and separating variables yields:

$$\frac{dC_p}{C_p} = \frac{0.624\ \alpha_3\ dQ}{C_p\ Q^{0.376}} \tag{6}$$

Substituting equation 4 for C_p on the right side yields:

$$\frac{dC_p}{C_p} = 0.624 \frac{dQ}{Q} \tag{7}$$

Equation 7 states that the installed pipe cost will change by about 60% of the change in discharge. That is, if the design discharge is over or under-estimated by 20%, the installed pipe cost will be over or under-estimated by approximately 12% (60% times 20%).

Although installed pipe cost is a reasonable indicator of total project cost, it may not adequately represent the sensitivity of total project cost to changes in discharge values. The writers address this uncertainty by evaluating two "project cost" expressions developed by Rawls (76). In 1972, Rawls collected drainage cost data from across the nation. He related total project costs (C_T) to cost determinant variables easily available to designers and planners. The variables were: recurrence interval (F), average ground slope (S_G), runoff coefficient (R), number of manholes and inlets (I), smallest pipe size (D_B), largest pipe size (D_E), total capacity (Q), total length of lines (L_T), total drainage area (A_T), and total developed area (A_D). He developed linear and non-linear relations from data supplied by 41 agencies.

The linear model is:

$$C_T = -104{,}766.0 + 428.6\ F - 6893.3\ S_G + 56.6\ R + 1355.0\ I + 1801.7\ D_B + 18.9\ L_T + 60.2\ A_T + 137.4\ A_D + 991.2\ D_E + 41.6\ Q. \qquad (8)$$

The only variables in equation 8 that will be affected by a change in discharge are the largest pipe size (D_E) and the total capacity (Q). Therefore, equation 8 can be rewritten as:

$$C_T = K_1 + 991.2\ D_E + 41.6\ Q \qquad (9)$$

Using Manning's equation, this can be rewritten in terms of Q only.

$$C_T = K_1 + 991.2\ (\alpha_2 Q^{3/8}) + 41.6\ Q \qquad (10)$$

where

$$\alpha_2 = \frac{1.49}{n} S^{1/2} \frac{\pi}{4^{5/3}}$$

$$\simeq 31\ S^{1/2}, \qquad \text{when } n = 0.015.$$

Equation 10 indicates that the sensitivity of project cost (C_T) to changes in discharge (Q) depends on other project characteristics (K_1). If K_1 is very large compared to the last two terms of equation 10 a change in Q will cause a relatively minor change in C_T. Alternatively, the project cost will be most sensitive to changes in discharge (Q) when K_1 is small. Therefore, to estimate the largest impact of discharge changes on cost changes, a hypothetical basin with a relatively small K_1 value is needed.

The writers selected variable values for such a basin from Rawls' data. The variables chosen are:

$F = 5$ years

$I = 10$ manholes

$A_T = 250$ acres

$S_G = 2$ ft per 100 ft

$D_B = 18$ inches

$A_D = 50$ acres

$R = 0.5$

$L_T = 2000$ ft

$Q = 400$ cfs.

To evaluate the magnitude of impact, equation 10 is differentiated with respect to Q to yield:

$$\frac{dC_T}{dQ} = \frac{3/8 \ 991.2 \ \alpha_2}{Q^{5/8}} + 41.6 \ . \tag{11}$$

Manipulating the equation in a fashion similar to the manipulations of equation 5 yields:

$$\frac{dC_T}{C_T} = \left[\frac{3/8 \quad 991.2 \ \alpha_2 \ Q^{3/8} + 41.6Q}{K_1 + 991.2 \ \alpha_2 \ Q^{3/8} + 41.6Q}\right] \frac{dQ}{Q} \ , \tag{12}$$

and substituting the variable values for the hypothetical basin listed above yields:

$$\frac{dC_T}{C_T} = 0.68 \ \frac{dQ}{Q} \ . \tag{13}$$

That is, the total project cost as estimated by Rawls' linear model will change by about 70% of the change in discharge.

Rawls' non-linear model is:

$$C_T = 58{,}273.0 + 8.73(F^{0.04} S_G^{\ -0.89} R^{0.64} D_B^{\ 0.23} A_D^{\ 0.71} Q^{0.73}) \tag{14}$$

This equation can be rewritten as:

$$C_T = 58{,}273.0 + K_2 Q^{0.73} \tag{15}$$

Again, the sensitivity of project cost (C_T) to changes in discharge (Q) depends on the other project characteristics (K_2). In this case, a hypothetical basin with a relatively large K_2 value is needed to estimate the largest impact of discharge changes on cost changes. The variable values selected for this basin are:

$F = 50$ years $S_G = 0.2$ ft per 100 ft $R = 0.75$

$D_B = 18$ inches $A_D = 250$ acres $Q = 500$

The magnitude of the impact is evaluated as before to yield:

$$\frac{dC_T}{C_T} = 0.62 \frac{dQ}{Q} \quad . \tag{16}$$

That is, the total project cost as estimated by Rawls' non-linear model will change by about 60% of the change in discharge.

The results of these three cost function analyses are quite consistent. The expected change in project cost is about 60-70% of the change in discharge. That is, if a rainfall-runoff model over-predicts the design discharge by 20% the project cost would only be 13% (65% of 70%) higher than it should be. This 60-70 percent factor can also be interpreted as the "economy of scale" factor in the following drainage facility cost equation:

$$C_T = \alpha_4(Q)^\beta \tag{17}$$

where C_T = total project costs

α_4 = coefficient

Q = peak discharge or facility capacity

β = economy of scale factor

Other investigators (78) have found similar values for β in developing cost relationships as a function of capacity. Equation (17) is commonly referred to as the "two thirds power rule" when β is in this range of .6 to .7.

Benefits - Benefits from major urban drainage and flood control projects are measured as the reduction in average annual flood water damages. This reduction in damages is based on two damage-frequency curves as illustrated in Figure II-5. The lower "improvement" curve is drawn through the damage-frequency plotting points calculated for the basin with the proposed project (lined channels, pipes, etc.). The upper "no improvement" curve is based on the plotting points calculated without the proposed project. The plotting points for each are located by routing a particular frequency flood through the basin (with or without the project) and estimating the flood damage for that frequency. The area between these two curves is the estimate of the average annual reduction in flood damages, or benefit, attributable to the proposed project (see reference 40 for further details).

Assume that the two curves in Figure II-5 represent the "actual" real world damage-frequency curves. If the predicted discharge frequency distribution were different from the actual distribution, the predicted damage-frequency curves would not coincide with those shown in the figure. The predicted damage-frequency curves would be shifted as shown in Figure II-6 to one side or the other depending on whether the predicted discharges were greater or less than the actual discharges. The effect of this shift on the calculated benefits -- the area between the two curves -- is not immediately obvious. To assess the impact of poor discharge prediction, the writers arbitrarily assumed an "actual" discharge frequency distribution and from this computed "actual" benefits. They then compared these "actual" benefits to predicted benefits which were computed from shifted discharge frequency distributions.

The actual and predicted discharges were defined by the following log-Pearson type III frequency distribution:

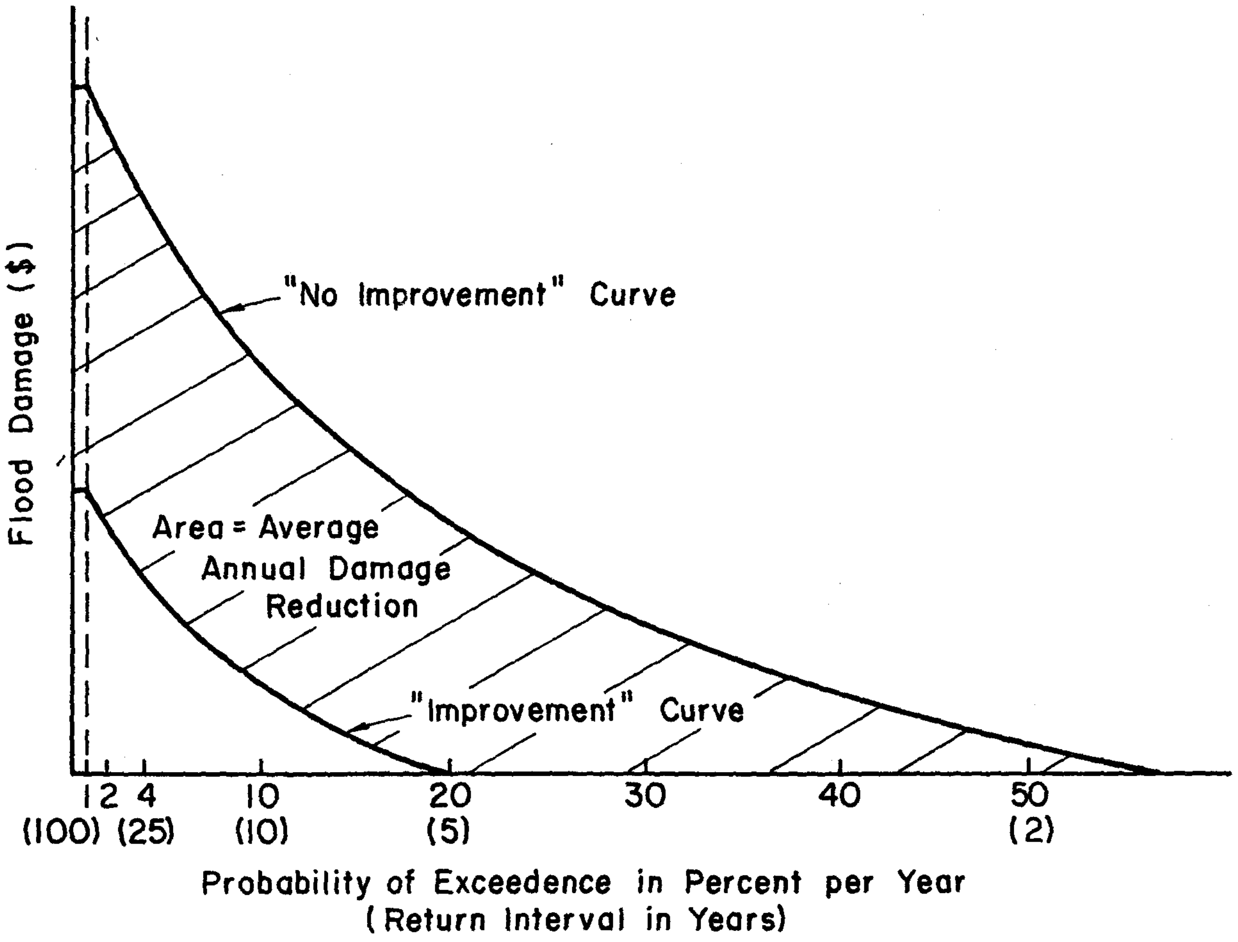


Figure II-5. Sample Damage-Frequency Curves for Actual Runoff Distributions.

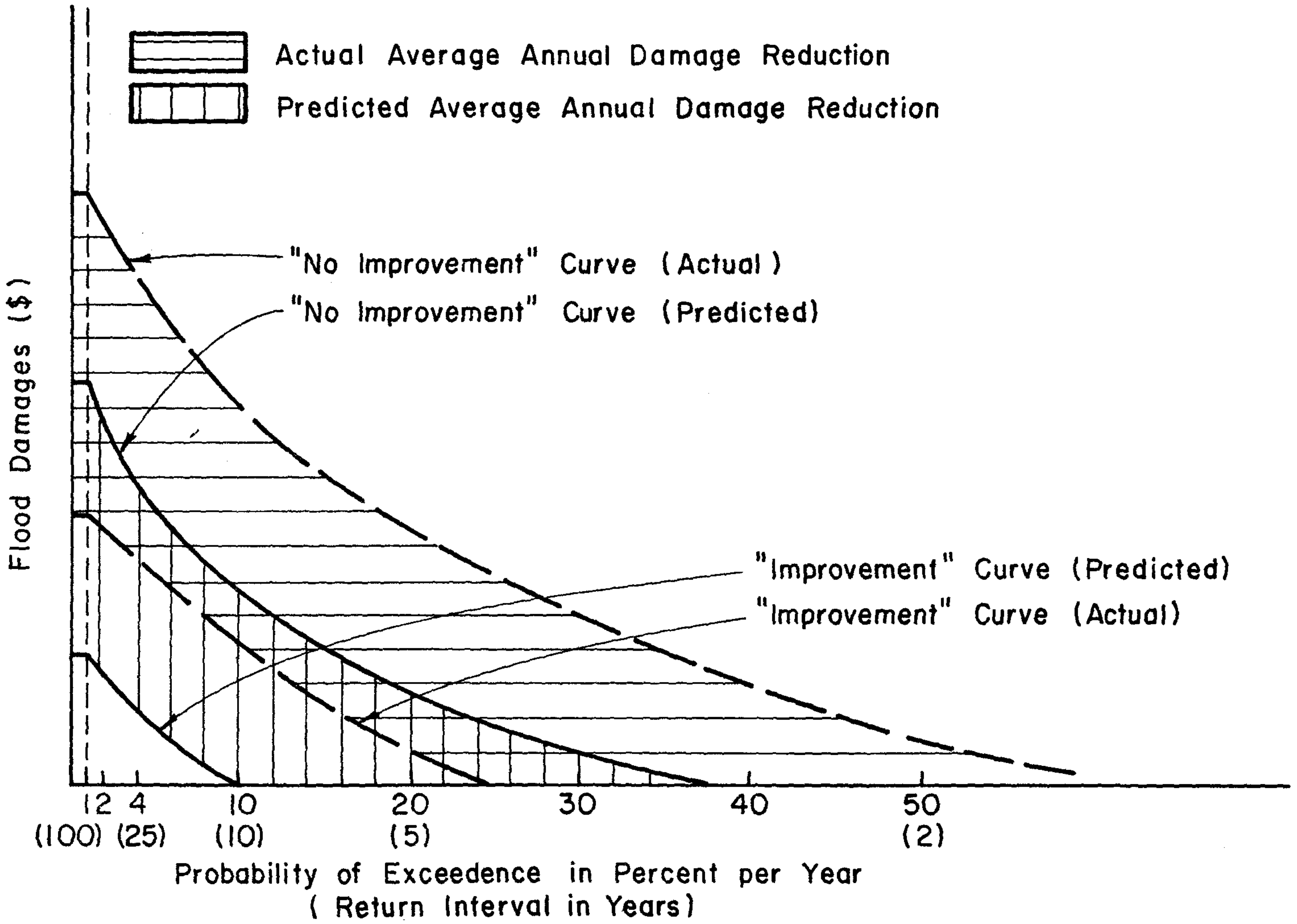


Figure II-6. Sample Damage-Frequency Curves for Actual and Predicted Runoff Distributions.

$$\log Q_{TR} = \overline{\log Q} + K_{TR}(S_{\log Q}) \qquad (18)$$

where

$\log Q_{TR}$ = log value of the discharge with recurrence interval TR,

$\overline{\log Q}$ = mean of the log values of the discharge data (note: the anti-log of $\overline{\log Q}$ is the 2-year event for zero skewness),

$S_{\log Q}$ = standard deviation of the log values of the discharge data (note: $S_{\log Q}$ is the slope of the frequency distribution plotted on log-probability paper),

K_{TR} = skew curve factor for the discharge with recurrence interval TR.

Typical urban basin values of the independent variables of equation (18) were selected for the "actual" distribution. Various "predicted" frequency distributions were then developed within a ±40% corridor about the actual distribution. These "predicted" distributions are illustrated in Figures II-7a through d.

The damage-frequency plotting points are computed from an expression developed by James (49) relating urban flood damage to flood water depth and inundated area. His empirical expression is:

$$C_D = \alpha_5 \, h \, \overline{A} \qquad (19)$$

where

C_D = flood damage cost for a particular flood event (\$),

h = average flood depth over inundated area (ft),

$\overline{A}$ = flooded area (acres) ,

α_5 = 2640 (from the data he analyzed).

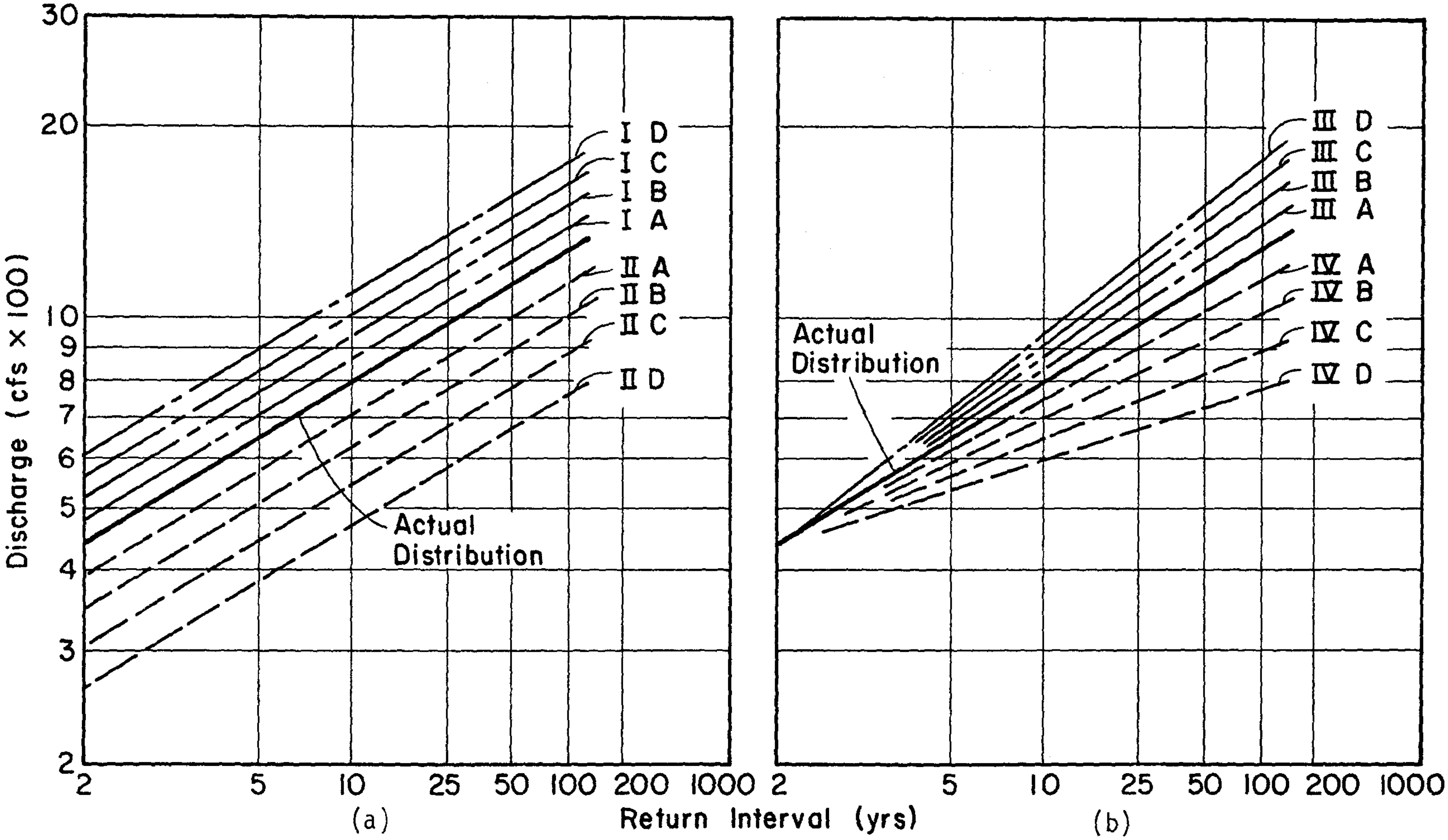


Figure II-7. Test log-Pearson Type III Runoff Distributions.

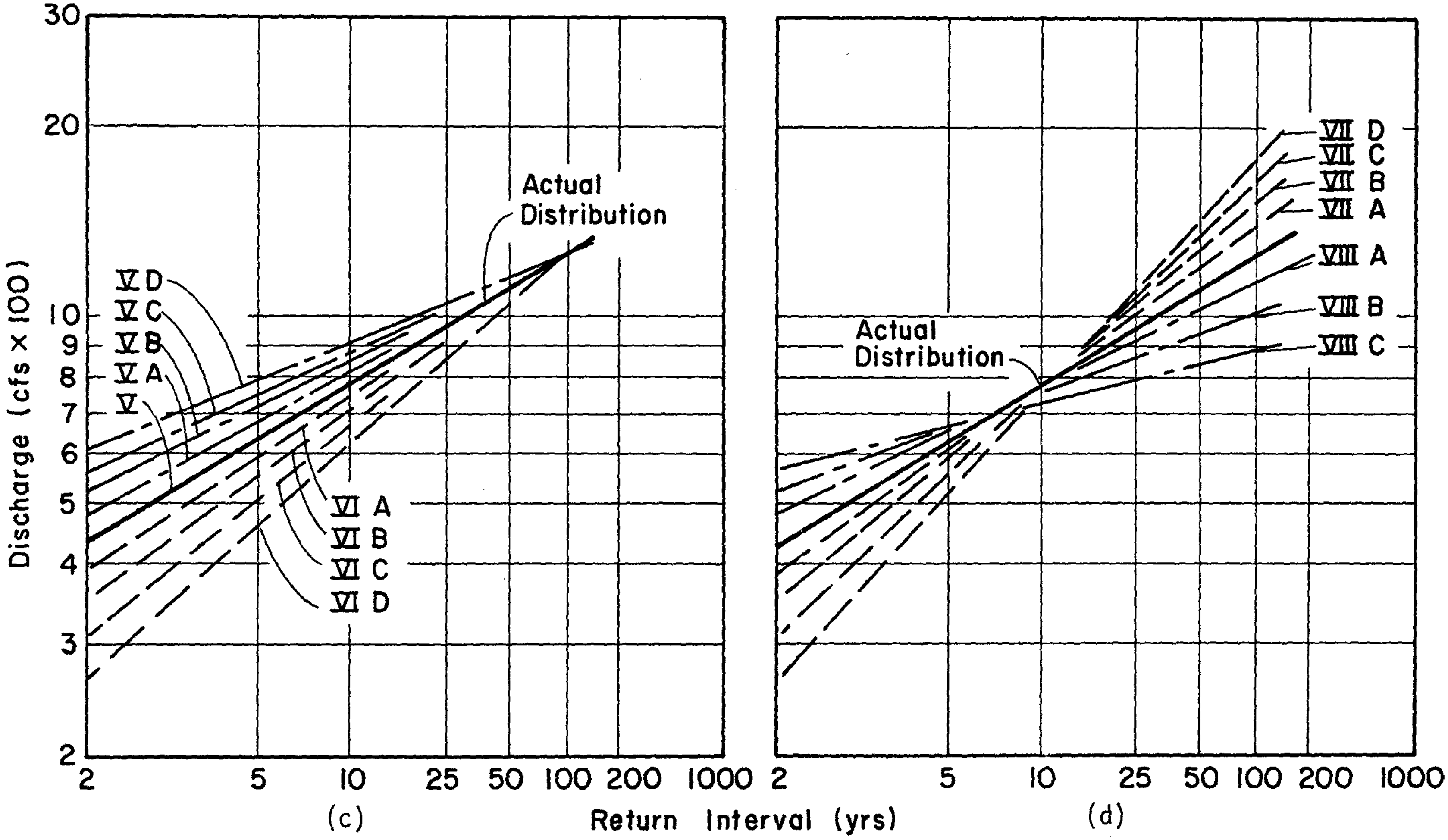


Figure II-7. (Continued).

This relationship ignores the damages that might occur as a result of increases in the velocity or duration of stormwater flow at a specific flood depth. This situation was suggested in Figure II-2 where the peak discharge rate -- and therefore the flood depth -- did not change with urbanization. However, the volume of stormwater runoff did increase which, in turn, increased the duration of stormwater runoff. This increase in flow duration could incur damages such as erosion damages or increased clean-up costs. The relationship between flood damage cost and flow velocity and duration can be significant and should be included when constructing actual damage-frequency curves. However, equation (18) is sufficient for our purposes of examining the sensitivity of benefit calculation to errors in discharge prediction.

In order to express equation (19) as a function of discharge (Q), the writers assumed a triangular channel geometry with side slopes of Z:1 (see Figure II-8). The average flood depth (h) then becomes

$$h = \frac{h_m}{2} \qquad (20)$$

where h_m = maximum flood depth in the channel and the flooded area ($\bar{A}$) becomes:

$$\bar{A} = \frac{2h_m ZL}{43560} \qquad (21)$$

where L = length of channel in feet.

Substituting equations (20) and (21) into equation (19) yields:

$$C_D = 2640\ (h_m/2)\ \frac{2h_m ZL}{43560}$$

$$C_D = (0.06ZL)h_m^2 \qquad (22)$$

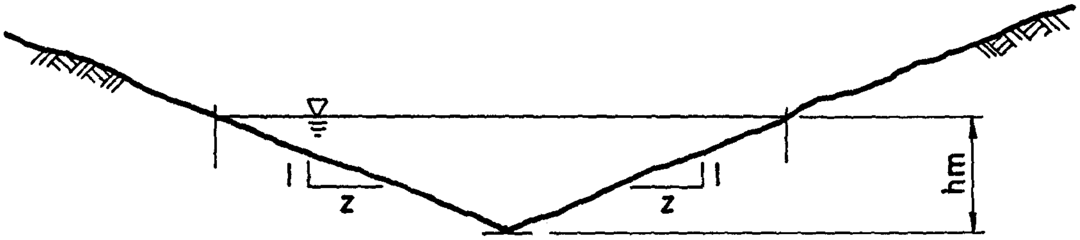


Figure II-8. Typical Urban Drainage Channel Geometry.

Equation (22) implies that damages are incurred for every flood water depth greater than 0 (see Figure II-9). This is rarely the case. Flood damages usually begin to occur after the water level reaches some threshold level. To account for this threshold, equation (22) is modified as follows:

$$C_D = (0.06ZL)(h_m - h_o)^2 \tag{23}$$

where h_o = threshold depth = depth above which damage occurs.

The cross-sectional area of flow (A), and the hydraulic radius (R) of the triangular channel shown in Figure II-8 are:

$$A = Zh_m^2 \tag{24}$$

$$R = \frac{h_m}{2} \quad \text{for relatively large Z.} \tag{25}$$

Substituting equations (24) and (25) into Manning's equation yields:

$$Q = \frac{1.49}{n} S^{1/2}(Zh_m^2)(h_m/2)^{2/3} \tag{26}$$

which simplifies to:

$$Q = \frac{1.49\ S^{1/2}Z}{n\ 2^{2/3}}\ h_m^{8/3} \tag{27}$$

Solving equation (27) for h_m yields:

$$h_m = [\frac{n\ 2^{2/3}}{1.49\ S^{1/2}Z}]^{3/8} Q^{3/8} \tag{28}$$

Similarly:

$$h_o = [\frac{n\ 2^{2/3}}{1.49\ S^{1/2}Z}]^{3/8} Q_o^{3/8} \tag{29}$$

where Q_o = discharge when the water depth equals h_o.

Substituting equations (28) and (29) into equation (23) creates a functional relationship between flood damage and discharge. That is:

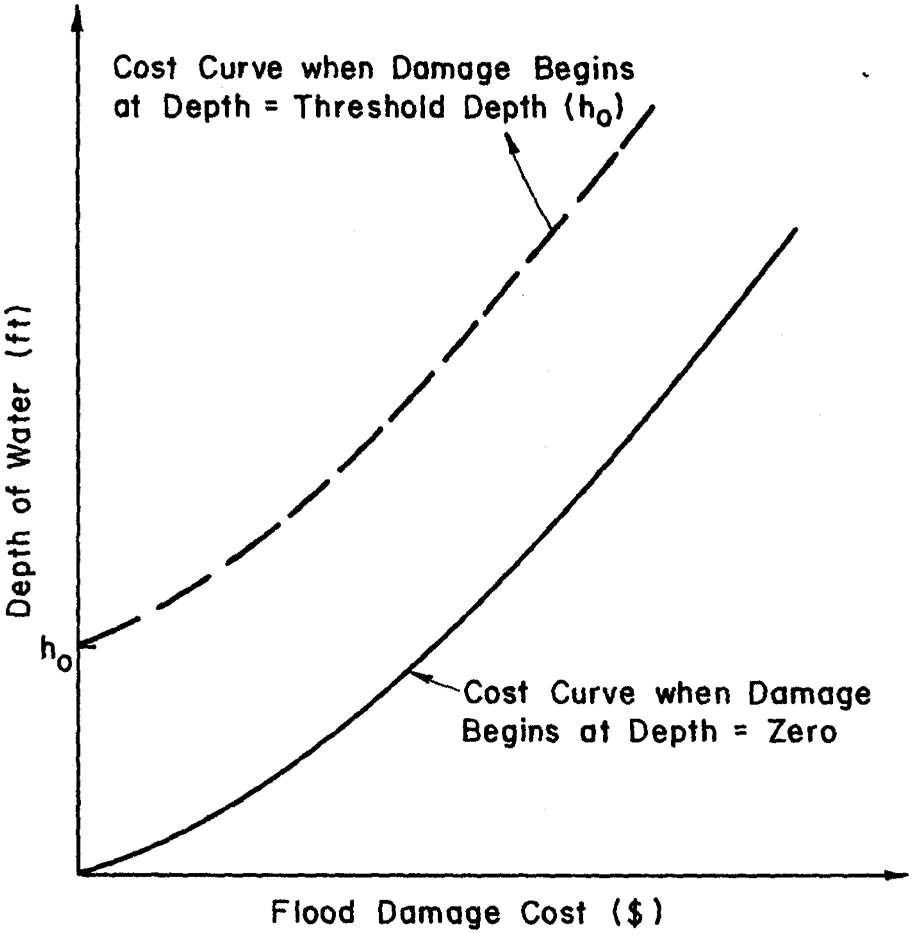


Figure II-9. Typical Urban Depth Damage Curve.

$$C_D = \alpha_6(Q^{3/8}-Q_o{}^{3/8})^2 \tag{30}$$

where

$$\alpha_6 = 0.0636 \frac{Z^{1/4}Ln^{3/4}}{S^{3/8}} \quad .$$

The independent variables of α_6 for an urbanizing subbasin might be:[2]

$L = 5$ mi $= 26{,}400$ ft,

$n = 0.05$,

$S = 0.025$ ft/ft,

$Z = 20$.

All of these variables are independent of discharge except the side slope (Z) of the flood plain. As the discharge changes, the mean side slope value may change as illustrated in Figure II-10. However, the "fringe" area of the flood plain, where most flood damages occur, has a relatively uniform slope. Thus, the use of a constant Z value in this analysis is justified.

Substitution of these variable values into equation (30) yields:

$$C_D \simeq 1{,}500\ (Q^{3/8}-Q_o{}^{3/8})^2 \ . \tag{31}$$

With equation (31) and the various discharge distributions, the writers were able to assess the impact of poor discharge prediction on benefit calculations. The analysis is based on a fixed effectiveness criterion (40) or a design storm approach and proceeds as follows (refer to Figure II-11).

1) The "no improvement" damage frequency curve is computed for the predicted discharge distribution with the use of equation (31). The predicted 2-year storm is arbitrarily selected as the "no improvement" threshold discharge (Q_o).

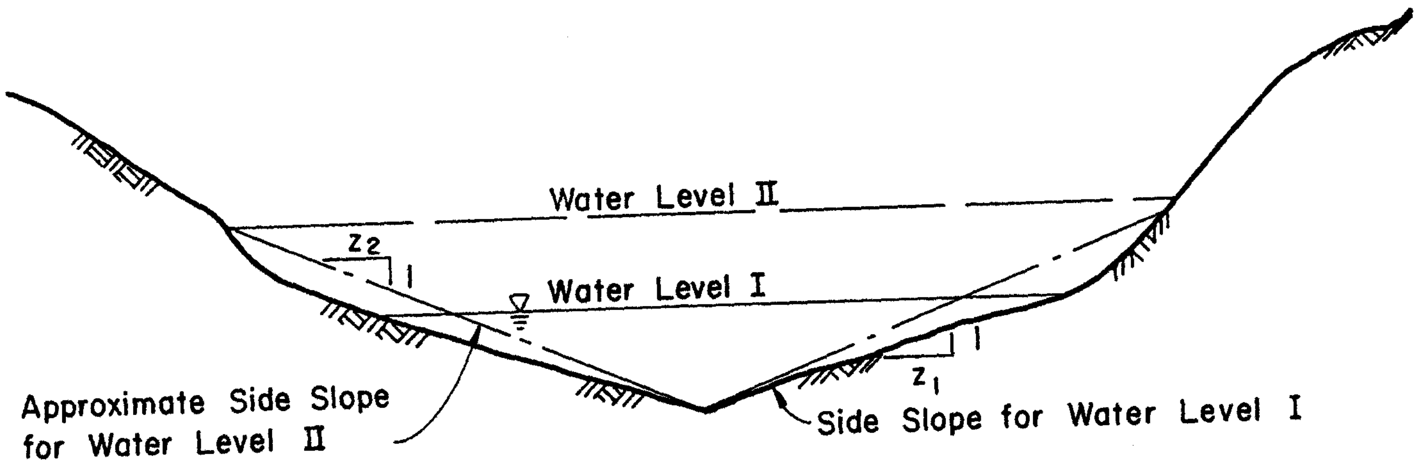


Figure II-10. Changes in Channel Side Slope Due to Depth Changes.

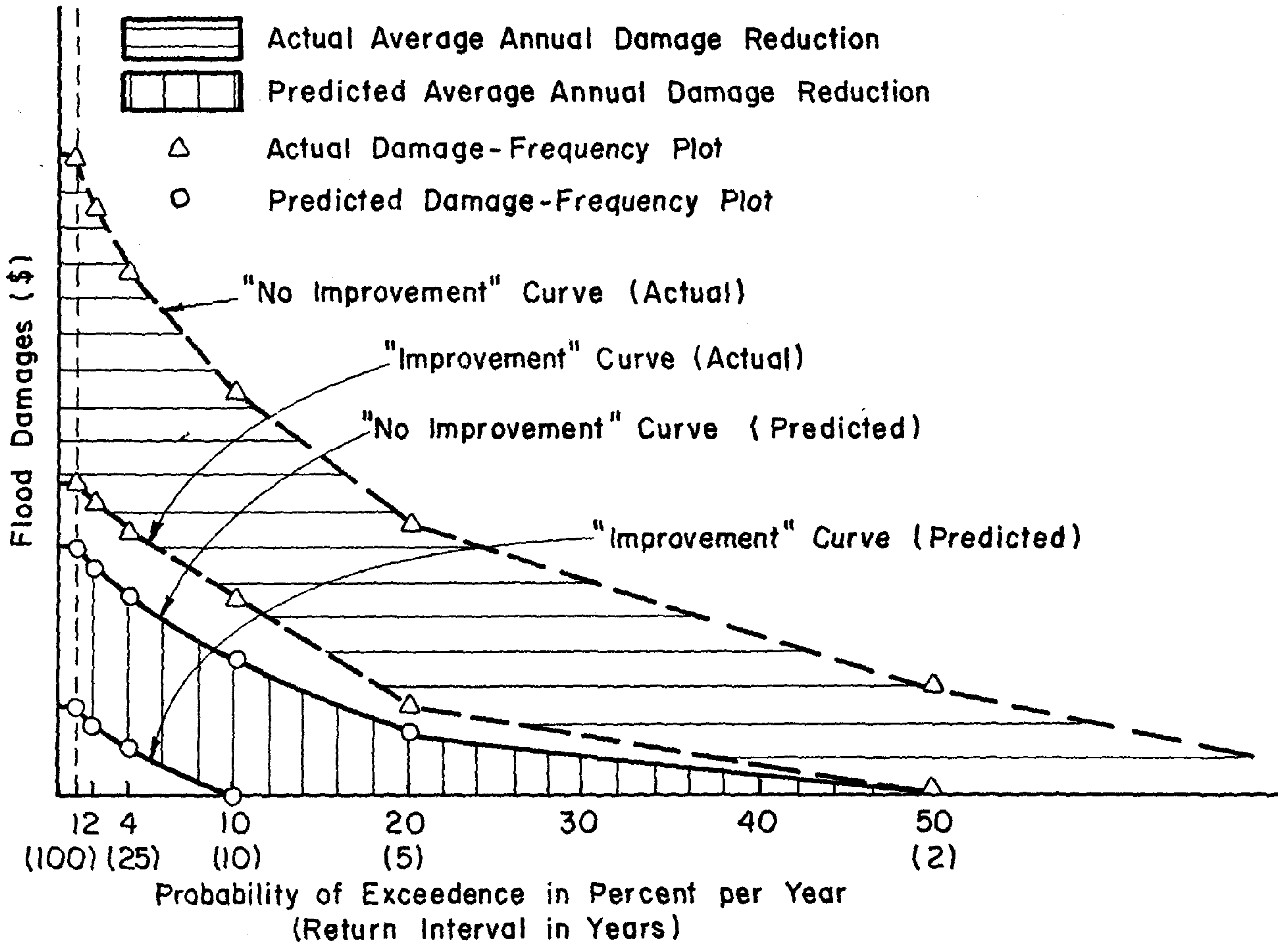


Figure II-11. Construction of Damage-Frequency Curves and Computation of Reduced Average Annual Damages for Actual and Predicted Runoff Distributions.

2) A design storm (Q_D) is selected as the "improvement" threshold discharge. This ranged from the predicted 5-year to the predicted 50-year storm. The "improvement" damage frequency curve is then computed for the predicted discharge distribution.

3) The predicted benefit -- the area between these two curves -- is computed using the rectangular rule of integration (56).

4) The "no improvement" and "improvement" damage-frequency curves are computed for the actual discharge distribution using the same threshold values of discharge (Q_0 and Q_D) as in steps 1 and 2 above.

5) The actual benefit -- the area between these two actual damage-frequency curves -- is computed using the rectangular rule of integration.

6) The predicted benefits are compared to the actual benefits by simple division. All of the predicted discharge frequency distributions were analyzed. The results are listed in Table II-8 and plotted in Figure II-12 and II-13. The slopes of the curves in Figure II-13 represent the sensitivity of the calculated benefits to errors in discharge prediction. To illustrate, let us write the equation for the slope of any of the curves at some particular point. The equation is:

$$M = \frac{d(B_p/B_A)}{d(Q_p/Q_A)} \tag{32}$$

where M = slope

B_p = predicted benefits

B_A = actual benefits

Q_p = predicted discharge

Q_A = actual discharge

Table II-8

Sensitivity of Reduced Average Annual Damages to Errors in the Predicted Runoff Distribution

(a) For 5-Year Design Storm

PREDICTED DISTRIBUTION		DESIGN STORM DISCHARGE RATIO	PREDICTED AADR	ACTUAL AADR	PRED/ACT AADR RATIO	SENSITIVITY (M)
I	A	1.10	2488.	1813.	1.37	3.72
I	B	1.20	2656.	1390.	1.91	4.55
I	C	1.30	2820.	1044.	2.70	5.67
I	D	1.40	2982.	787.	3.79	6.98
II	A	.90	2141.	2943.	.73	2.73
II	B	.80	1960.	3749.	.52	2.39
II	C	.70	1773.	4778.	.37	2.10
II	D	.60	1579.	5973.	.26	1.84
III	A	1.04	2802.	2416.	1.16	4.54
III	B	1.07	3295.	2500.	1.32	4.66
III	C	1.10	3792.	2570.	1.48	4.77
III	D	1.13	4291.	2630.	1.63	4.88
IV	A	.96	1843.	2189.	.84	4.23
IV	B	.92	1387.	2017.	.69	4.03
IV	C	.88	958.	1787.	.54	3.83
IV	D	.83	571.	1477.	.39	3.63
V	A	1.06	2025.	1729.	1.17	2.73
V	B	1.12	1761.	1266.	1.39	3.17
V	C	1.18	1524.	911.	1.67	3.69
V	D	1.24	1309.	650.	2.01	4.23
VI	A	.93	2639.	3113.	.85	2.34
VI	B	.87	2997.	4228.	.71	2.19
VI	C	.80	3393.	5729.	.59	2.00
VI	D	.72	3833.	7717.	.50	1.81
VII	A	.97	3146.	3247.	.97	.97
VII	B	.93	4053.	4546.	.89	1.48
VII	C	.88	5026.	6288.	.80	1.62
VII	D	.82	6056.	8573.	.71	1.59
VIII	A	1.02	10276.	9597.	1.07	3.09
VIII	B	1.04	10927.	9633.	1.13	3.71
VIII	C	1.04	11463.	9640.	1.19	4.85

Table II-8

(Continued)

(b) For 10-Year Design Storm

PREDICTED DISTRIBUTION		DESIGN STORM DISCHARGE RATIO	PREDICTED AADR	ACTUAL AADR	PRED/ACT AADR RATIO	SENSITIVITY (M)
I	A	1.10	2978.	2132.	1.40	3.97
I	B	1.20	3179.	1610.	1.97	4.87
I	C	1.30	3375.	1194.	2.83	6.09
I	D	1.40	3568.	882.	4.05	7.61
II	A	.90	2562.	3614.	.71	2.91
II	B	.80	2345.	4761.	.49	2.54
II	C	.70	2122.	6173.	.34	2.19
II	D	.60	1890.	7853.	.24	1.90
III	A	1.05	3364.	2841.	1.18	3.41
III	B	1.11	3966.	2895.	1.37	3.50
III	C	1.16	4577.	2935.	1.56	3.60
III	D	1.20	5192.	2964.	1.75	3.69
IV	A	.94	2198.	2675.	.82	3.16
IV	B	.88	1648.	2534.	.65	3.02
IV	C	.82	1134.	2335.	.49	2.88
IV	D	.75	673.	2025.	.33	2.72
V	A	1.04	2416.	2072.	1.17	3.80
V	B	1.09	2096.	1523.	1.38	4.41
V	C	1.12	1808.	1106.	1.64	5.08
V	D	1.16	1550.	801.	1.94	5.74
VI	A	.95	3170.	3734.	.85	3.27
VI	B	.90	3613.	5098.	.71	3.06
VI	C	.85	4109.	6958.	.59	2.77
VI	D	.80	4666.	9443.	.49	2.47
VII	A	1.01	3790.	3818.	.99	-1.42
VII	B	1.00	4915.	5283.	.93	******
VII	C	.98	6141.	7269.	.84	10.10
VII	D	.96	7459.	9915.	.75	5.78
VIII	A	.98	10575.	9963.	1.06	-4.05
VIII	B	.96	11098.	9920.	1.12	-2.95
VIII	C	.92	11540.	9847.	1.17	-2.27

Table II-8

(Continued)

(c) For 25-Year Design Storm

PREDICTED DISTRIBUTION		DESIGN STORM DISCHARGE RATIO	PREDICTED AADR	ACTUAL AADR	PRED/ACT AADR RATIO	SENSITIVITY (M)
I	A	1.10	3201.	2257.	1.42	4.18
I	B	1.20	3417.	1678.	2.04	5.18
I	C	1.30	3628.	1229.	2.95	6.51
I	D	1.40	3836.	895.	4.28	8.21
II	A	.90	2754.	3943.	.70	3.02
II	B	.80	2521.	5272.	.48	2.61
II	C	.70	2281.	7009.	.33	2.25
II	D	.60	2032.	9179.	.22	1.95
III	A	1.07	3623.	3008.	1.20	2.75
III	B	1.15	4280.	3024.	1.42	2.82
III	C	1.22	4947.	3032.	1.63	2.89
III	D	1.29	5621.	3034.	1.85	2.96
IV	A	.92	2358.	2928.	.81	2.55
IV	B	.85	1764.	2836.	.62	2.44
IV	C	.76	1210.	2686.	.45	2.33
IV	D	.68	716.	2415.	.30	2.20
V	A	1.02	2592.	2233.	1.16	6.75
V	B	1.05	2245.	1648.	1.36	7.86
V	C	1.07	1934.	1201.	1.61	9.12
V	D	1.09	1656.	873.	1.90	10.34
VI	A	.97	3414.	4005.	.85	5.74
VI	B	.95	3901.	5458.	.71	5.31
VI	C	.92	4450.	7440.	.60	4.76
VI	D	.88	5070.	10097.	.50	4.20
VII	A	1.05	4091.	4038.	1.01	.28
VII	B	1.09	5329.	5522.	.97	-.41
VII	C	1.12	6689.	7538.	.89	-.97
VII	D	1.14	8170.	10236.	.80	-1.49
VIII	A	.95	10707.	10160.	1.05	-.99
VIII	B	.88	11173.	10100.	1.11	-.92
VIII	C	.82	11572.	10003.	1.16	-.85

Table II-8

(Continued)

(d) For 50-Year Design Storm

PREDICTED DISTRIBUTION		DESIGN STORM DISCHARGE RATIO	PREDICTED AADR	ACTUAL AADR	PRED/ACT AADR RATIO	SENSITIVITY (M)
I	A	1.10	3249.	2276.	1.43	4.27
I	B	1.20	3468.	1683.	2.06	5.30
I	C	1.30	3682.	1229.	3.00	6.65
I	D	1.40	3893.	895.	4.35	8.37
II	A	.90	2795.	4034.	.69	3.07
II	B	.80	2558.	5435.	.47	2.65
II	C	.70	2315.	7290.	.32	2.28
II	D	.60	2062.	9665.	.21	1.97
III	A	1.09	3678.	3033.	1.21	2.42
III	B	1.17	4348.	3035.	1.43	2.48
III	C	1.26	5028.	3035.	1.66	2.52
III	D	1.35	5715.	3035.	1.88	2.55
IV	A	.91	2391.	3000.	.80	2.28
IV	B	.82	1788.	2945.	.61	2.20
IV	C	.73	1226.	2827.	.43	2.10
IV	D	.64	725.	2598.	.28	1.99
V	A	1.01	2629.	2268.	1.16	14.20
V	B	1.02	2276.	1676.	1.36	16.62
V	C	1.03	1960.	1223.	1.60	19.34
V	D	1.04	1677.	891.	1.88	22.01
VI	A	.99	3467.	4061.	.85	11.94
VI	B	.97	3964.	5530.	.72	10.99
VI	C	.96	4525.	7535.	.60	9.78
VI	D	.94	5161.	10224.	.50	8.54
VII	A	1.07	4156.	4071.	1.02	.28
VII	B	1.14	5421.	5545.	.98	-.15
VII	C	1.21	6814.	7554.	.90	-.47
VII	D	1.27	8335.	10248.	.81	-.70
VIII	A	.92	10735.	10217.	1.05	-.64
VIII	B	.84	11188.	10174.	1.10	-.62
VIII	C	.75	11579.	10077.	1.15	-.60

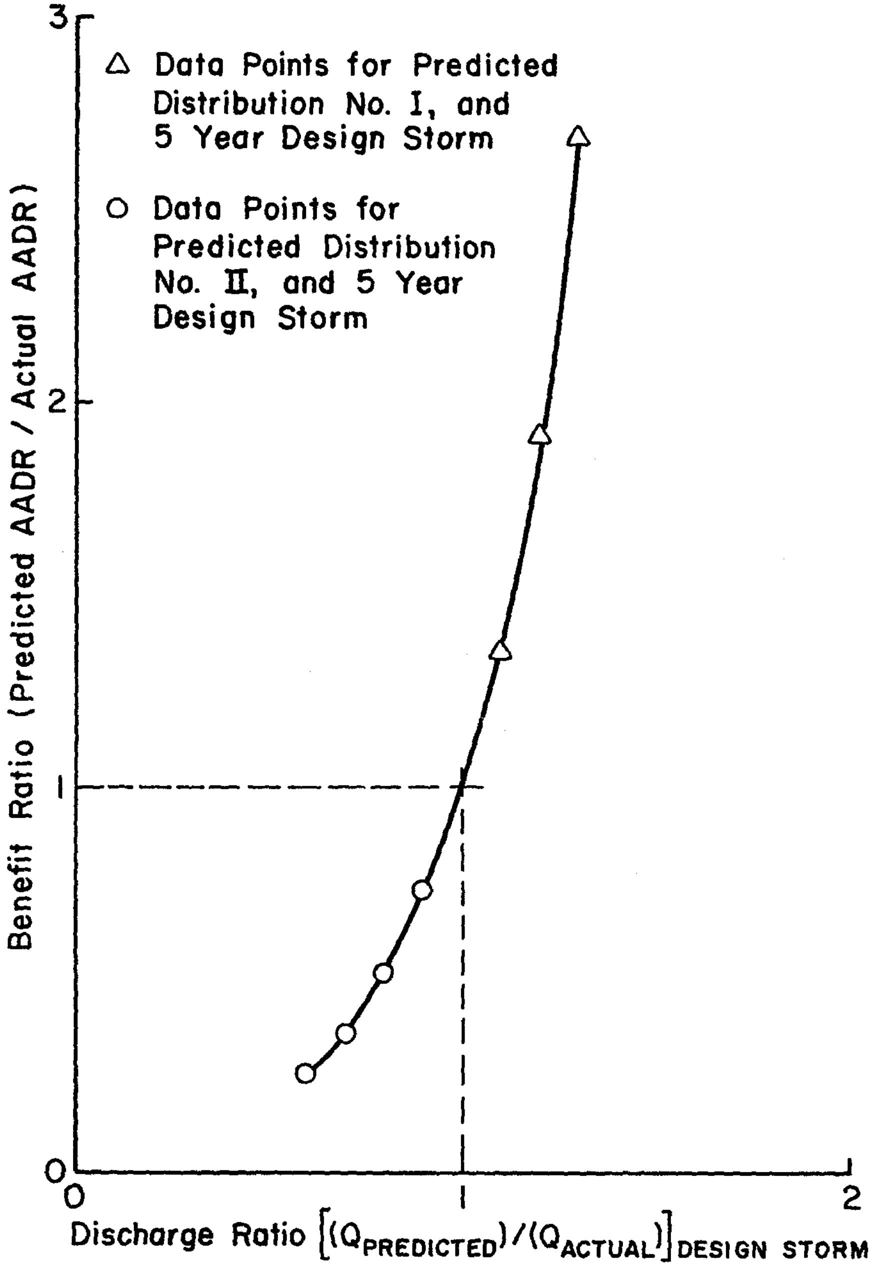


Figure II-12. Benefit Ratio Versus Discharge Ratio Plots for Predicted Distributions I and II.

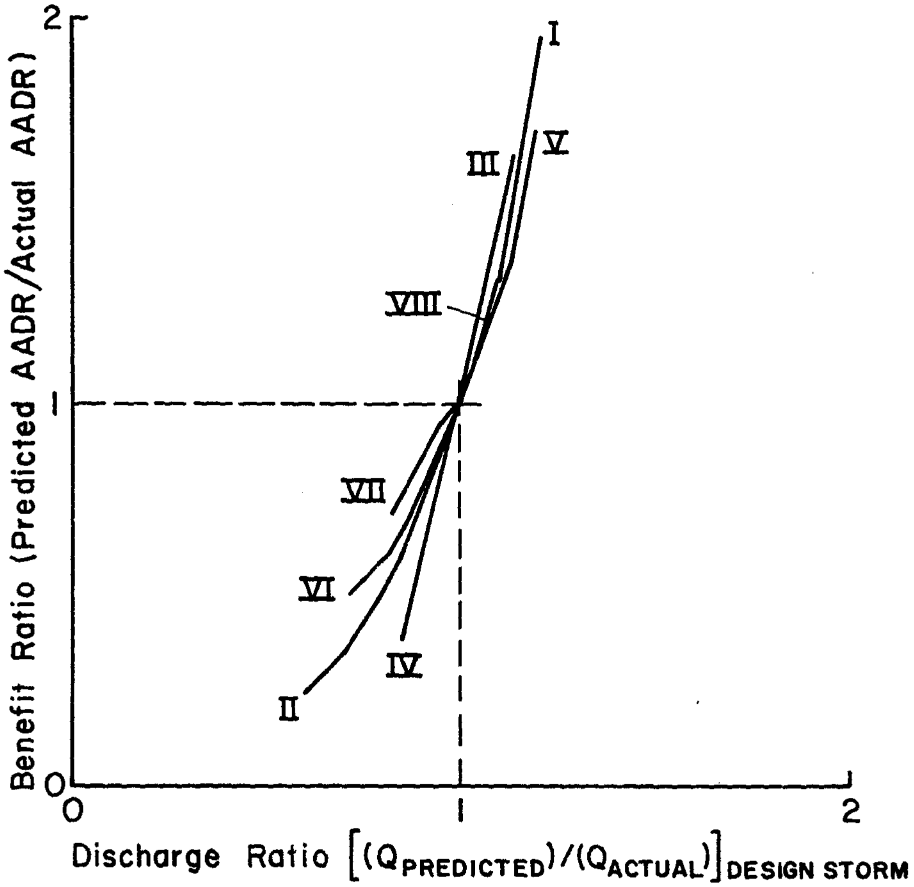


Figure II-13. Benefit Ratio Versus Discharge Ratio Curves for Predicted Distributions I Through VIII.

Since the actual benefit (B_A) and the actual discharge (Q_A) do not change, equation (32) reduces to:

$$M = \frac{d\ B_p/B_A}{dQ_p/Q_A} \tag{33}$$

and in general

$$\frac{dB}{B} = M\ \frac{dQ}{Q} \tag{34}$$

The values of M for linear segments of the curves are listed in Table II-8. These values, all greater than one, illustrate that the calculated benefits are sensitive to prediction errors. Unlike costs, the error in calculated benefits is greater than the error in predicted discharge. For example, if the predicted discharge distribution was curve IA and a 10-year storm was selected as the design storm, the discharge prediction error would be 10%. The calculated benefit error, however, would be 40%!

<u>Benefit/cost ratio</u> - The benefit/cost ratio (BCR) originated from the Flood Control Act of 1936 and is an indicator of project viability. If the total project benefits exceed total project costs, the BCR will be greater than one and investment in the project is economically justified. Although urban drainage and flood control projects are not judged on economic criteria alone, the BCR is the only project indicator that can be reliably quantified. It should be accurately estimated. In this section, the writers combine the previous two sections to evaluate the sensitivity of the BCR to discharge prediction errors. Specifically, they evaluate α_7 in the following equation:

$$\frac{d(B/C)}{(B/C)} \approx \alpha_7 \frac{dQ}{Q} \tag{35}$$

Where α_7 is the sensitivity coefficient of the BCR to poor estimates of discharge. Two approaches are used to evaluate α_7.

The first approach (method A) is based on the assumption that the predicted cost of the project will be the actual expenditure on the project. That is, the urban drainage and flood control facilities will be built to accommodate the <u>predicted</u> design storm at the predicted cost. The <u>actual</u> benefits from the facility will, however, be different from the <u>predicted</u> benefits. This approach simplifies equation (35) to:

$$\frac{dB}{B} = \alpha_7 \frac{dQ}{Q} \tag{36}$$

since the cost (C) is constant with respect to differences in <u>predicted</u> and <u>actual</u> discharge (Q). Equation (36) describes the sensitivity of benefits to discharge prediction errors. The BCR sensitivity parameter, α_7, for this approach is the same as the benefit sensitivity parameter, M, developed in the previous section. Thus, the values for α_7 will be the same as those listed for M in Table II-8.

In the second approach (method B) the writers compare the BCR evaluated from two separate analyses -- the predicted discharge analysis, and the actual discharge analysis. The <u>predicted</u> cost and the <u>actual</u> cost of the flood control facility will not be the same in this approach since each is calculated with a different discharge. Table II-9 lists the BCR sensitivity parameter, α_7, for this approach.

Table II-9. Sensitivity of Benefit Cost Ratio to Errors in the Predicted Runoff Distribution*

	Predicted to Actual Design Storm discharge ratio	Predicted to Actual cost Ratio	Predicted to Actual BCR Ratio		BCR Sensitivity (α7) to discharge errors	
			Method A	Method B	Method A	Method B
Predicted Distribution						
I A	1.10	1.05	1.37	1.31	3.70	3.10
B	1.20	1.10	1.91	1.74	4.55	3.70
C	1.30	1.15	2.70	2.35	5.67	4.50
D	1.40	1.20	3.79	3.16	6.98	5.40
II A	.90	.95	.73	.77	2.70	2.30
B	.80	.90	.52	.58	2.40	2.10
C	.70	.85	.37	.44	2.10	1.87
D	.60	.80	.26	.33	1.85	1.68
III A	1.04	1.02	1.16	1.14	4.00	3.50
B	1.07	1.03	1.32	1.27	4.57	3.86
C	1.10	1.05	1.48	1.41	4.80	4.10
D	1.13	1.06	1.63	1.53	4.85	4.08
IV A	.96	.98	.84	.86	4.00	3.50
B	.92	.96	.69	.72	3.88	3.50
C	.88	.94	.54	.57	3.83	3.58
D	.83	.92	.39	.42	3.59	3.41
V A	1.06	1.03	1.17	1.14	2.83	2.33
B	1.12	1.06	1.39	1.31	3.25	2.58
C	1.18	1.09	1.67	1.53	3.72	2.94
D	1.24	1.12	2.01	1.80	4.21	3.33
VI A	.93	.97	.85	.88	2.14	1.71
B	.87	.93	.71	.76	2.23	1.85
C	.80	.90	.59	.66	2.05	1.70
D	.72	.86	.50	.58	1.79	1.50
VII A	.97	.98	.97	.98	1.00	.67
B	.93	.96	.89	.93	1.57	1.00
C	.88	.94	.80	.85	1.67	1.25
D	.82	.91	.71	.78	1.61	1.22
VIII A	1.02	1.01	1.07	1.06	3.50	3.00
B	1.04	1.02	1.13	1.11	3.25	2.75
C	1.04	1.02	1.19	1.17	4.75	4.25

*Note: This table is for the 5-year design storm. The BCR sensitivity for the other design storms is similar.

The parameter is slightly smaller in this approach due to the sensitivity of project costs to discharge prediction errors. The sensitivity parameter would, in fact, approach zero if the sensitivities of both costs and benefits were the same. That is, if

$$\frac{dC}{C} = \alpha_8 \frac{dQ}{Q} \tag{37}$$

and

$$\frac{dB}{B} = \alpha_9 \frac{dQ}{Q} \tag{38}$$

and

$$\alpha_8 = \alpha_9$$

then

$$\frac{d(B/C)}{(B/C)} = 0 \frac{dQ}{Q} \tag{39}$$

implying that the BCR is insensitive to discharge prediction errors. Tables II-8 and II-9 indicate that the sensitivities of the costs and benefits are far from identical and that the sensitivity of the BCR to prediction errors is significant. The values in the tables reveal that it is possible for a project to have a predicted BCR greater than one, when the actual BCR is less than one. For example, if the predicted distribution was IC and the calculated BCR was 2.0, the actual BCR would be about .7. The calculated BCR indicates that the project is economically viable, whereas in reality, the cost of the project exceeds the realized benefits.

Minimum cost analysis - The planning objective of minimum cost analysis is the minimization of the sum of the residual expected annual flood damages and the annual cost of urban drainage and flood control measures. The analysis optimizes the size or extent of flood control facilities as illustrated in Figure II-14. It is equivalent to maximizing net benefits.

To examine the sensitivity of optimal sizing to prediction errors, the writers assumed that the estimated annual cost of measures is equal to the actual annual expenditure for those measures as in the Method A approach of the previous section. Therefore, changes in the total cost curve are a function of changes in the residual damage curve only. Further, if the computed residual damage curve for the predicted discharge distribution is parallel with that for the actual discharge distribution, the "optimal" design frequency will remain unchanged (see Figure II-15 and II-16). Thus, the sensitivity of optimal sizing is a function of the parallelism of the predicted and the actual residual damage curves.

Table II-10 lists the differences between actual residual damages and predicted residual damages for the various discharge distributions at various design levels. The differences are not constant for the various design levels indicating that the residual damage curves are not parallel. This condition will force the predicted "optimal" design frequency to shift. The extent of the shift is not easily ascertained since it will depend on the degree of curvature of both the cost and the damage curves.

The writers suggest that the "Total Average Annual Flood Control Cost" curve will in general be quite flat, and the "optimal" design level determined from that curve will be suspect no matter how accurate the discharge prediction. The approximations made in the analysis create a fairly wide confidence interval about the total cost curve and the "optimal" design level could occur within a considerable range (see Figure II-17).

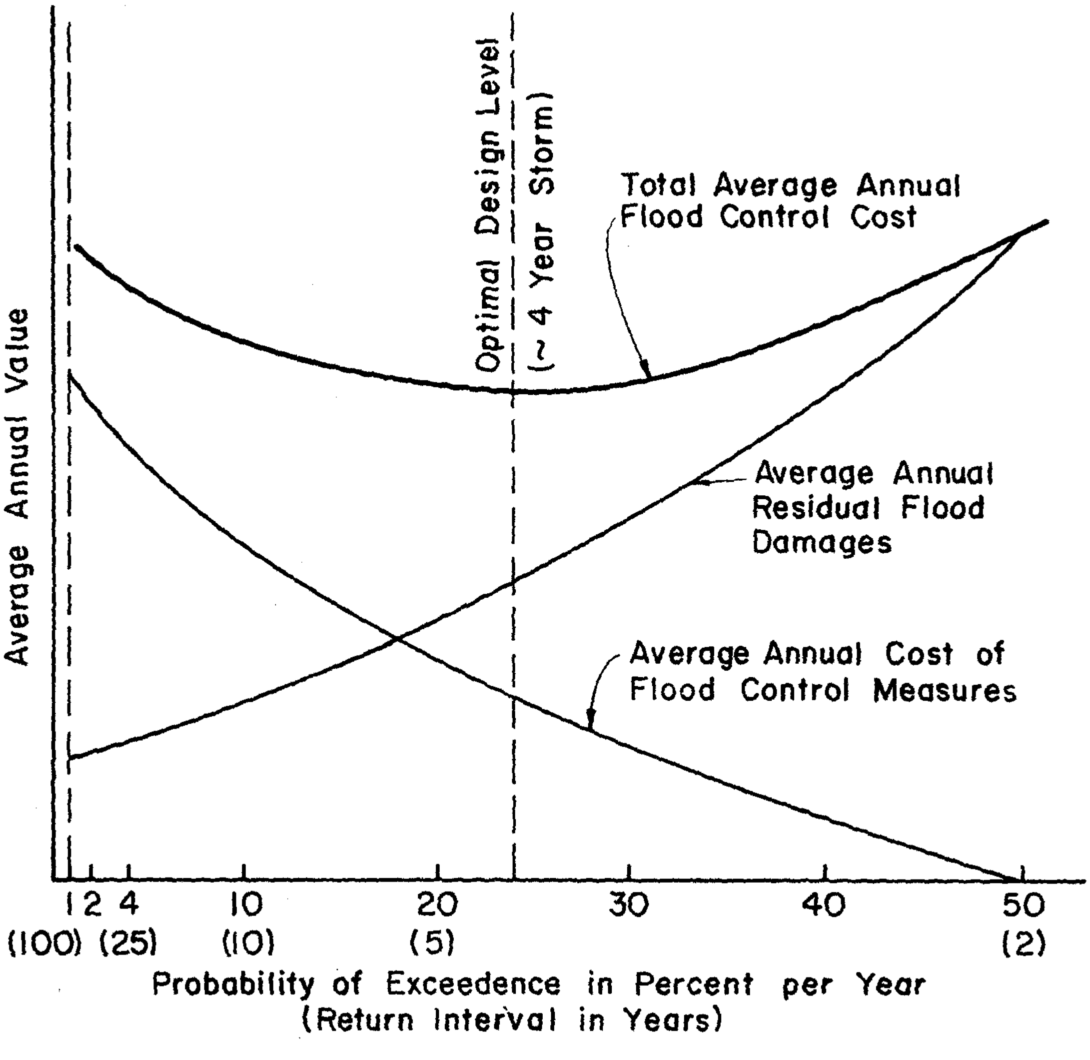


Figure II-14. Sample Minimum Cost Analysis Curves for Actual Runoff Distribution.

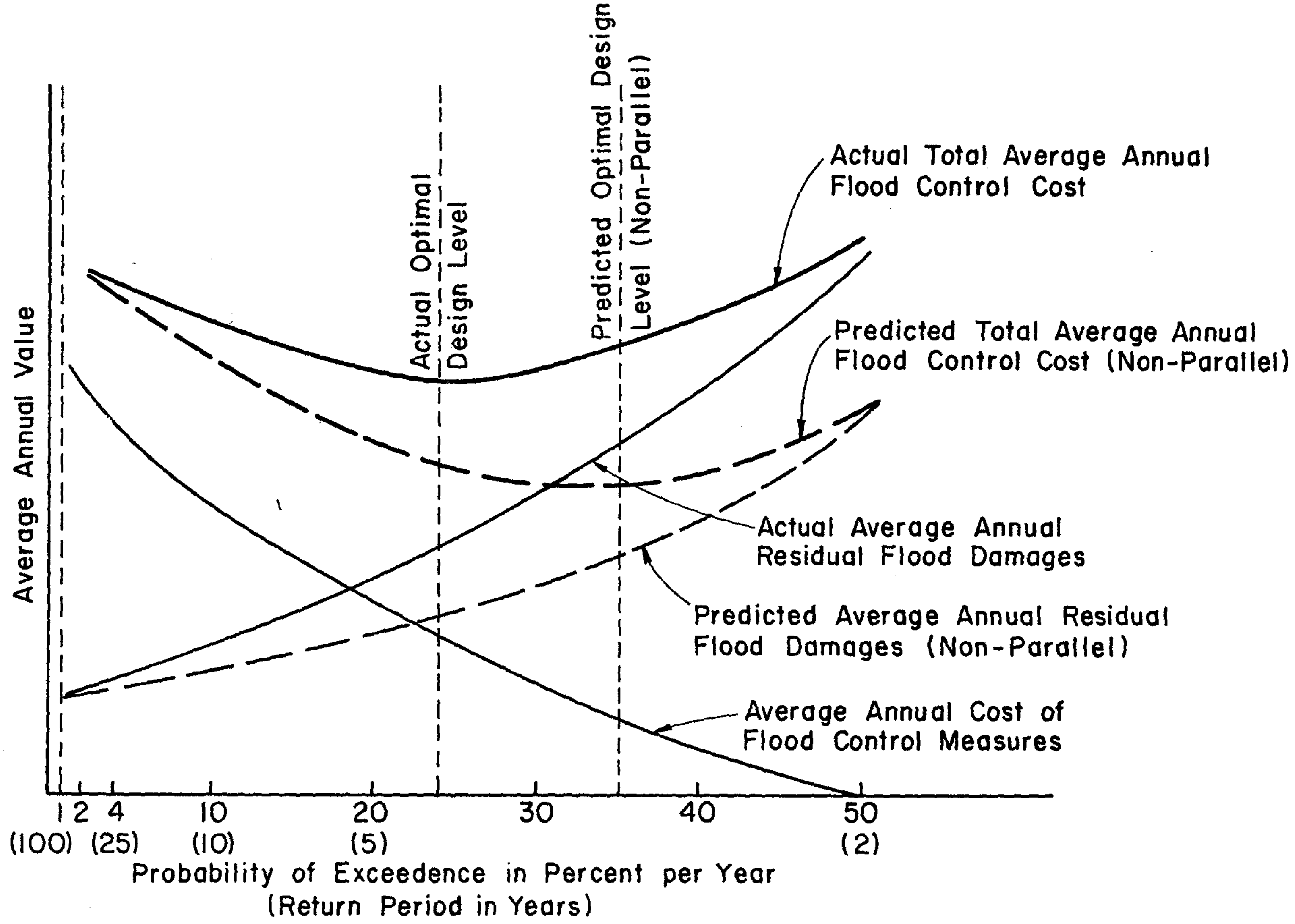


Figure II-15. Sample Minimum Cost Analysis Curves for Actual and Predicted Runoff Distributions (Non-Parallel Residual Flood Damage Curves).

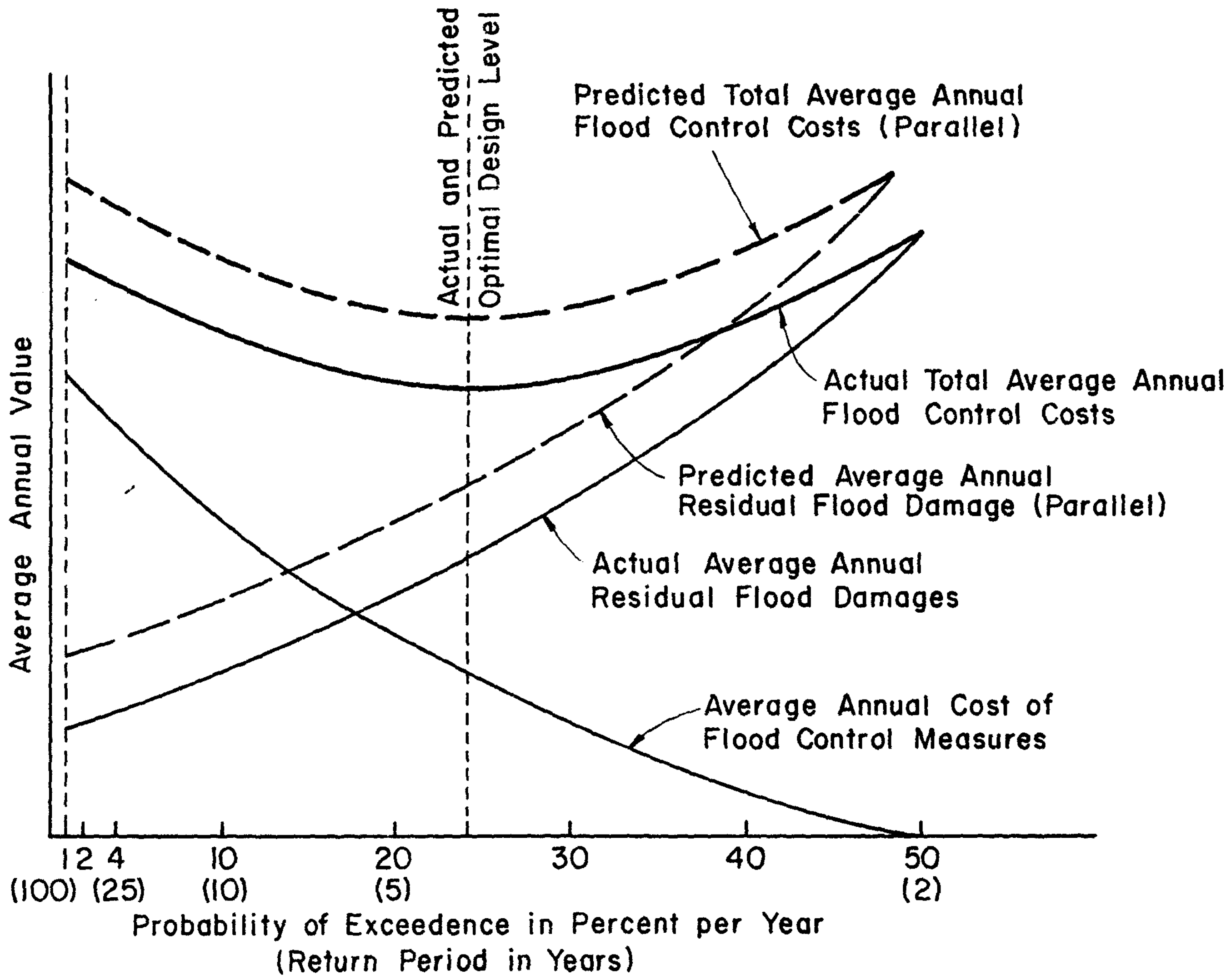


Figure II-16. Sample Minimum Cost Analysis Curves for Actual and Predicted Runoff Distributions (Parallel Residual Flood Damage Curves).

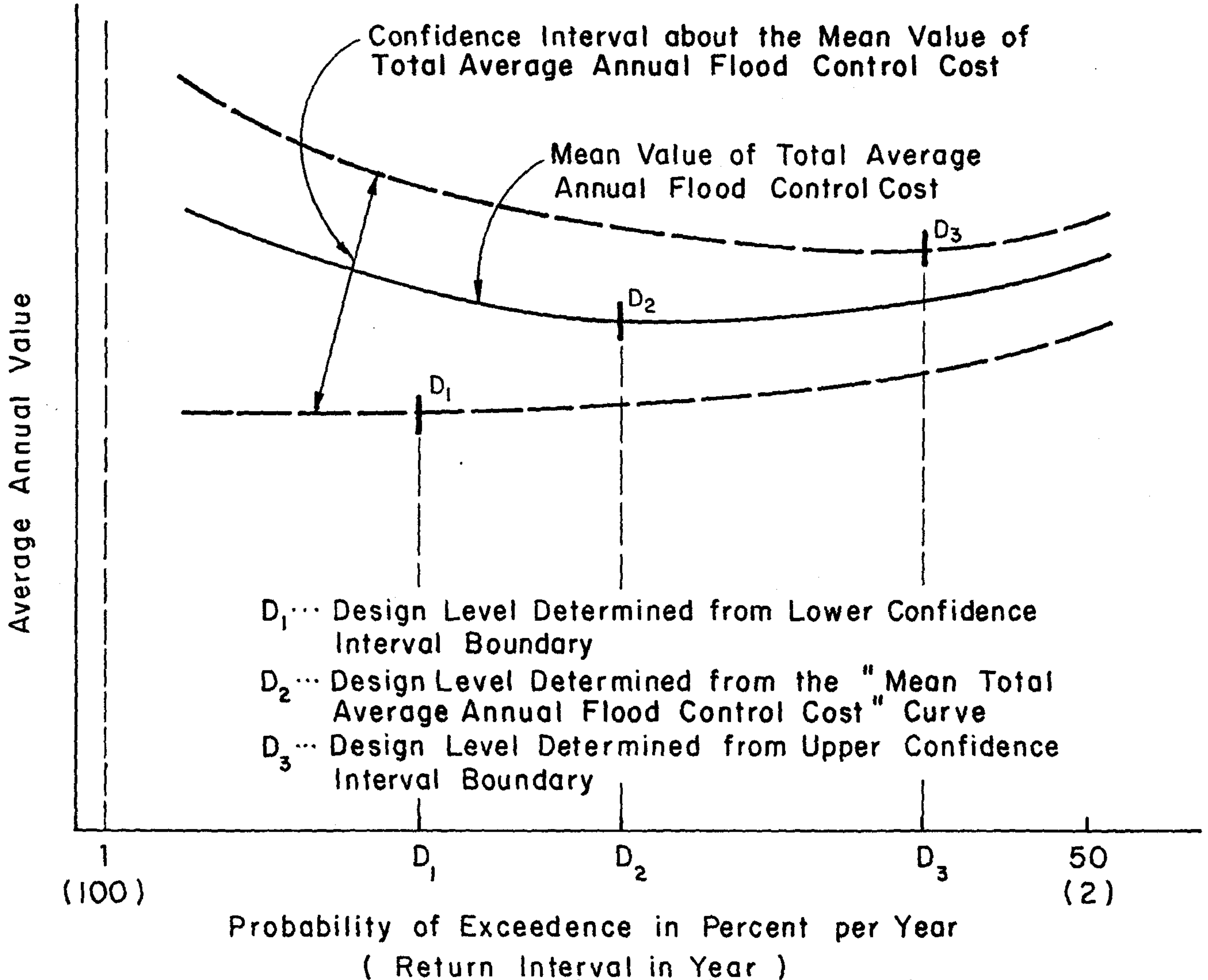


Figure II-17. Sensitivity of Optimal Design Level Within an Estimated Confidence Interval About the Mean Total Average Annual Flood Control Cost Curve.

Table II-10. Residual Flood Damage Differences for the Predicted Runoff Distributions.

	Residual damage differences (Predicted - actual = difference) for return interval design storm.			
	5 Year	10 Year	25 Year	50 Year
Predicted Distribution				
I A	2,052	909	259	68
B	3,536	1,519	385	77
C	4,597	1,896	440	82
D	5,435	2,159	465	86
II A	-3,112	-1,444	-532	-201
B	-7,923	-3,745	-1,511	-677
C	-14,843	-7,867	-3,356	-1,707
D	-25,234	-14,773	-6,879	-3,842
III A	1,808	897	282	78
B	3,561	1,714	488	105
C	5,271	2,465	645	126
D	6,944	3,162	776	148
IV A	-1,929	-1,054	-435	-181
B	-4,074	-2,368	-1,128	-558
C	-6,509	-4,027	-2,197	-1,362
D	-9,346	-6,369	-4,058	-2,899
V A	434	111	10	0
B	701	185	18	0
C	831	228	23	0
D	851	247	25	0
VI A	-799	-195	-22	-1
B	-2,235	-539	-67	-3
C	-4,499	-1,080	-141	-7
D	-7,874	-1,918	-258	-14
VII A	1,328	845	303	89
B	2,609	1,770	603	144
C	3,682	2,788	924	199
D	4,298	3,890	1,290	268
VIII A	-1,244	-789	-360	-164
B	-2,339	-1,567	-860	-473
C	-3,267	-2,401	-1,580	-1,132

Summary of project analysis sensitivity to discharge prediction errors - In this section, the writers examine the sensitivity of four flood control evaluation criteria to prediction errors. They find that the cost of a particular project is relatively insensitive to prediction errors; whereas, the calculation of the benefits and the benefit/cost ratio is quite sensitive to prediction errors. The "optimal" size project is found to vary with prediction errors but the extent of variability is not certain.

The sensitivity of these criteria may not be as significant as first thought. If a community uses the same rainfall-runoff prediction tool, the analyses for various projects will have a consistent base. The predicted BCRs for each project may not be accurate, but they will precisely define the relative economic merits of each project. In the urban drainage and flood control area, where the BCR's for politically justified projects are not always greater than one, this relative consistency can be more important than truly accurate BCR values.

Recommended Technical Element

In the preceding three sections of this chapter, the writers describe the requirements for the Technical element of an urbanizing community's drainage management program and examine various techniques that meet these requirements. The significant findings are:

1) Drainage and flood control management of an urbanizing basin requires an estimate of growth-induced changes to all aspects of runoff response. The models that satisfy this requirement can be classified into 2 categories: Conceptual and physically-based rainfall-runoff models. The physically-based models are relatively time-consuming to initiate and expensive to support. They require extensive data,

support personnel with expertise in hydrology and computer science, and computer facilities. The conceptual "black-box" models on the other hand can be initiated rather quickly and are cheaper to support.

2) The predictive capability of the physically-based models is not significantly better than the predictive capability of the conceptual models. In addition, the predictive capability of the physically-based models appears to be more sensitive to the model user. This results in a greater chance of inconsistent prediction with physically-based models.

3) Project analyses such as benefit/cost analysis and minimum cost analysis are quite sensitive to poor predictions of discharge. This sensitivity may not be significant if the discharge prediction errors are consistent throughout the planning area. Nevertheless, methods with "demonstrated" improvements in accuracy should be used as they become available.

Based on these findings, the writers recommend that the Technical element of the drainage and flood control management program be simple and consistent. The minimal financial, data, and expertise requirements of a simple model encourage quick initiation of that model. It is far better to quickly initiate an acceptable Technical element of the management program than to sustain substantial delays in developing and initiating state-of-the-art modeling techniques. Management of development-induced drainage impacts can be realized much sooner. The option will always be open to incorporate sophisticated techniques into the management program if funds and improved models become available.

To insure consistent application of the management program the same techniques must be used throughout the planning area. This consistency criteria is extremely important; without it, the management program will not be equitable, the community's staff of drainage personnel and the local consulting engineers will lose their credibility in the eyes of the citizens and decisionmakers alike, and the faith in and support of the program will quickly disappear.

Chapter III

FINANCIAL ELEMENT ON THE DRAINAGE MANAGEMENT PROGRAM

In Chapter II, the writers outline the urbanization effects on the hydrologic response of a watershed. Suburban development alters the stormwater runoff response of the watershed which, in turn, reduces the adequacy of downstream urban drainage and flood control facilities. Who is responsible for the increased flooding damages caused by this reduction in facility adequacy?

The answer to this question is not clear. In this chapter, the writers review pertinent case law and suggest that it is prudent for both the local government and the developer to insure against unreasonable development-induced drainage impacts. This guarantee is generally in the form of measures such as channel improvements, detention ponds, and flood plain zoning to reduce the devlopment-induced impacts. The expense of these measures and the joint responsibility demand a sharing by the local government and the developer of the costs to provide these measures.

Therefore, the writers continue in this chapter with an examination of the legal issues involved in this cost sharing through an analysis of drainage assessment case law. They also review existing cost calculation and cost apportionment techniques. They then recommend a financial element with new cost calculation and apportionment methods. The financial element has a strong legal basis and is relatively easy to initiate and administer.

Municipal Responsibility for Development-Induced Flood Damages

There are two major actors involved in suburban developments -- the developer or builder; and the community who, through some agency, approves the development. Which of these two bears the responsibility of the development-induced increase in flooding damages? The selection of a Financial element for the drainage management program will be guided by the answer to this question. Identification of the responsible party is necessary in order to legally encumber (through fees or construction requirements) that party for measures required to mitigate damages. Unfortunately, the law does not clearly establish which party should be responsible for development-induced drainage impacts. In this section, the writers suggest an answer to the responsibility question through a brief review of surface water law and an analysis of pertinent case law.

Surface water law - In the United States there are three rules that govern the drainage of diffuse surface waters: 1) the "common enemy" rule, 2) the "natural flow" rule, and 3) the "reasonable use" rule. The "common enemy" or "common law" rule is a doctrine that treats surface runoff as a common enemy. The rule allows a landowner to "deal" with surface runoff as he wishes in order to protect his property, regardless of any injury so caused. This doctrine, which apparently grew from a desire to promote land development during the 19th century has been tempered over the years to include a requirement of "reasonableness" in one's actions to protect himself against this common enemy. "Wilful, wanton, and malicious" conduct concerning the disposition of surface waters can now result in liability of the landowner under this doctrine (4).

The "natural flow" or "civil law" rule is based on the *agua currit* maxim -- "water runs as it is wont to run, and ought to run. "(4). Following the laws of nature, this doctrine assumes the existence of a natural easement or servitude over lower lands within a drainage basin. The owners of these servient lands cannot obstruct the <u>natural</u> flow of water to the detriment of the higher (or dominant) landowner. If strictly construed, this doctrine does not require a servient landowner to accommodate development-induced changes (quantity or quality) in stormwater flows. In the words of the Supreme Court of Colorado, this doctrine provides that "Natural drainage conditions may be altered by an upper proprietor provided that water is not sent down in a manner or quantity to do more than formerly "(85). The word "natural" in this instance has been interpreted to mean natural in both amount and velocity (85).

Like the "common enemy" rule, the "natural flow" rule has been modified over the years to include a reasonableness criterion. Servient landowners may now modify existing drainage patterns as long as the modifications are reasonable. Likewise, the dominant landowners may alter the natural drainage as long as the alteration is not ruled unreasonable.

The "reasonable use" doctrine is concerned with the rights of individual landowners, be they dominant or servient. This doctrine states that any landowner may make reasonable use of his land even though such use may alter surface water flow to the injury of others. How much injury can be sustained before the use is ruled unreasonable? Beck (4) lists three criteria the courts have used to answer this question:

1) Was there reasonable necessity for the actor to alter the drainage to make use of his land?

2) Was the alteration done in a reasonable manner, with due care to prevent injury to another's land?, and

3) Does the utility of the actor's conduct reasonably outweigh the gravity of the harm to others?

Determination of reasonable use can be ascertained only upon judicial review of these criteria.

It is apparent that the "reasonable use" doctrine is not significantly different from the modified interpretations of the "common enemy" and "natural flow" doctrines. The only suggested difference among all three is in "the practical question of prediction and proof" (4). That is, the basic philosophy of all three doctrines is identical -- reasonable use of one's own property. However, each doctrine places the burden of proving unreasonable use on different actors, either the servient or dominant landowners. This "burden of proof" shift can result in different decisions for factually similar situations.

Responsibilities for development-induced drainage impacts can be assigned with the modified "common enemy" rule, the "natural flow" rule, and the "reasonable use" rule. The responsibilities will stem from either an unreasonable use of one's property or the alteration of natural surface flows. However, readers are cautioned to verify the prevailing Surface Water Law of their state. Strict application of the "common enemy" rule would preclude any developer assignment of responsibility for development-induced drainage impacts. Each landowner would be free to alter the surface drainage as he sees fit.

Case law - The responsibility to mitigate development-induced drainage impacts is established in Surface Water Law. The surface water doctrine does not, however, specify which of the development actors -- developer or municipality -- should bear that responsibility.

The identification of responsible parties comes from the following analysis of case law.

The courts have had little difficulty applying the surface water doctrines in cases involving private landowners. They have generally granted relief to servient landowners where it is shown that the dominant landowners have altered natural surface runoff. In Clark vs. Beauprez, for example, the Colorado Supreme Court affirmed a lower court decision to enjoin Clark from continuing to drain a marshy portion of his land to the detriment of Beauprez.[3] In reclaiming this marshy area, Clark had installed a network of subsurface drain tiles. These drain tiles collected the water and conveyed it away from the marshy land. This collection and conveyance was established by the court to be a diversion of the marsh water from its natural flow pattern to Beauprez's irrigation ditch. The court held that since the marsh water was not now "flowing in its natural course and manner..,"[4] the servient landowner, Beauprez, was not "responsible for accommodating the additional flow."

The Colorado Supreme Court affirmed a similar finding by a lower court in Hankins vs. Barland.[5] In this case, the trial court found that the increased use of irrigation water from the Colorado Big Thompson project was causing surface water to be "... sent down in a manner and gravity to do more harm than it formerly had done or in amounts in excess of natural amounts."[6] Here again the court ruled that the servient landowner was not responsible for accommodating this extra runoff water.

The court's application of surface water doctrine differs from that of these two cases when the alteration of natural surface runoff is a result of municipal action. The courts have been considerably lenient in their treatment of municipal governments. This leniency is inherent in Breiner vs. C & P Home Builders, Inc..[7] In this case, Breiner brought suit against a land developer and a municipal government. The suit claimed that the construction of 38 houses over a period of seven years on land adjacent to Breiner's property had increased surface water flow onto his land. This increase in flow prevented him from continuing a commercial strawberry farm operation. The lower court, using a "reasonable man" critera, found both the developer and the municipal government liable for damages. On appeal, the federal appellate court (Third Circuit) affirmed the developer's liability but released the municipal government. The release was based on 3 arguments:

1) In issuing a building permit, a municipality is not insuring that the resulting structure complies with all applicable regulations.

2) Issuance of a building permit does not make the municipality liable for a builder's negligence.

3) The underlying policy of the municipality's ordinance was the protection of citizens of that particular community.

The court elaborated on the third argument by suggesting that the municipality need not worry about adjacent properties outside the municipality when acting on subdivisions. Does this mean that the outcome of the case would have been different if the Breiner property was located within the municipal boundaries? Truly the action taken by the municipality would then not have been in the interests of all citizens.

This favored treatment of municipal governments is also illustrated in City of Englewood vs. Linkenheil.[8] In this case, Linkenheil filed suit against the city claiming that the new developments, street paving, and storm drain systems in his neighborhood had increased the flooding of his property. The lower court ruled in favor of Linkenheil but the

Colorado Supreme Court reversed this decision. The factors that contributed to this reversal were the uncertainties with regard to the extent of flooding and the fact that Linkenheil had probably worsened the flooding condition by constructing an elevated driveway.

Notwithstanding these factors, the courts posture in reversing the lower court's decision seems a little unreasonable. First, the court thought it was the responsibility of Linkenheil "...to take effective measures to protect [his] property by bringing it up to grade, or constructing drainage facilities so as to minimize their recurrent damage..."[9] In the instant case this would mean raising a 35+ year old house up to street grade! Second, the court acknowledged that there had been an alteration in the natural flow condition but neglected to include the "natural flow" clause in their controlling argument. They rely on the modified civil law doctrine and claim that it "...subjects the servient owner of land to a drainage easement in favor of those who are fortunate enough to own adjacent land on the higher level."[10]

A group of Kansas cases also illustrate the courts favorable treatment of municipal governments in surface water cases. In Welch vs. City of Kansas City, the plaintiff alleges that the flooding of his property was a result of inadequate storm sewers and drainage facilities under adjacent streets.[11] The plaintiff sued the city to recover damages caused by this flooding. Unfortunately, the courts found that the complaint had been filed after the time specified in the statute of limitations and never ruled on the merits of the pleading. The Supreme Court of Kansas did, however, suggest that a municipal government could be held liable for approving development projects. They state that:

> "It appears to be the universal rule that municipal corporations are liable for damages occasioned to private property from the overflow of surface waters cast upon it through the action and fault of the municipality, its officers and agents."[12]

The approval of development projects is generally a discretionary action taken by an elected or appointed official of the municipal government. The previous quote would seem to support an argument of municipal liability if the approved development could be shown to cause an overflow of downstream surface waters.

In Baldwin vs. City of Overland Park, the Supreme Court of Kansas quashes this theory.[13] In this case, Baldwin claims that the city is liable for the increase in storm water flow that has occurred as a result of urban growth. Specifically, he claims that:

> "Over a period of years the defendant (city) has greatly increased the amount of runoff water in the ditch (adjacent to Baldwin's property)...by the construction of new streets, draining streets into the ditch, and construction of artificial water courses which carried surface water from streets and numerous cul de sacs into the ditch. Many new homes... have been erected in the area...causing an additional flow of surface water into the ditch."[14]

The lower court ruled in favor of Baldwin holding that the defendant city had "created and maintained" the flooding problems. The Supreme Court of Kansas, however, reversed the ruling of the lower court. The Supreme Court felt that since the city had not actually done the development work -- constructing streets and residences -- it had not "created" the flooding problems. They support this argument from 18 McQuillin, Municipal Corporation, 3rd ed. rev., §53.141 which states:

> "...a municipality is not liable to a property owner for the increased flow of surface water over or onto his property, arising wholly from the changes in the character of the surface produced by the opening of streets, building of houses, and the like, in the ordinary and regular course of the expansion of the municipality."[15]

This argument is qualified in Wilber Development Corporation vs. Les Rowland Construction, Inc., where the court attempted to differentiate between increases of flow in natural channels and increases of flow from artificial channels.[16] The court states that:

> "On the other hand, (the municipality) is liable if, in the course of an authorized construction, it collects surface water by an artificial channel or in large quantities and pours it, in a body, upon the land of a private person, to his injury."[17]

They explain that compensation is required when this concentration of water causes substantial injury to the subservient land.

The factual situation in the Wilber case affords a clear distinction between increases of surface flows from ordinary municipal expansion, and increases of surface flows from artificial concentration of water. The writers submit that in reality this distinction is not clear. During ordinary municipal expansion, development will occur which will increase the total amount of runoff from a basin. The flow pattern of this increased runoff, however, will be different from the natural pattern. The surface water will be collected in streets and drainage facilities and discharged downstream at other than natural flow locations. If the downstream channel is not capable of passing this increased and concentrated flow, the water will be "thrown" out of the channel and onto properties adjacent to the channel in an unnatural fashion.

From this analysis of case law, we see that there is legal precedent for holding a developer liable for development-induced drainage impacts. Municipal liability in this area is still clouded. There are legal arguments for establishing municipal liability as illustrated by the lower court actions. However, the higher courts, in reversing these lower court rulings, have chosen to rely on alternate arguments that favor municipal governments. Shoemaker (85) in his analysis of Colorado cases, suggests that this preferential treatment of municipal governments in surface water actions against them stems from an inadequate development of facts. That is the "...injured landowners failed or were unable to develop facts to accurately attribute damage to the specific municipality" (85).

Based on surface water doctrine and the arguments presented in the cases, the writers suggest that both developer and municipal government are liable for development-induced drainage impacts. As illustrated in Breiner vs. C & P Home Builders, the developer is accountable for his construction activity. He is responsible for the kind and quality of construction, and the effects it may have. He must insure that his alteration to the land does not unreasonably affect downstream landowners. The building permit issued by the municipality does not transfer his responsibility to the municipality. The developer remains responsible for insuring that his development complies with all applicable building codes.

The municipality, on the other hand, is responsible for damages resulting from its discretionary actions as discussed in Welch vs. City of Kansas City. This responsibility can also be inferred from the police power authority of municipal governments to protect the general health, safety, and welfare of the community. Municipal governments use their police powers to act on development issues. Zoning and subdivision regulations will articulate these powers by relating the necessity of the regulations to the protection of the health, safety and welfare of the community. The municipal government can not use these powers as authority to regulate if the regulations or the interpretation of the regulations through discretionary acts do not, in fact, promote community welfare.

In addition, this dual liability seems appropriate since these two -- the developer and the municipal government -- are the principal actors of development. Without wilful actions by both parties, the development, and any drainage problems associated with that development, would not occur.

Project Cost Calculation

The dual liability of developer and municipal government suggests that a cost sharing approach be developed for the Financial element of the drainage management program. The cost of measures required to mitigate development-induced drainage impacts should be shared by the developer and the municipal government. In addition, the high cost of these measures supports the need for a cost sharing approach. But how shall the costs of the required measures be calculated? And, how shall they be apportioned between municipal government and developer?

The writers answer the second question in the next section. In this section, they suggest a planning procedure for quickly calculating "reasonable" estimates of project cost. The approach is based on a review of the legal issues of cost calculation and a review of existing cost calculation techniques.

Legal issues - The courts have maintained that a cost recovery program is a matter under legislative control and not normally subject to judicial overrule. The judiciary can invalidate legislative actions in this area if there is a clear indication of legislative impropriety. This presumption of validity of legislative actions has limited the scope of court review of drainage programs to questions of cost apportionment. There has been no action taken that questions the methods used to calculate project costs.

This failing is disconcerting because virtually all of the drainage programs with cost recovery provisions in the U. S. are based on costly Master Plans of Drainage. The question facing rapidly urbanizing communities is whether or not they can initiate a program for collecting drainage fees based on a relatively inexpensive "simplified" drainage plan. Would the courts rule this simplification a gross abuse of legislative discretion" and invalidate the fee collection program? The writers cannot answer this question. Truly, a local government stands a better chance of winning an "arbitrary and capricious" argument if the program is based on some kind of plan. However, the required detail of this plan has simply not been defined by the courts.

Project cost calculations with drainage master plans - In the United States, the typical document for estimating the costs of major flood control systems is the Drainage Master Plan. This plan is developed through a comprehensive basin-wide planning effort. Professionals from various disciplines work together to formulate strategies for attaining commonly desired goals from a data base of present and projected demands. Since the basic philosophy of drainage master planning mirrors those of general urban system master planning, it seems appropriate to quickly review the latter.

Urban system master planning - The objectives of the urban system master planning process are (1):

1) To maximize economic efficiency by coordinating the size and location of community infrastructure with projected community demands. This objective recognizes the long lead time required for major public improvements, the possibile misallocation of funds through single

purpose planning, and the opportunities for realizing economies of scale in multipurpose projects.

2) To maximize desired relationships between different land use activities and required physical structures. This objectives assumes that without governmental intervention individual land owners will create external costs, and environments of maximum desirability will be largely unobtainable.

3) To allocate land to desired activities. This objective, too, assumes an imperfect market system and the necessity of government intervention to stimulate private investment towards desired goals.

4) To provide a general urban design that is pleasing.

5) To provide a plan that can be used as a guide to development or to the allocation of public funds. The plan will act as a tool by which decisionmakers can function on a day-to-day basis. The plan will set forth goals and recommendations, yet will remain flexible enough to facilitate the realities of change in the decisionmakers' world.

These objectives provide a framework for a complete and systematic analysis of the urban system. The inherent characteristics of the urban system, however, present real difficulties in implementing this framework of analysis. These difficulties can be expressed as shortcomings of the master planning process which include:

1) The flexibility of the Master Plan. Although this flexibility is desirable from a decisionmaking point of view, it creates the opportunity for abuse. If the decisionmakers are not consciously committed to the goals of the Master Plan, their actions can quickly dissolve all credibility of the plan; the plan rapidly becomes completely out-of-date and useless as a decisionmaking or management tool.

2) Generalized Master Plan goals. Politically or administratively unworkable goals quickly dilute the effectiveness of a Master Plan. The personnel charged with implementing the Master Plan must be shown how certain goals can be achieved or they will simply ignore those goals.

3) Projections. It should be remembered that all planning efforts are based on best estimates of future occurrences. The comprehensive, interdisciplinary approach does not make up for the insufficient data, uncertain system interrelationships, or unknown technological advances. The Master Plan will only be as valid as the assumptions made (either implicitly or explicitly) and the data available.

4) Planner biases. The Master Plan is created by planners with their own personal biases. The outcome can be a plan with a limited focus, unrelated to actual economic and social goals. For example, the terms "desired" and "pleasing" in the master planning objectives will be interpreted by the planner from his reference point and may not reflect true societal values.

5) Expense. Master Planning is not cheap! Development of an adequate plan requires time-consuming inventories of existing system components, development of alternative solution strategies, public comment, revision, etc.. The process is complicated and expensive in both time and money.

6) Public acceptance. The concept of master planning is not universally accepted as the cure for development impacts. There are strong advocates for letting land use be determined in the market place. These antiplanners believe that property owners "...are the best planners of their own land because [they] will use their property toward its highest value "(61).

Drainage Master Planning - An efficient design of a major drainage system will satisfy the urban system master planning objectives listed above. This fact is understandable since the drainage, or hydrologic, system is after all a subsystem of the total urban system. This relationship demands an integrated planning approach for drainage systems that recognizes the multipurpose (flood control, recreation, open space, water supply) and interjurisdictional nature of drainage facilities.

The communities of the Denver, Colorado region and the Colorado Legislators have recognized the necessity for such coordinated planning. The State Legislature established the Urban Drainage and Flood Control District (UDFCD) for these purposes in 1969. The district is charged with the partial financing and coordination of all drainage facility master planning, design, and construction within the communities of the district.

The district's policy for drainage system planning is guided by the master planning framework. They utilize the systematic procedure for drainage basin planning, design, and implementation developed by the Denver Regional Council of Governments. The steps in this procedure are (6):

1) Acquire and develop the facts.
2) Perform present and future runoff analysis.
3) Identify major drainage concepts.
4) Master plan major drainage and design initial drainage.
5) Operate system programs and enforce regulations.

Figure III-1 illustrates the sequence of tasks performed and the various components of each of these tasks.

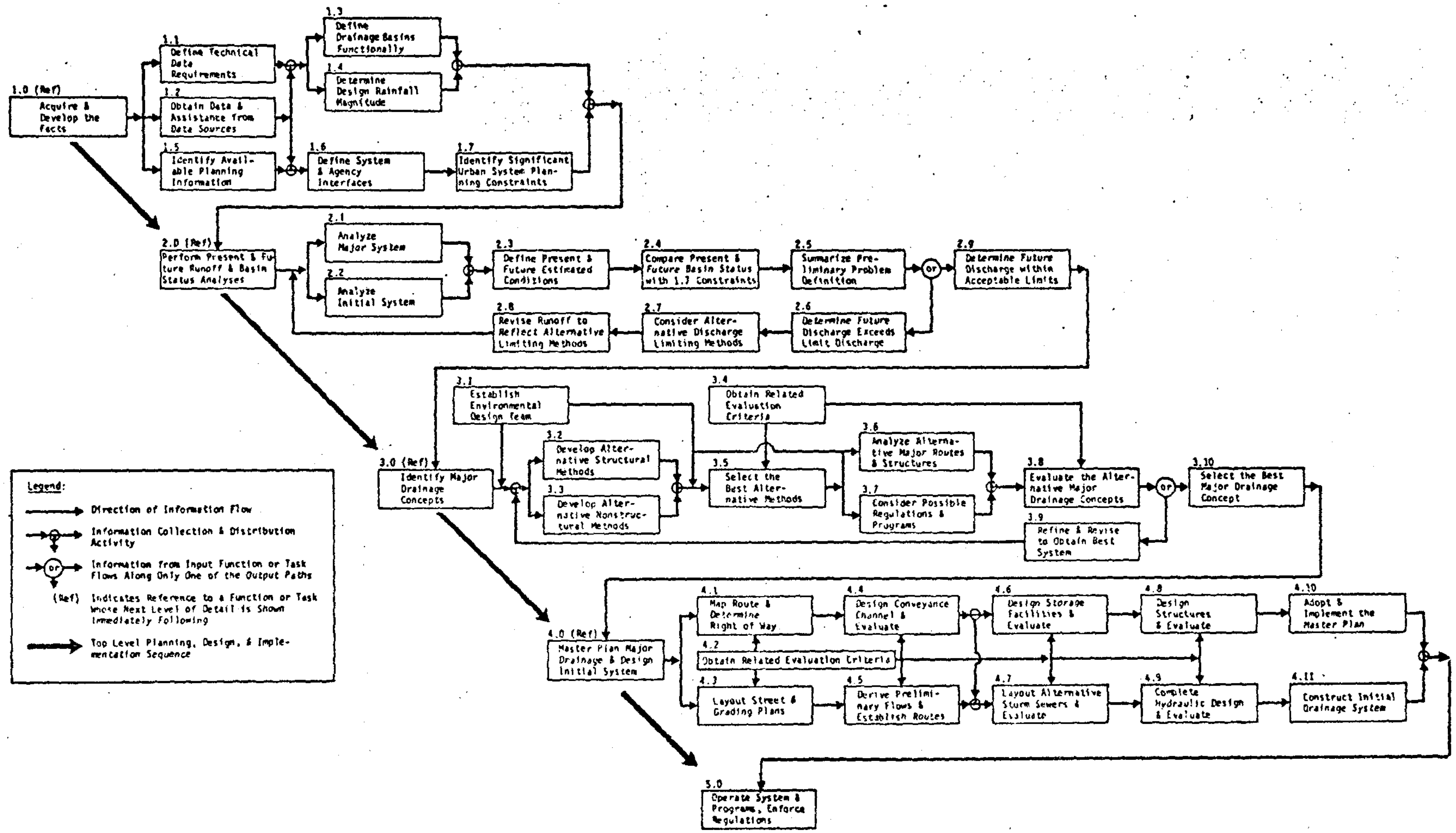


Figure III-1. Tasks in Drainage Master Planning.(From Ref. 6).

Operationally, the district has separated the plan formulation portion (steps 1, 2, and 3) and the plan finalization portion (step 4) of the masterplanning process into two phases -- Phase A and Phase B. The operation and enforcement of the program is really left to the local governments within the district.

The objective of the Phase A study is the preparation of a consistent evaluation of all feasible drainage alternatives so that the best drainage and flood control plan for the basin can be determined and justified. The alternative plans are to be developed by experts from various disciplines and the evaluation of each plan is to consider:

1) Flood damage reduction/cost of flood control facilities.
2) Water quality aspects.
3) Environmental impact and other intangible aspects.
4) Legal aspects.
5) Goals of the urban area.
6) Multipurpose opportunities.

The description and evaluation of these alternative plans are presented in an engineering report. This report is prepared for the public in order to solicit review of and comments on the suggested alternatives. At the end of this review period, one of the described alternatives, or a modification thereof, is chosen as the "best" alternative for that basin. With this decision the second phase -- Phase B -- of the master planning process begins. The Phase B study is directed toward a more detailed analysis of the selected alternative. The analysis is presented as an evaluative report and a series of preliminary improvement plans. It is this output from the Phase B study that constitutes the basin Master Drainage Plan. This plan is in a suitable format for day-to-day use by local and regional governmental administrators, developers, lending institutions, and private citizens.

This two-part drainage master planning process takes about two years from authorization. The Phase A report takes about one year to complete; and the review, recommendation, and completion of the Phase B Master Plan takes another year. The cost of a drainage study (both Phase A and Phase B) varies with the hydrologic complexity of the particular drainage basin and can range from about $2,000 to $6,000 per mile excluding mapping costs.[18]

Alternative cost calculation technique - The Denver region master planning approach to drainage systems is sound and thorough. The methodology is the result of real concern for the total urban system that is expressed by the Denver Regional Council of Government. The continued support from and involvement with these regional governments has minimized the "Planner Biases" and "Generalized Goals" shortcomings of the planning process. The approach does, however, fall prey to the other failings.

Of particular interest in this report is the cost, in both time and money, of preparing a particular basin Master Drainage Plan. A two year planning process can severely restrict sound drainage-related land management such as apportionment of drainage facility costs in a fast growing community. To be sure, rapid urbanization can create critical drainage problems in less time. In addition, the costs of preparing Master Drainage Plans must be financed by the community and can represent significant "front end" expenditures that a young community simply cannot afford.

Clearly, an alternative planning process, or a modification of current methods, is needed to insure expenditious implementation of drainage management in urbanizing communities. Specifically the alternative planning process must generate reliable drainage facility cost estimates as quickly and as inexpensively as is possible.

The writers suggest an alternative planning procedure similar to Denver's Master Planning process. The procedure would have three phases: 1) The Initial Study Phase, 2) the Alternative Plan Phase, and 3) the Final Plan Phase. The objectives of the Initial Study Phase are:

1) To identify one reasonable drainage basin plan based upon intimate knowledge of both the basin under study and the political and social climate of the controlling jurisdictions.

2) To compute the benefit to cost ratio of this plan using accepted economic accounting methodology. If the benefit to cost ratio of this plan is greater than 1, then at least this plan (which may not be the "best") is viable and justified. If the benefit to cost ratio is less than 1, then the selected plan is not viable unless there are overriding political or social aspects to the contrary. These aspects are important in urban drainage and flood control projects and quite regularly override the economic analysis.

3) To compute an apportionment schedule for recovering the costs of constructing the selected plan if it is determined to be viable.

The objectives of the Alternative Plan Phase and the Final Plan Phase are identical to those of Denver's Phase A and Phase B studies respectively.

A drainage basin study can be tailored to meet the objectives of the Initial Study Phase within a certain time frame and at a certain cost. The obvious objection to this approach is the acceptability of using the plan prepared during this study to estimate project costs. This estimate of costs is the basis for the cost apportionment schedule. Will the courts allow a municipal government to use this abbreviated methodology to exact drainage fees from developers?

The final construction bill is, of course, the perfect calculation of project costs. Unfortunately, funds need to be generated to initiate construction projects and an estimate of costs must be made from some plan of the proposed drainage facility. These plans can be the final construction drawings or preliminary construction drawings similar to Denver's Phase B study drawings. Barring any final changes, these drawings are reasonable facsimiles of the proposed drainage facility and should clearly be appropriate documents for cost calculation. However, these drawings are prepared well into the basin planning process - at least two years from project authorization. If a community could use conceptual plans similar to Denver's Phase A plans or the proposed Initial Study plan as the cost calculation document, it could realize from 1 to 2 years of additional cost apportionment and land management. Clearly, this would constitute a significant gain for rapidly growing communities.

The writers devised a test to determine the reasonableness of using the proposed Initial Study plan as the cost calculation document. The test required two steps. In the first step, the writers assumed the appropriateness of using preliminary drawings similar to Denver's Phase B study drawings to estimate drainage facility costs. They then compared the cost estimates of these Phase B studies to the cost estimates prepared from the recommended conceptual drainage plans of the Phase A studies. In the second step of the study they examined the cost estimate ratios of various conceptual drainage plans to determine the possible relationships of the recommended conceptual alternative to the plan of the proposed Initial Study. The data used for both steps comes from 8 completed (Phase A and Phase B) master drainage studies in the Denver region.

Step I - Table III-1 lists the estimated construction costs of the recommended Phase A drainage plan and the estimated construction cost of the Phase B plan. It should be noted that the Phase B plans were, in all cases, conceptually similar to the recommended Phase A plan.

The disparities in the Phase A and Phase B cost estimates can generally be accounted for by either changes in the scope of work or in the detail of the cost estimate. The mean and standard deviation of the cost estimate ratios listed in Table III-1 are 1.15 and 0.41 respectively. That is, the Phase B estimates were, on the average, 15% higher than the Phase A estimates and there is a 90% chance that the Phase B estimate will be within 0.90 to 1.4 times the Phase A estimate. In considering the construction industry and the 20-40% contingency factors employed in that industry, the cost calculation differences do not appear that significant. A cost estimate that has a good chance of being

TABLE III-1

Comparison of the UDFCD's Phase "A" and Phase "B" Study Estimates

Basin	Phase "A" Estimate	Phase "B" Estimate	ENR Index Ratio	Adjusted Phase "B" Estimate	Ratio Phase "B" Est. / Phase "A" Est.
1973					
Big Dry Creek I	2,399,600	1,846,700	.97	1,791,300	.75
So. Boulder Creek	1,707,000	3,120,000	1.00	3,120,000	1.83
1974					
Niver Creek	2,900,000	2,526,350	.98	2,475,820	.85
1975					
Big Dry Creek II	--	--		--	1.00
Hidden/Bates Lake	592,400	649,500	.97	628,250	1.06
First Creek	1,442,000	2,290,000	.97	2,219,650	1.54
1976					
SJCD	495,744	389,150	.92	358,110	.72
1977					
Westerly Creek	8,300,000	13,190,400	.92	12,165,900	1.47

Mean:	1.15
Std. Dev.:	.41
90% Confidence Interval:	.86-1.45

within ± 30% of the actual construction bill would be acceptable. Thus, the data in Table III-1 indicate that the recommended Phase A plan should also enjoy the status of a reasonable cost calculation document.

Step 2 - Table III-2 lists the cost estimates of the various Phase A alternative plans whose benefit to cost ratio is greater than 1, and compares them to cost estimate for the recommended Phase A plan and the Phase B plan. The cost estimate comparison is not encouraging. Clearly, serious economic consequences (either under or over apportionment) could result if the wrong Phase A alternative plan was studied during the proposed Initial Study Phase. The writers feel, however, that the likelihood of this occurring is small. A drainage planner familiar with the study basin and the political and social climate of the controlling jurisdictions is more likely to identify and examine a plan that is conceptually similar to the recommended Phase A alternative and, ultimately, the Phase B plan. If this assumption is accepted, then the proposed Initial Study plan should be recognized as a reasonable planning approach for calculating drainage facility costs. If this assumption is not accepted, the proposed Initial Study plan can still be used for cost calculation by modifying the cost apportionment/rebate provisions of the drainage management program discussed in the later sections of this chapter.

The writers recommend that this alternative cost calculation method be used in the Financial element of the drainage management program. The significance of the abbreviated planning approach has been stated earlier. An urbanizing community has a limited amount of personnel and financial resources for developing a drainage management program. This simplified,

TABLE III-2

Comparison of the UDFCD's Recommended Phase "A" and Other Phase "A" Study Estimates

Basin	Recommended Phase "A" Estimate	Other Phase "A" Estimates (BCR ≥ 1.0)	Ratio Other/Recommended	Adjusted Phase "B" Estimate	Ratio Phase "B"/Other Phase "A"
Niver Creek	2,900,000	420,000	.14	2,475,820	5.89
		3,380,000	1.17		.73
First Creek	1,442,000	2,568,000	1.78	2,219,650	.86
		2,822,000	1.96		.79
Westerly Creek	8,300,000	4,957,088	.60	12,165,900	2.45
		8,891,777	1.07		1.37
		11,416,793	1.38		1.97
		Mean:	1.16		1.88
		STD. DEV.:	.64		1.87
		90% Confidence Interval:	.65-1.66		.40-3.36

yet rational, technique will allow the community to study the entire city in less time and at a much lower cost than existing techniques. The obvious advantage of studying the entire city for less money and in less time is that the urbanizing community can readily establish a city-wide drainage management program. This city-wide management program will insure that drainage-related standards are consistently applied in actions on developments throughout the city. These advantages and the numerous uncertainties associated with any cost estimate justify the use of the alternative cost calculation method. The method is not arbitrary or capricious and should, therefore, withstand judicial review.

Effectiveness of the recommended cost calculation technique - The effectiveness of the recommended planning procedure for calculating project costs can be illustrated by estimating the savings in time and money expected when using those procedures. The cities of Lakewood and Thornton, Colorado -- two suburban communities outside of Denver, Colorado -- were used to illustrate the expected savings. The characteristics of the two cities listed in Table III-3 were provided by city personnel.

The recommended planning procedure was compared with the Urban Drainage and Flood Control District's state-of-the-art method of master drainage planning. As stated before, their method takes about two years to complete and costs about $2,000 to $6,000 per mile. If we assume an average value of $4,000 per mile, then the master planning costs for the entire city of Lakewood would be $140,000; for Thornton, the costs would be $49,000. These cities would have to expend this money and wait a minimum of two years before any management of development-induced drainage impacts could begin.

TABLE III-3

Some Characteristics of the Cities of Lakewood and Thornton, Colorado

CHARACTERISTICS	LAKEWOOD	THORNTON
Area	51 mi^2	18 mi^2
No. of Major Basins	7	7
Average Length of Basin	5 mi	1 3/4 mi
Estimated Development Growth Rate (Past 10 Years)	6.5%	14%
Current Flood Control Financing	- General fund financing for major flood control works - No special assessment districts and no fees apportioned to new developments for these major drainage facilities - Developer responsible for on-site improvements only	- General fund funancing for major flood control works - No special assessment districts and no fees apportioned to new developments for these major drainage facilities unless the development will discharge more than the historic runoff - Developer responsible for on-site improvements and for discharging no more than historic runoff
Annual Budget (1978)	$30,000,000	$10,000,000

The recommended planning procedures would enable these cities to begin management about one and a half years earlier and at about 25-35 percent of the above-estimated master planning costs if the base information (maps, projected growth, etc.) was available.[19] That is, these cities could begin city wide management of development-induced drainage impacts within six months and at an estimated planning cost of $42,000 for Lakewood and $15,000 for Thornton.

The importance of this savings in time and money cannot be over-emphasized. A rapidly urbanizing city needs a program for manageing development-induced drainage impacts, yet they generally cannot afford to front end the money required for preparing final Master Drainage Plans for every basin within the city. The city under these circumstances either ignores the drainage problems or establishes a rather arbitrary drainage management program. The recommended planning procedure will stop these actions. The procedure will allow cities to quickly establish a rational drainage management program at a relatively low initial cost.

Project Cost Apportionment

Legal issues - The particular method of allocating project costs is a matter under legislative control and not normally subject to judicial overrule. Unlike Project Cost Calculation methods, cost allocation methods have been examined by the courts. The judiciary has, on a number of occasions, found legislative impropriety in apportioning project costs. Three questions have been raised regarding cost apportionment methods. They are:

1) Do the benefits of the project have to be greater than the costs of the project?

2) Do all benefits have to accrue to the area being assessed?, and

3) What is a "proper" apportionment of costs?

Benefits greater than costs - A common element noted in the various legislation that authorize the establishment of improvement districts (including drainage districts) is the requirement that the costs of constructing the improvement shall not exceed assessed benefits. The courts have consistently upheld this requirement. Unfortunately, the term "benefit" is generally not specifically defined within the authorizing legislation, and the courts have had to interpret the legislatively implied definition of "benefit." The resultant broad range of interpretations makes it difficult for a municipal government to estimate project benefits. A standard interpretation is needed to insure the proper and consistent identification of the special and general benefits that can be included in a computation of project benefits and the relative weights of each. Such a breakdown has recently been developed but its use has been limited to the allocation of project costs financed through assessment districts (85).

Benefits accruing to assessed area - In addition to demanding that the benefits of a project are greater than its costs, the authorized agency (district, municipal government, etc.) must insure that the proposed drainage project especially benefits the area to which the cost assessments are made. A California court in City of Buena Park vs. Boyar upheld the collection of a drainage fee which was to be used expressly for a drainage project that would benefit the development to which the fee was assessed.[20] In addressing an earlier California case (Kelber vs. City of Upland)[21] where the court held a similar drainage fee invalid, the *Boyar* court differentiated the two cases stating that, "...in *Kelber vs. City of Upland*, the city (of Upland) could use the collected fees *anywhere* in the city..." (emphasis added).[22]

This requirement for "special" benefit has similarly been upheld in a number of different situations. In *Duncan vs. St. John Levee and Drainage District* for example, the court found that delinquent payments on bonds issued for a certain portion of a drainage district -- with separate and distinct benefits accruing to it -- *cannot* be paid back with money collected from bonds issued over the other portions of the district.[23] The court stated that this would amount to taxing property for benefits that did not exist, and that, "any attempt by taxing authorities to impose a burden without a compensating advantage is power arbitrarily exerted, amounts to confiscation and violates the due process provisions of the 14th amendment."[24] This citing of Constitutional quarantees is prevalent in improvement district cases and appears in a case dissolving a drainage district. The court, in *Thibault vs. McHaney*, in determining the amount of authorized claims against the district states, "...from *Kirst vs. Street Improvement District No. 120*:[25] 'Special assessments for local improvements find their only justification in the peculiar and special benefits which such improvements bestow upon the particular property assessed. Any exaction in excess of the special benefits is, to the extent of such excess, taking of property without compensation.'"[26]

Proper apportionment of costs - The law regarding the equitability of a particular cost recovery program is clear; the courts have universally maintained that an assessment program or cost recovery program is a matter under legislative control and not normally subject to judicial overrule. In Luckehe vs. Reclamation District No. 2054, the courts affirmed an assessment for cost recovery and maintained that "... the formation of a reclamation district is a legislative act carried out in the exercise of the police or taxing power of the state."[27] The importance of legislative authority in this area is also expressed in Funkhouser vs. Randolph in which the court found that a law providing for the organization of the Little Wabash River Drainage District was void because it directed the county court to "decide legislative questions," namely, the extent of the district, who benefits, etc..[28] In still another case, Reclamation Board vs. Chambers, a California court in determining the legality of the state appropriating money from the general fund for payment to a reclamation district explained:

> "The method of paying for the same (drainage works) is solely a matter of legislative discretion. The state, if it elects, may pay all the costs, or place the same upon the land specially benefited by the work, or it may in its descretion divide the burden between the landowners and the state in such proportions as the state may deem equitable" (emphasis added).[29]

The courts, however, have recognized the problems with this "blanket" legislative authority and have warned that the judiciary can invalidate legislative actions in this area if there is a clear indication of legislative impropriety. Unfortunately, the courts have given varied interpretations of legislative impropriety. In Hurley vs. Board County Commissioners of the County of Douglas, the Kansas Supreme Court maintained that a sewer assessment scheme (equal acreage charge throughout service area) based on "equal benefits" is not proper since all lands within the district are simply not benefited equally.[30] The assessment was ruled "unjust, unreasonable, discriminatory, and grossly disproportionate to the benefits received." In this case the action by the administrative body that should have been "conclusive on property owners and courts," was nullified because it was not "fair, just, and equitable".

In contrast to the Hurley case, the Kansas Supreme Court in City of Wichita vs. Robb upheld a state law which apparently taxed landowners for costs associated with drainage works within the Arkansas River Basin who would not enjoy any direct benefits.[31] The court ruled that "...the legislature may exercise its discretion in fixing a taxing district for drainage or flood control projects, and its action in so doing is not open to judicial inquiry unless it is wholly unwarranted and a flagrant abuse and by its arbitrary character is a mere confiscation of particular property."[32] The court relied heavily on the "general" benefit principal stating that, "...benefits to a taxpayer conferred under a drainage and flood control project may be direct or tangible, or they may be indirect and intangible where they redound to the benefit of the whole taxing district in which he is a taxpayer."[33]

A Florida case further illustrates the variety of interpretations of legislative impropriety. In Board of Supervisors of South Florida Conservancy District vs. Warren, Governor, the Florida Supreme Court affirmed the assessment of benefits to the plaintiff who claims that his lands were not benefited in any way by the reclamation project.[34] The court acknowledged that the plaintiff had constructed, on his own, certain on-site structures for reclamation but that the benefits of the assessment project in question go beyond simply direct benefits to particular parcels. The dissenting opinion, however, places significantly more weight on the criterion of "special" benefits, and disagrees with the reasonableness of the assessment to plaintiff's property. The opinion feels that the facts of the case support a holding that the assessment was an abuse of legislative discretion![35]

In this area of case law is the additional question of whether over apportionment of facility costs with provision for payback is proper. Urban drainage and flood control facilities, like other parts of the urban infrastructure, must be built in fairly large units to take advantage of scale economies. The hydraulic considerations generally dictate that these drainage units be constructed sequentially from the downstream end. In addition, it is wise to build these drainage facility units during periods of construction activity in the area. This prevents undue social and environmental disruption as well as unnecessary demolition and reconstruction of structures adjacent to the drainage facility.

For these reasons, it is sometimes practical for the municipal government to get a needed drainage facility built during the construction of an approved development. However, where does the construction money in excess of the developer's responsibility come from? There are two sources:

1) The municipal government shares the cost of construction with the developer at the time of construction.

2) The developer pays for the entire facility desired by the municipal government and the municipal government pledges to reimburse him in a timely fashion, for money spent in excess of his share.

The problems with the first approach stem from disagreement regarding the proportionate share of costs that each actor should bear. This was addressed in an earlier section of this chapter and does not concern us here. The problem with the second approach is that the developer is forced to provide front-end money for the construction of a needed facility. The legal basis for requiring this front-end money was questioned in <u>Wood Bros. vs. City of Colorado Springs</u>.[36] In this case, Wood Bros. sought relief from a condition of final subdivision plat approval. The condition required Wood Bros. "...to advance or guarantee payment of $292,000 as font-end money for the construction of a major drainage channel..." located near their proposed subdivision.[37]

The district court acknowledged that the city's ordinances allowed them to "...collect funds for construction of drainage facilities from subdevelopers as a condition of plat approval,"[38] but ruled that in the instant case the city had improperly interpreted them. They ruled that the city's interpretation of its ordinances was "...unconstitutional because it authorized 'a taking of private property for public purpose' without just compensation or due process of law."[39]

The court also ruled that "...the unconstitutionality of the city's interpretation was not remedied by the rebate ordinance, which was itself unconstitutionally vague and indefinite."[40]

On appeal, the Colorado Supreme Court affirmed the lower court's ruling that the city had exceeded the authority granted in the ordinances. The Supreme Court's ruling is instructive. It seems to set out certain ordinance additions that would have helped in the city's defense. The court states that:

> "No language in the ordinances requires a developer, under the facts here, to bear the entire cost of improving existing facilities or constructing new facilities which serve an area far greater than the subdivision. The credit provision of the ordiances does not remedy this attempt to coerce Wood Bros. into financing a currently needed project of general benefit. At best, the credit provision furnishes a long-postponed remedy, uncertain of performance."[41]

The writers feel that the result of the case would have been different under an improved Colorado Spring's ordinance. The improvements would be:

1) Specific language that addresses the hydraulic and construction considerations of drainage and flood control facilities, and that authorize the city to require front-end money for the construction of logical flood control segments, and

2) The creation of a viable payback mechanism that insures developer reimbursement within one year of cash outlay.

The importance of ordinance language is also illustrated in Baltimore County vs. Security Mortgage Corp..[42] In this case, the county was requiring Security Mortgage Corp. to share in the cost of a bridge and culvert for a street on which the subdivision was located. Security's complaint was based on the fact that the bridge was beyond the sudivision boundaries and on another's property. The court granted relief to Security in ruling that the regulations did not give the county authority to impose that kind of cost sharing.

Existing cost apportionment methods - The previous review of case law, indicates the court's willingness to distinguish between special and general benefits of drainage projects. Unfortunately, the distinction of what constitutes a special or general benefit is far from clear (see Refs. 40 and 85 for additional discussion and analysis). To be sure, most urban drainage and flood control projects provide both types of benefits which creates a spectrum of viable cost apportionment methods.

At the one end, urban drainage and flood control is viewed as a community service that benefits the general public. No liability is recognized for development-induced drainage impacts. As such, the total project costs are paid by the public at large. This payment takes the form of general revenue bonds supported by special or general taxes (12), or monthly "service" fees for construction and maintenance of needed drainage facilities (90). The attractiveness of this alternative is its administrative simplicity. Its drawback is that an urbanizing community is essentially subsidizing growth. The general public is paying for the facilities that new developments are requiring. Whether this subsidy actually promotes growth or not is questionable. The alternative does reduce development costs which in turn reduce housing costs assuming an inelastic demand. However, the community taxing structure is high which might reduce the desirability of the community and, in turn, growth. Regardless of this counter-balancing, the incidence of the facility costs does not rest with the true beneficiaries and the alternative is not equitable.

At the other end of the financing spectrum, urban drainage and flood control is viewed as strictly the responsibility of the developer. The facilities have become necessary due to developments within the basin that have altered existing hydrologic patterns and should, therefore, be paid for by those producing the changes.

There are a number of cost apportionment formulae based on this developer responsibility principle. One of the simplest is prorating the total project cost by land area (90). The project cost is divided by the number of acres in the basin and developers are then assessed an acreage fee for drainage. This apportionment formula has been expanded to include land use. The rationale is that denser development will have a greater impact on the hydrologic response than will less intense development. Dague (22) has gone further to develop a detailed hydrologically sound apportionment formula that is based on the major physiographic features that affect runoff response.

These formulations are more difficult to administer but are more equitable than the general benefit financing alternative. They cause the developer to internalize the impact costs of his development. This will cause an increase in housing cost as the developer passes on his increased developmental costs. Interestingly enough, the impact of this increased housing cost on community growth might be tempered by the fact that it should be cheaper to live in that community. The community is not paying for drainage facilities from the general fund, therefore the local taxes should, in theory, be lower.

Based on the problems with these extreme approaches and on the previous discussion of municipal and developer responsibility, the writers favor a middle of the spectrum apportionment method. A portion of the project costs should be allocated to the municipal government and a portion to the developer. This approach requires a division of total project costs in proportion to the responsibility of the municipal government and the developer. Once divided, the project costs can be allocated within each of the two groups by the extreme approaches discussed above.

In addition, the writers suggest that the uncertainties of project cost estimates and the need for some developer construction, demand some kind of adjustment procedure for over and under apportionments. The success of the Financial element rests on how effective the local government is in generating front-end money, and how prompt it is in reimbursing it. Without the front-end money, the local government cannot readily construct needed facilities, and without proper reimbursement it leaves itself open to judicial attack. It is surprising that very few apportionment methods allow for adjustment in light of the fact that apportionment errors will be the rule rather than the exception.[43]

Recommended division of project costs - General - The recommended division of project costs is based on the benefits that accrue to the municipal government and to the developer. These benefits have been described by Grigg (40) and can be grouped into two categories -- reduced liabilities and non-quantifiables (see Table III-4).

The non-quantifiables are generally community-wide aspects of urban drainage and flood control. They are not measurable in economic terms but are nevertheless important. In many cases, decisionmakers will attach a strong weight to these non-quantifiables and will recommend that an economically poor project (BCR is less than 1) be built.

Reduced liabilities are measured as the reduction in average annual damages from the basin damage-frequency curves. These damages include all measurable damages attributable to flood discharge such as damages to structures, erosion damages, and clean-up costs (see reference 40 for further discussion). Losses in economic rent should also be included as a measurable damage but these losses are substantially affected by flood plain zoning practices. If a municipal government is able to exercise its police power authority to limit development within a designated flood plain zone, then there is no "legal" loss of economic rent. That is, the property being zoned has not been damaged in a legal sense. Therefore, neither the municipal government nor the developer is liable for the loss in economic rent caused by increases in stormwater flow within the delineated flood plain zone.

TABLE III-4

Benefits of Drainage and Flood Control Facilities

Grigg's Classification*

General Benefits:

1. Reduction of damage to public property
2. Reduction of drainage induced maintenance problem
3. Prevention of life loss
4. Alleviation of health hazards
5. Aesthetic improvements
6. Provision of recreational opportunities
7. Improved public convenience

Special Benefits:

1. Reduction of damage to private property
2. Reduction of drainage liability caused by property development
3. Improved land values

Writer's Classification

General Benefits:

A. Reduced Liabilities

    1. Reduction of damage to private and public property caused by existing development
    2. Reduction of drainage liability caused by existing development
    3. Reduction of drainage induced maintenance problems caused by existing development

B. Non-quantifiables

    1. Prevention of life loss
    2. Alleviation of health hazards
    3. Aesthetic improvements
    4. Provision of recreational opportunities
    5. Improved public convenience
    6. Improved land values

Special Benefits:

A. Reduced Liabilities

    1. Reduction of damage to private and public property caused by new development
    2. Reduction of drainage liability caused by new development
    3. Reduction of drainage induced maintenance problems caused by new developments

*See reference (40)

The writers suggest, however, that municipal governments should be cautious of their flood plain zoning practices. They feel that in certain instances flood plain delineation may constitute a "taking" of private property making losses in economic rent a valid flood discharge damage. This damage, in turn, makes it necessary to include the cost of rights-of-way and easements when estimating project costs.

The situation contemplated is illustrated in Figure III-2. Property A represents development existing within the basin before the city exercised developmental control over that basin. All of the developments are outside of the historic 100-year flood plain. Subsequent to the city's exercise of development control a number of developments have been approved and constructed. These developments (Property B) have caused an enlargement of the flood plain. This existing 100-year flood plain is further enlarged by future development (Property C) to the ultimate 100-year flood plain. The enlargement of the flood plain from historic to ultimate is a direct result of municipal government and developer actions. It is hard to justify zoning of private property for the benefit of later developments. The developments that have taken place in the basin and the municipal government in approving those developments have caused an enlargement of the historic 100-year flood plain. They should be answerable to that "taking" of private property.

In keeping with Grigg's classification, the benefits of a flood control facility that accrue to the developer will be referred to as "Special" benefits. They consist of the reduction in liability for his specific development-induced drainage impacts. The municipal government's benefits will be referred to as "General" benefits. These benefits consist of the reduction of liability for drainage impacts caused

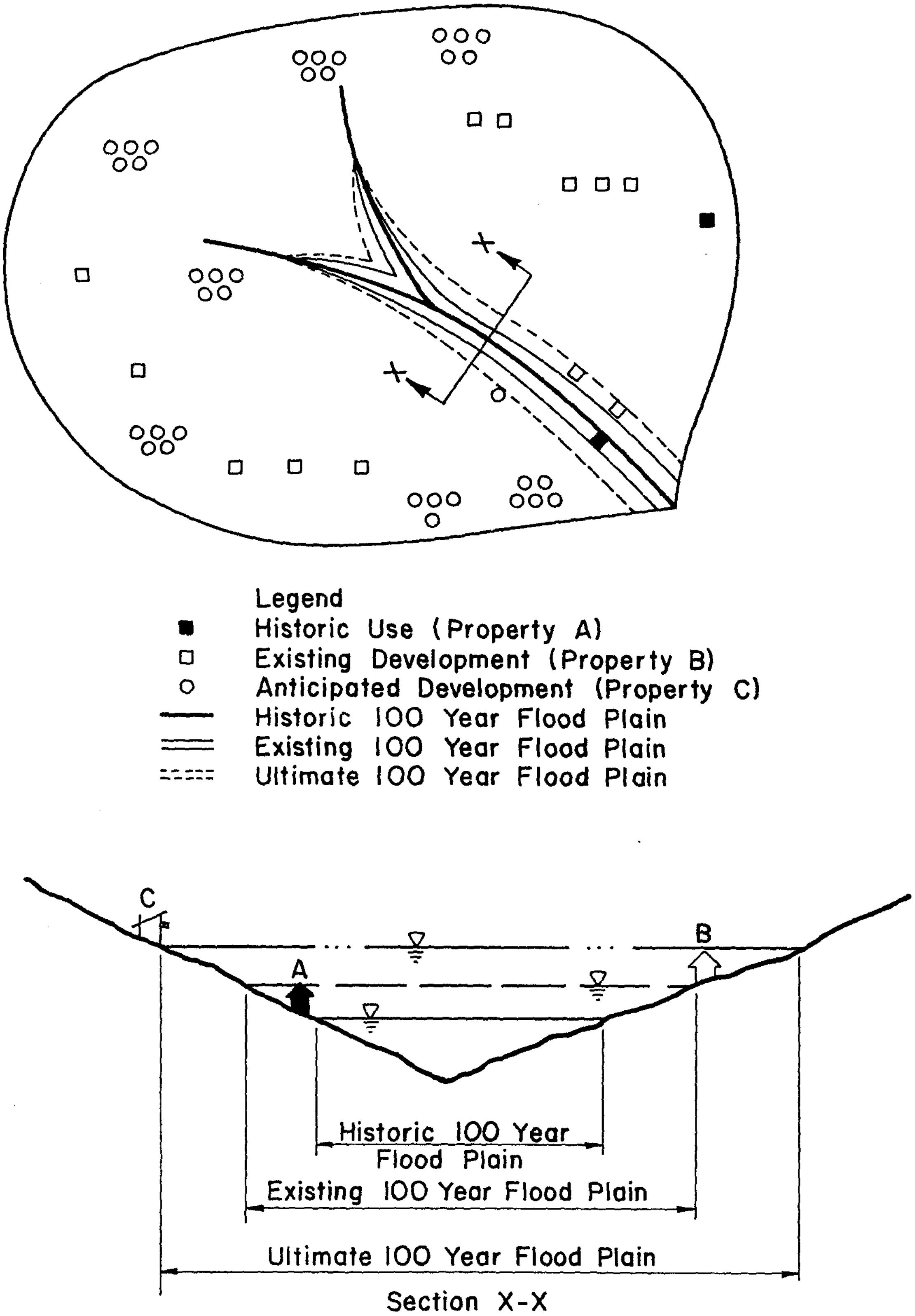


Figure III-2. Development-Induced Impacts on the Flood Plain Limits.

by past actions such as subdivision and annexation approvals, and the non-quantifiables that benefit the general community. In this classification, the writers lump reduced liabilities with reduced damages since one property's reduced damage is either the municipal government's or the developer's reduced liability. This, of course, is not the case if the property lies within the historic 100-year flood plain. In addition, "improved land value" was moved from the special to the general benefit category. The writers feel that the market system will not adequately recognize individual increases in land value and that this aspect of drainage control is more a non-quantifiable benefit that accrues to the entire community.

Procedure for dividing project costs - The following procedure outlines the method for dividing the project costs into the special and general portions. The procedure begins after a basin plan similar to the Initial Study Phase plan described earlier in this chapter has been formulated. At this stage, there is sufficient information to estimate the cost of the project and to construct the following four damage-frequency curves shown in Figure III-3 (see ref. 40 for specifics on constructing these curves):

1) Ultimate development without new drainage facilities (U1).

2) Existing development without new drainage facilities (E1).

3) Ultimate development with new drainage facilities as outlined in the basin plan (U2).

4) Existing development with new drainage facilities as outlined in the basin plan (E2).

Step 1 - Calculate average annual damage reduction (AADR) of the project.

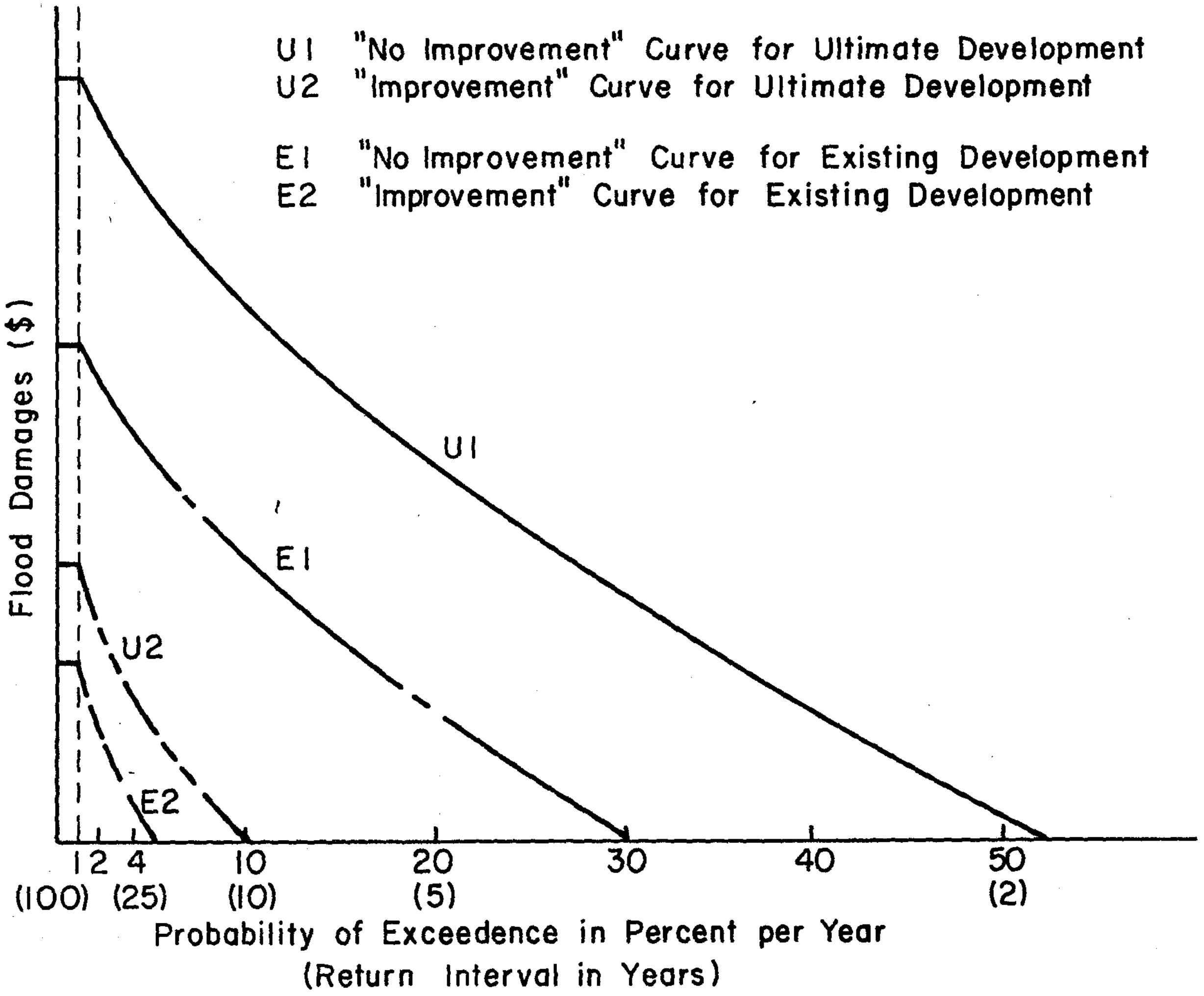


Figure III-3. Sample Damage-Frequency Curves Generated From the Initial Drainage Study.

The economic benefit of a drainage project is computed as the average damage reduction expected each year (or AADR) after the project is constructed and after the basin reaches ultimate development. It is the area in Figure III-3 between the U1 and the U2 curves.

Step 2 - Calculate special benefit portion of project (B_S). The special benefit portion of the project is the reduction in liability for development-induced impacts. It is the AADR measured for ultimate development without new drainage facilities to the existing conditions. It is the area in Figure III-3 between the U1 and the E1 curves.

In earlier sections of this report the writers stated that both the municipality and the developer were responsible for increased damages due to new developments. This implies that the AADR from curve U1 to curve E1 is a benefit to both, and each should contribute in proportion to that benefit. The writers feel that the municipal government is contributing its portion of this benefit by implementing and administering the drainage management program. That is, the municipal government's responsibility is taking positive management actions to mitigate development-induced drainage impacts. For this reason, the entire area between curve U1 and curve E1 is assigned as special benefits attributable to new developments.

Step 3 - Calculate general benefit (B_G). There are two elements of the general benefit. The first is the reduction in liability that the community has incurred through past actions of its elected officials. This element is the AADR from existing conditions to the conditions that existed when the municipal government began exercising authority over land development. This latter condition might be difficult to ascertain and the writers suggest that a practical substitute for it is the existing conditions with the new drainage facilities. The AADR measured from curve E1 to E2 in Figure III-3 reasonably establishes the portion of the new facility that reduces municipal responsibility.

The second element of general benefit is the non-quantifiable aspects of urban drainage and flood control facilities. These are important in dividing project costs when the benefit to cost ratio (BCR) of a viable project is less than 1.

Step 4 - Compute special and general fractions of project cost.

a) BCR is greater than 1. When the BCR is greater than 1, the sum of the special benefit and the general benefit will be greater than or equal to the total project cost (C_T). That is:

$$B_S + B_G = B_T \geq C_T \tag{40}$$

where

B_T = sum of the special and general benefits.

Therefore:

$B_S/B_T = F_S$ = special fraction of project cost

and $B_G/B_T = F_G$ = general fraction of project cost.

Thus, the cost allocated to developers (C_S) is:

$$C_S = (F_S)C_T \tag{41}$$

and the cost allocated to the general fund (C_G) is:

$$C_G = (F_G)C_T \quad . \tag{42}$$

b) BCR is less than 1. In this case, the project is viable only with the addition of the non-quantifiable element of the general benefits. This element is assigned a minimal economic value to equitably divide the project costs. To calculate the special and general portions in this case, the BCR is expressed in the following form:

$$B_T/C_T = 1 - R \tag{43}$$

where R = the non-quantifiable fraction of project benefit to economically justify the project, and

B_T, C_T are as defined above.

Expanding and rearranging equation 43 yields:

$$B_S/C_T + (B_G + RC_T)/C_T = 1 \tag{44}$$

From equation 44, we see that

$$B_S/C_T = F_S \tag{45}$$

and

$$\frac{B_G + RC_T}{C_T} = F_G \quad . \tag{46}$$

The cost allocated to the developers (C_S) and to the general fund (C_G) are as before:

$$C_S = (F_S)C_T \tag{47}$$

$$C_G = (F_G)C_T \quad . \tag{48}$$

Recommended apportionment adjustment method - There are two purposes for an apportionment adjustment method. First, to adjust for the cost of construction work done in lieu of drainage fee payment; and second, to adjust for poor estimates of project cost.

Construction work adjustment - This "adjustment" is necessary when the construction of a logical flood control segment is desired. The developer constructs the desired facility at a cost greater than or less than his computed responsibility for development-induced drainage impacts.

The case of underspending by the developer for the desired facility is probably rare. Nevertheless, the Financial element of the drainage management program should address the possibility. It should insure that the developer's total expenditures -- off-site facility construction plus drainage fees -- is equal to his computed share of drainage facility costs.

The case of overspending by the developer is more typical. Proper adjustment in this situation is critical as illustrated by the Wood Bros. vs. City of Colorado Springs case. The Financial element of the drainage management program must create a viable payback mechanism to avoid constitutional attack. There are three sources of funds for payback and the writers suggest that they be utilized in the following order:

1) The basin fund.
2) Other basin funds.
3) The general fund.

Each basin within the city will have its own fund. This insures that money contributed by a developer will be spent in the basin where the development occurred. However, the drainage facility needs of each of these basins will be different. Some of the basins may be able to accommodate growth for a number of years without appreciable damage, while others are already experiencing serious flooding problems. This characteristic allows a basin to borrow money from other basin funds for construction of a facility in that basin. The other basin funds are paid back with contributions from developers building in the basin where the facility was installed.

The final funding source for construction adjustment is the general fund. If there is not enough money in the general fund to reimburse the developer during the current year, then the local government must appropriate the necessary money to insure adjustment within a reasonable period of time. The writers suggest that the appropriation be made for the following fiscal year. Again, the general fund would be paid back by contributions from developers in the basin that borrowed the money.

If the municipal government cannot guarantee a timely reimbursement, then they have two options -- do not require the construction or use the construction requirement as a growth management tool. The municipal government, under the dual liability concept, must insure that subdivision approval actions do not create serious new flooding problems or aggravate existing flooding hazards. If the municipal government is unable to guarantee timely reimbursement, then they must withhold subdivision approval until they can guarantee the reimbursement. As an alternative, the municipal government could approve the subdivision if the developer provides the needed facilities and agrees to extend the reimbursement period. This growth control approach is similar to the timed-development approach used in Ramapoa, N.Y.[44] It should be very effective in properly accommodating development-induced drainage impacts.

It is clear that the local government must prioritize urban drainage and flood control facilities. They cannot haphazardly approve subdivisions and require developers to construct desired flood control facilities. They must first take into account the amount of money in the other basin funds and the amount of money that can be pledged from the general fund.

<u>Poor estimate adjustment</u> - The estimated project cost will almost certainly never equal the actual project cost. This is true regardless of the detail of planning.

A low project estimate leads to under apportionment of project cost. The municipal government suffers in this case because it has not properly assessed the special beneficiaries of the project. It would be improper for the municipal government to begin apportioning a higher cost to developers in order to adjust for the estimate error.

This approach would destroy the credibility of the planning process and subject the Financial element of the drainage management program to an "arbitrary and capricious" attack. The municipal government must bear the responsibility for the poor estimate. Two options are available.

1) They can supply the additional money from the general fund. This approach is justified if there are non-quantifiable general benefits that were not accounted for in the division of project costs.

2) They can scale down the project to the level of funding available. This "fixed cost" approach has been discussed by Grigg (40) and is effective under severe monetary constraints. It should be noted that the division of costs would remain the same with this scaled down version. Thus, the apportionment of costs to developers would not become an over-assessment but would better reflect the proportionate benefits received for the costs paid.

A high estimate leads to overapportionment of project costs. However, in this day of cost overruns, overapportionment is generally unlikely and should not be accepted as such until all construction bills are paid. In the event of a true overapportionment, the municipal government may have assessed costs in excess of benefits received. Without some kind of adjustment, they leave themselves open to judicial attack. The only practical adjustment is a credit to the contributing properties for the excess apportionment. This credit can then be used against any future assessments for other public works improvements such as streets and parks, or for any improvement that the residents of the basin might desire.

Effectiveness of the recommended cost apportionment method - The recommended cost apportionment method is based on the shared responsibility of the developer and the municipal government to mitigate drainage problems. The method utilizes existing analysis techniques to divide drainage project costs between these two sectors in proportion to the benefits each receives from that particular project. In addition, the method insures that proper adjustments are made in the event of any apportionment errors. However, the underlying motivation for developing a drainage management program is to help municipal governments accommodate development-induced drainage impacts. This requires money and it is appropriate, therefore, to examine how effective the recommended cost apportionment method is in raising revenues for drainage facilities.

The effectiveness of the recommended cost apportionment method was determined by comparing hypothetical revenues it generates with revenues actually spent by local governments on drainage facilities. It was assumed that the amount of money spent by these governments represents the maximum amount available for drainage facilities. The writers feel that this is a reasonable assumption for the cities examined since they have identified flood control as a priority item.

The cities of Thornton and Lakewood, Colorado, were used for the comparison. The amount of money spent on drainage facilities was supplied by city personnel and is listed in Table III-5. The amount of money that could have been generated under the recommended cost apportionment method is computed from development information which was also supplied by city personnel.

From this information, the writers calculated that the average annual residential growth in the city of Lakewood between 1971 and 1977 was 343 acres per year. The average annual business and industrial growth was 113 acres per year. Based on drainage studies in Colorado

TABLE III-5

Drainage Facility Expenditures for the Cities of Lakewood and Thornton, Colorado*

	Lakewood (1971-1977)	Thornton (1973-1978)
1. Mapping, Planning and Engineering	475,733	292,400
2. Construction	2,112,861	442,600
3. Total	2,588,634	735,000

* Includes regional funds from the Urban Drainage and Flood Control District.

and California,[45] a reasonable drainage fee for these categories of land use might be $700/acre for residential and $1400/acre for business and industrial. Applying these drainage fees to past developments results in a generated revenue of approximately $3,000,000 from developers over a seven year period. If this money had been collected, there would have been twice as much money available for drainage and flood control.

Similar calculations for the City of Thornton over a six year period result in a generated revenue of $700,000. Again, if this money had been collected, the drainage and flood control funds would have almost doubled. The writers suggest that these examples illustrate the ability of the recommended financial element to generate revenues for needed drainage facilities. Further, the element creates a better cash flow position with regard to the city's drainage program. Money is collected at the time of development for drainage facilities that will be required because of the cumulative drainage impacts of all future developments within a particular basin. This money does not have to be spent immediately; it can be held in a fund until the drainage facilities within that basin are actually needed.

Recommended Financial Element of the Drainage Management Program

In the previous three sections of this chapter, the writers examine the legal issues concerning the Financial element of a drainage management program, and review existing techniques that could be used in financing drainage facilities. Based on this examination and review, the writers suggest the following:

1) There is a dual liability for development-induced drainage impacts. The developer is responsible because he actually constructs the houses and the roads that modify the hydrologic response of the

basin; the municipal government is responsible because it allows the development to occur through its actions on subdivisions, annexations, etc..

2) A reasonable drainage plan that can be inexpensively prepared in a relatively short period of time is an appropriate cost calculation document. Cost estimates universally are subject to a wide variety of uncertainties no matter how detailed the estimating document. The value of spending more time and money to obtain a "better" cost calculation document is questionable, whereas the value of quick management action in an urbanizing community is substantial.

3) Apportionment of project costs is generally under legislative control. However, to avoid judicial attack the financial component developed by the local government should insure that:

a) Project benefits are greater than project costs.

b) Project benefits accrue to the area being assessed.

c) The apportionment of cost schedule has a reasonable basis.

d) The regulation contains specific language regarding developer construction in excess of his responsibility.

e) A viable apportionment adjustment mechanism is developed.

The writers synthesize these suggestions into the recommended Financial element of the drainage management program. The financial element consists of a flow of decisions and money as illustrated in Figure III-4.

Cost apportionment - The flow begins with the preparation of a reasonable drainage plan. From this plan, the project costs are estimated and the special and general benefits are computed as outlined earlier. If the total benefits are less than the total costs, and the

COST APPORTIONMENT

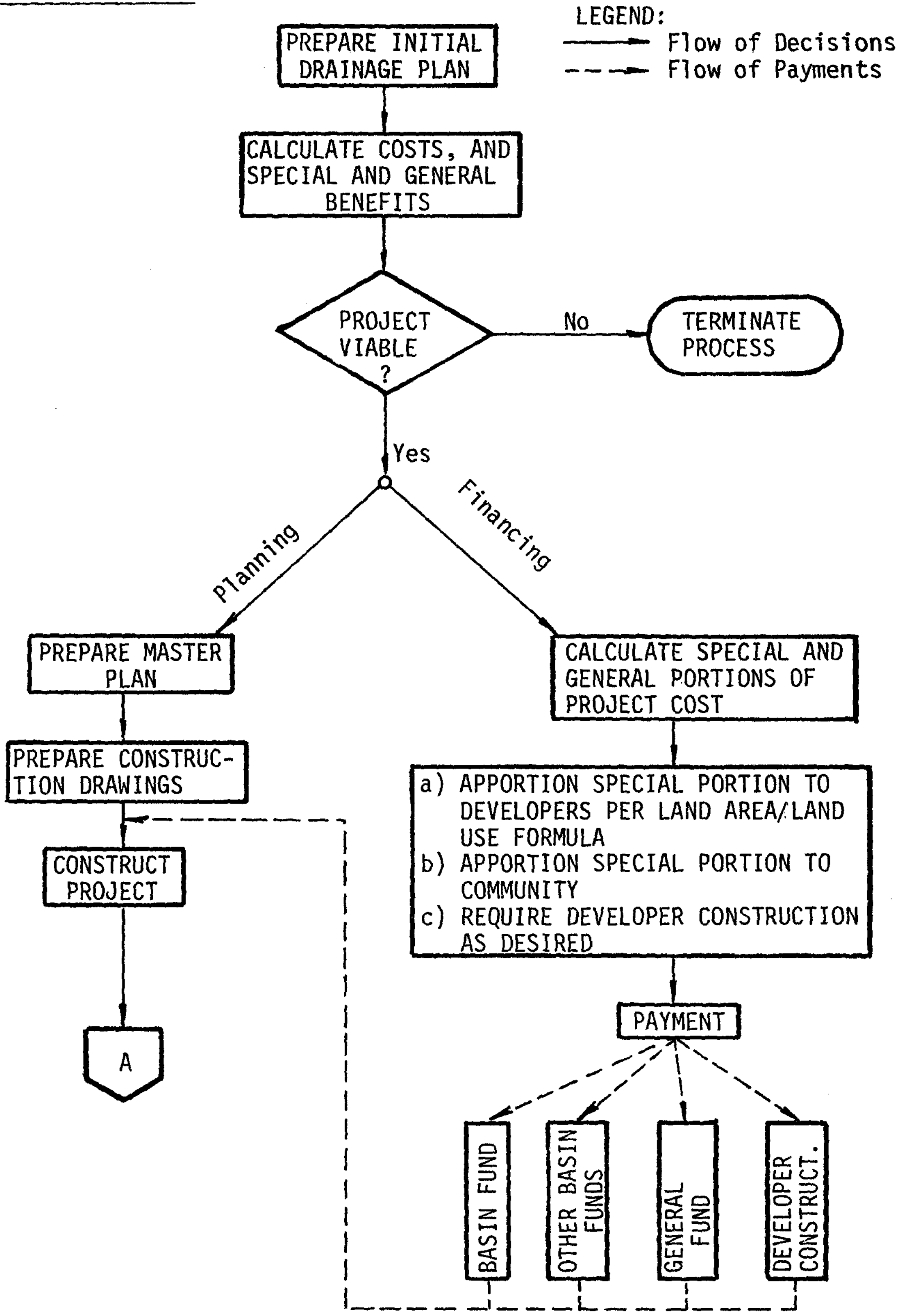


Figure III-4. Procedural Flow Chart for the Recommended Financial Element.

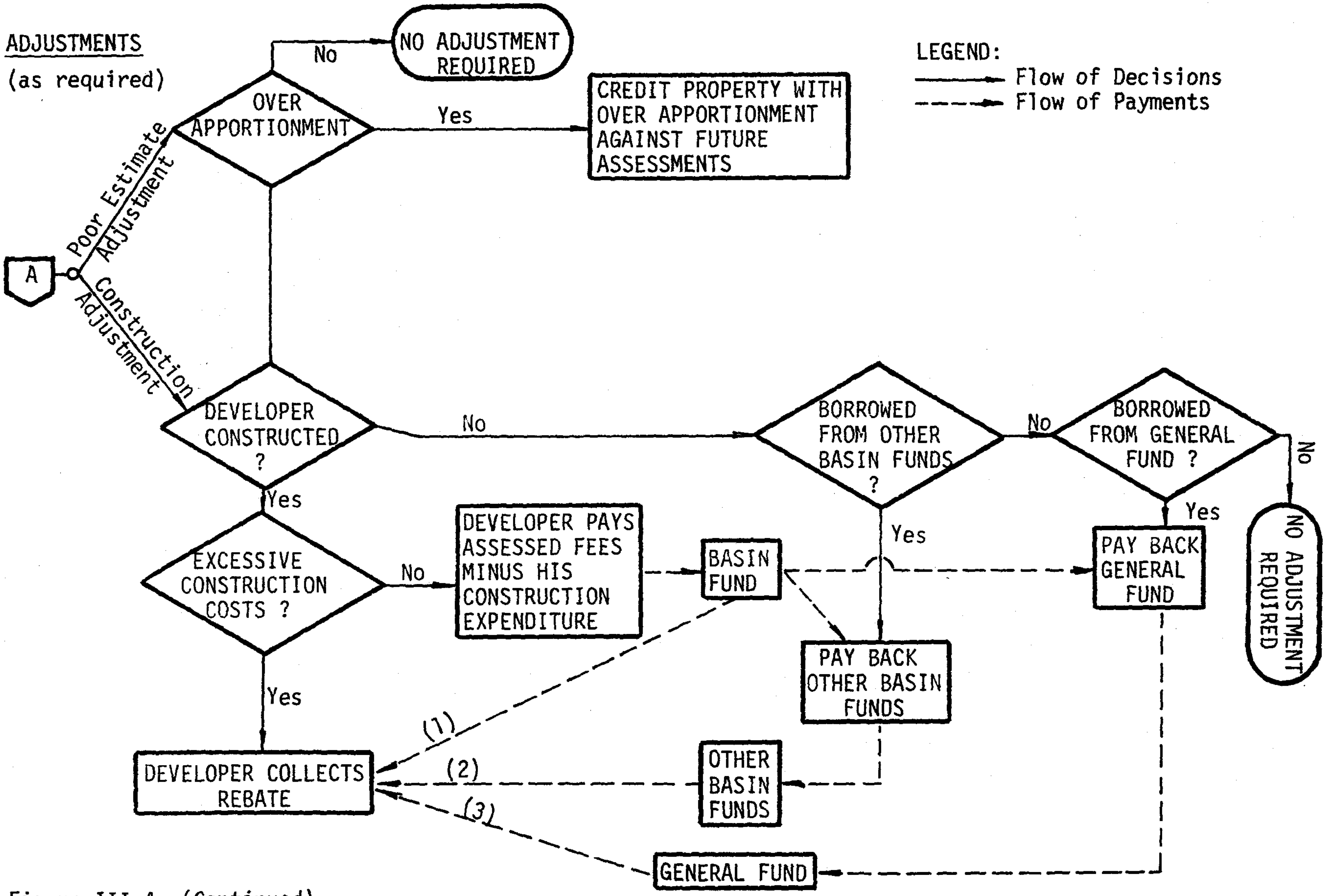


Figure III-4. (Continued).

non-quantifiables do not override the economic analysis, the project is not viable and the process is terminated. If the project is viable, the processing flow divides into financial actions and planning actions.

Financial actions

1) The special and general portions of project costs are computed using the procedure outlined earlier.

2) The general portion is apportioned to the community through encumbrances on the general fund, issuance of general obligation bonds, etc. (see Ref. 12 for a review of the various general financing alternatives).

3) The special portion is apportioned to developers as they request subdivision plat approval using any one of a number of allocation formulae (see Ref. 22 and 23). The writers recommend an allocation formula based on land area and land use. It includes the major hydrologic factors, yet is simple enough for easy computation and administration.

4) As an alternative or in addition to item (3), the developer may be requested to install some of the planned facilities during the construction of his development.

Planning actions

1) The master planning process continues for a viable project. The Alternative Plan Phase expands the Initial Study Phase to include alternative basin plans. The alternative plans are reviewed by the community and various agencies, and a recommended Final Plan is developed.

2) From the Final Plan, construction drawings of the basin facilities are prepared. These are let out for bid, a contract is awarded, and the project is constructed.

3) The funds for the construction of the project are generated from one or a combination of the funding sources shown on the financial side: the basin fund, other basin funds, the general fund, or developer construction funds.

Cost adjustment - The decisions for adjustments are divided into poor estimate adjustments and developer construction adjustments. The poor estimate adjustments consists of crediting properties with the over-apportionment. The developer construction adjustment consists of collecting additional fees from the developer or reimbursing him as necessary. The reimbursement comes from the basin fund, other basin funds, and the general fund, in that order. The adjustments also illustrate the reimbursement of the other basin funds and the general fund from the basin fund that had borrowed money from them.

The Financial element described above purposely places all of the burden of mitigating *past* development-induced drainage impacts on the local government. In recommending this approach, the writers avoid the need for the generally cumbersome and politically unsavory assessment districts. However, if a community is not averse to form assessment districts, the local government can use them as another funding source. The portion of total project cost assignable to assessment districts is based on the dual liability concept -- the developer and the municipal government sharing the responsibility for mitigating past development-induced drainage impacts. In this instance, however, the developer is represented by the homeowners. These owners paid less than the actual value of their home because the costs for reduced liability were never included. This cost is paid when the assessment district is formed.

The amount of total project cost assessed to the district is a fraction of the general portion. That is, the general benefit calculated as the AADR from existing conditions to existing conditions with the drainage facility is divided into a general benefit and a past special benefit. The division is arbitrary but controlled by citizen sentiment. The ratio of these benefits is then used to divide the general portion of project costs into a general and a past special portion. The general portion is assigned to the local government and the past special is assigned to the assessment district.

Effectiveness of recommended Financial element - The features of the recommended Financial element enable a community to quickly and inexpensively initiate a program for mitigating development-induced drainage impacts with confidence that the program is not arbitrary and open to judicial overrule. The element is based on an abbreviated planning procedure for calculating project costs and establishing a cost apportionment schedule. This abbreviated methodology can reduce the front end drainage planning costs by approximately 65-75 percent. This is a substantial reduction in light of the keen competition for municipal funds. The city's financial situation with regard to drainage management is further improved through the element's cost apportionment method. It generates revenues from developers as well as from the municipal government and can double the money available for drainage facilities.

These cash flow and financial advantages would be short-lived if the recommended Financial element did not have a firm legal foundation. This foundation stems from the legal analysis of development-induced drainage impact liability. The recommended Financial element uses existing project analysis techniques to divide the responsibility for mitigating drainage problems between the actors causing the impacts --

the municipal government and the developers. The element provides a method whereby a municipal engineer can confidently assign proportionate and equitable charges for drainage facility costs to these actors.

Chapter IV

REGULATORY ELEMENT OF THE DRAINAGE MANAGEMENT PROGRAM

In the previous chapters of this report, the writers discuss the Technical and Financial elements of the drainage management program. The advantages of the recommended elements will not be realized unless the program is packaged within an effective regulatory mechanism. Regulatory legislation that insures the consistent, equitable, and reasonable application of the recommended elements must be developed. The legislation must be carefully drafted to minimize the number of legal uncertainties that might subject the regulatory program to interpretative court actions.

In this chapter the writers review the authority of local governments to develop regulatory programs and review some of the United States' drainage regulations in effect today. From this review, the writers recommend two regulatory approaches for implementing the drainage management program. The concepts of drainage management under each approach are included in this chapter, and example legislation for each is presented in Appendix C.

Authority to Establish Drainage Control Programs

All of the modern drainage-related costs recovery programs find their origin in the early storm drainage and reclamation districts. These districts, affirmed in the courts, were based on the "police power" authority and the "power to tax" authority of the legislature. The "police power" authority is a right vested with a sovereignty to require owners of property to use their property only to the extent that such use does not preclude a neighbor's reasonable enjoyment in his land. This authority allows regulation, management, and control of private property to promote the general health, safety, and welfare of the community. The "power to tax" is a right similarly vested with a sovereignty to require the general public to pay for services that are rendered in the interest of the general health, safety, and welfare of the community.

Currently enforced municipal drainage ordinances account for the societal and environmental needs and desires that have grown over time. It cannot be ignored that these ordinances regulate and tax private property far more than the early drainage districts, yet they still rely on the "police power" authority for affirmation. The expansion of the "police power" authority required to support these ordinances has been upheld by the U.S. Supreme Court in Euclid vs. Ambler.[46] This case, establishing the general constitutionality of zoning, suggests the necessity of such expansion:

> Regulations, the wisdom, necessity, and validity of which, as applied to existing conditions are so apparent that they are now uniformly sustained, a century ago, or even half a century ago, probably would have been rejected as arbitrary and oppressive. Such regulations are sustained, under the complex conditions of our day, for reasons analogous to those which justify traffic regulations, which, before the advent of automobiles and rapid transit street railways, would have been condemned as fatally arbitrary and unreasonable. And in this there is no inconsistency, for while the meaning of constitutional guarantees never varies, the scope of their application must expand or contract to meet the new and different conditions which are constantly coming within the field of their operation. In a changing world it is impossible that it should be otherwise.[47]

As Platt has inferred, this expansion of the "police power" authority is not essential to justify drainage and flood plain regulations. He points out that the Euclidean zoning deals with the homogeneity and sanctity of use districts whereas flood plain regulations are "...intended specifically to save lives and property." (73) These purposes can only be construed to protect the public health, safety, and welfare. The writers have suggested in Chapter III that this relationship actually creates a municipal obligation -- an obligation that imposes a real dilemma for municipal governments. The municipal government must insure an adequate review of proposed developments and must impose requirements for the protection of the community welfare. But how much can the municipal government require before it constitutes a "taking"?

U.S. Drainage Ordinances

An answer to the above question can be inferred from a review of existing drainage regulations in the U.S. These drainage ordinances have grown from the "police power" and the "power to tax" authorities and from court decisions regarding other land management programs. They should represent a level of regulation that does not constitute a "taking" of private property.

For continuity, the writers will discuss the different elements of the existing ordinances separately.

Technical element - The ordinances reviewed address the technical element in two ways. The engineering techniques for estimating development-induced drainage impacts are either specified within the ordinance (Tampa, Florida) or within an engineering criteria manual referenced by the ordinance (Boulder, Colorado; Dekalb, Georgia; Fairfax, Virginia). This manual is generally developed and maintained by the Municipal Engineer.

As might be expected, the recommended engineering techniques vary from the simple conceptual rainfall-runoff models to the more detailed physically-based ones. However, only the larger municipalities are attempting to use the detailed models. The small, to medium sized communities are universally employing forms of the Rational Method in combination with a unit hydrograph method. Interestingly, the use of the simpler Technical element is not limiting the municipal governments to simple Financial elements. Colorado Springs, for example, bases its cost apportionment method on engineering calculations using the Rational Method and the SCS Hydrograph Method.

Financial element - The Financial element of the drainage ordinances consists of the drainage-related requirements imposed upon builders and developers through the ordinance. As with the Technical element, there are a variety of financial requirements imposed by the different ordinances. At one end of the spectrum, there exist drainage ordinances that deal only with new development, and at the other end there exist drainage ordinances that permit drainage control and management over all phases of development (from raw undivided land to existing populated areas). A review of all of these ordinances suggests dividing a particular ordinance into two portions for ease of discussion: one portion that deals exclusively with requirements imposed upon developers and builders (New Development), and another that deals with requirements imposed upon owners of already subdivided land (Existing Development). As implied above, not all drainage ordinances will necessarily contain both portions.

A. New development - All of the existing ordinances reviewed set some requirement for drainage within a proposed new development. Some of them (Tampa, Florida) address the satisfactory drainage within the new subdivision only, and make no mention of where the drainage waters collected within the development should be discharged. Other drainage ordinances are more specific requiring, in the case of Colorado Springs, Boulder, and Arvada, Colorado, the developer to insure that all his storm runoff waters and those draining onto his property are properly conveyed to a designated outfall -- the costs of this conveyance to be borne by the developer.

In other instances, the ordinances confine themselves to on-site drainage, but attempt to insure against drastic alterations in hydrologic response due to development by requiring detention of stormwaters. This detainment of water is accomplished by either on-site ponds or regional ponds as determined by the local authorities. The Dekalb County, Georgia, drainage ordinance is a good example of this approach, and the Metropolitan Sanitary District of Greater Chicago accomplishes similar objectives through a sewer permit issuance program that essentially mandates on-site detention of stormwater runoff.

In addition to on-site drainage facilities the more "advanced" drainage ordinances provide for off-site drainage improvement fee collection. These fees are generally referred to as Drainage Fees and are based on the rationale that upstream developers are impacting downstream drainage facilities (even with the installation of their on-site improvements). The fees are collected to either upgrade inadequate drainage facilities, or construct new downstream drainage facilities. This thinking is explicit in the Fairfax County, Virginia's zoning ordinance, Chapter 30, entitled, "Pro-Rata Share of Costs for Drainage Facilities," wherein they state:

> The purpose and intent of this section is to require a subdivider or developer of land to pay his pro-rata share of the cost of providing reasonable and necessary drainage facilities, located outside the property limits of the land owned or controlled by the subdivider or developer, but necessitated or required, at least in part, by the construction or improvement of his subdivision or development (90).

The apportionment of these drainage fees that "specially" benefit landowners within a particular basin have varied from ordinance to ordinance -- the two most popular being the "Acreage Fee" and the "Land Use Fee". The "Acreage Fee" assumes equal benefit throughout the drainage basin and is calculated by dividing the total cost of the proposed basin improvement by the total land area within the drainage basin. The Arvada, and Colorado Springs, Colorado drainage ordinances use this "Acreage Fee" apportionment method.

The "Land Use Fee" is computed in essentially the same way as the "Acreage Fee" except that the type of development is considered. This apportionment approach recognizes that single-family development does not alter the hydrologic response of a watershed to the extent that a shopping center does and hence should not be assessed the same acreage fee. Fairfax County, Virginia, has used this rationale to develop a system of graduated drainage fees based on land use. Des Moines, Iowa, has gone further than simply differentiating among land uses (22). They have developed a fairly complete set of variables (including area, runoff coefficient, distance to outlet, slope, etc.) that should be used to graduate the fee schedule in a way that best reflects the hydrologic impact of a specific development.

B. Existing development - Fees exacted from existing developed areas have taken three forms that are not necessarily a part of the drainage ordinance per se: Bond Issue, Assessment District, and Utility Fees. The Bond Issue requires a referendum and has not been very successful in recent years because of the unwillingness on the part of voters to vote themselves a higher tax. One example of a major bond issue is one that was voter approved in 1964 which generated funds to support a sizable flood control agency to deal specifially with drainage and flood control in the greater Los Angeles, California, area.

The assessment district, too, is not extremely successful. Part of this is due to the extra tax it imposes on landowners and part is due to the tremendous support required to initiate and administer the district. Another disadvantage of the assessment district is that it tends to be "piecemeal" with a number of small, non-cooperative districts that have no authority or desire to address basin-wide drainage problems. The apportionment approach of the existing districts is similar to the drainage fee assessed to new developments as described previously.

The "Utility Fee" is a relatively new approach in assessing general off-site drainage costs and has been implemented in Boulder, Colorado. This city created a "Storm Drainage and Flood Control Utility", similar to a water utility, whose task is to provide city-wide storm drainage services. The Utility collects a monthly fee from each landowner based on the use of the land (here again, the hydrologic impacts of different land uses are recognized). This technique affords a comprehensive city-wide approach to storm drainage control but relies heavily on the "general" rather than "special" benefits created by the control facilities.

The majority of the drainage ordinances reviewed do not have a payback provision for errors in the basin fee or for reimbursement of front end money supplied by the developer. The Colorado Springs ordinance did have a rebate provision but, as discussed in Chapter III, the viability of the rebate provision was questioned by the Colorado Supreme Court. Subsequent to the Wood Bros. case, the City modified their rebate provision to insure timely reimbursement.

Regulatory element - The ordinances for the management of development-induced drainage impacts are contained within building regulations, subdivision regulations, or separate Drainage ordinances. The ordinance language is generally not very specific. It appears that drainage sections were included within some of the regulations because other communities had included them. Except for some of the separate drainage ordinances, little time was spent developing a workable drainage management regulation. The impact of this poor development is, of course, poor management of development-induced drainage impacts.

Recommended Regulatory Element

Existing socio-political climate - At the present time, the politically practical approach to drainage management is based on local control without any regional or state intervention. The local governments can use their state granted authorities and their police power authorities to develop and implement a drainage management program. In this situation, the writers feel that the regulations for drainage management should be incorporated within the local subdivision regulations. The division of land marks the beginning of the alteration of the land, and in turn the alteration of the hydrologic response of the basin in which the land is located. The developer should, at the subdivision stage, be required to internalize the downstream damage costs that his land alteration is creating. The writers feel that incorporating the drainage requirements within the subdivision regulations is more desireable than creating a separate drainage ordinance with its own approval process. The subdivision review process will be more consolidated if all of the requirements are contained within the one ordinance.

Based on the land alteration rationale, the regulations for drainage management could also be contained within the local annexation ordinance or the local building codes. The writers feel that drainage requirements at the annexation stage are premature. Annexation of land into the corporate limits does not assure land alteration unless the local government's annexation contract with the developer allows the developer to bypass the procedural requirements for subdivision of land.

If the community wishes to share its responsibility for past subdivision approvals, it can include drainage regulations in local building codes. This will enable the community to attach drainage requirements to permits for development on previously subdivided land. The writers do not favor this approach unless the community also creates assessment districts over areas that were subdivided at the same time but developed earlier. Without the assessment districts, the community penalizes late developers with drainage requirements attached to the building permit. The community should carefully consider the desirability of assessment districts prior to incorporating drainage regulations within local building codes.

Proposed drainage management program additions to existing subdivision regulations - Although local subdivision ordinances vary from community to community, they generally are divided into the sections listed in Table IV-1. With this structure, there are three sections that need to be modified in order to incorporate the drainage management program into the subdivision regulations. These sections are the Policy Statement, Purposes, and Subdivision Requirements and Design Standards. The suggested modifications to these sections are described below and sample legislative language for the Subdivision Requirements and Design Standards section is included in Appendix C.

Table IV-1. Structure of Local Subdivision Ordinances.

Section	Title
I	Authority and Scope
II	Policy Statement
III	Purposes
IV	Definitions
V	Procedures for subdivision approval
VI	Subdivision requirements and design standards
VII	Enforcement and variances
VIII	Appeals

1. Policy Statement: This section of local subdivision ordinances articulates the overall policy of the municipality in exercising its granted authority to regulate subdivisions of land. A complete and well developed policy statement is important because it communicates the enforceable intentions of the lawmakers. It enables administrators to properly apply the regulations to situations not specifically covered in

the ordinance. More significantly, it is widely used in the courts to adjudge interpretative problems within the ordinance.

In the past the regulation of subdivisions has addressed land management at the subdivision level only (38). This is not acceptable since the efforts of land development are generally felt throughout a larger area. The drainage basin-wide effect of land development is one example of these extended impacts. For this reason it is important for the municipality to explicitly state its intentions to exercise its authorized grant of power in the broadest possible context. In addition, the Policy Statement of the subdivision regulation should include a statement declaring basin-wide drainage management to be a proper exercise of municipal police power.

2. Purposes: The general purpose of any local subdivision ordinance is to provide for relatively harmonious development of a community thereby protecting and enhancing the public health, safety, and general welfare of that community. To clarify any misinterpretation, specific urban drainage and flood control related purposes should be included in the Purposes section of the subdivision ordinance. These specific drainage-related purposes should include:

- the provision of adequate municipal drainage facilitites without excessively straining municipal resources,
- the provision for development to conform with applicable drainage plans, and
- the provision for approving only subdivided plots that are of a buildable character free from the dangers of flooding.

3. Subdivision Requirements and Design Standards: This section of local subdivision ordinances discusses the specific

requirements and design standards that the local government shall or may impose upon developers. It further describes the methods used to determine these requirements. This section in most subdivision ordinances is generally not very specific with regard to drainage, resulting in poor control of development-induced drainage impacts. In order to gain better control of these impacts, the following should be added to or incorporated within the Drainage and Flood Control subsection of the local subdivision ordinance:

a. Specific requirements for the provision of both on-site and off-site drainage facilities prior to subdivision approval. Except for excess capacity structures, the on-site facilities will be the sole responsibility of the developer. The excess capacity structures and the off-site facilities will be the responsibility of the developer and the local government.

b. References to the applicable engineering design manual which should be prepared in accordance with the recommended Technical element described in Chapter II.

c. Details of the methodology for computing the developer's responsibility for the excess capacity structures and the off-site facilities, and for adjusting that responsibility to account for developer construction and poor cost estimates. This methodology should follow the recommended Financial element described in Chapter III.

Alternative socio-political climate - Even if a community incorporates the most "advanced" drainage management program into its subdivision regulations, it would probably not realize completely satisfactory management results. The effectiveness of the existing local drainage regulations is being hampered by their parochial nature. The local government has no control over its neighbors; it has no extraterritorial review prerogative or right. The impact of this lack of coordination is unequal development potential. The drainage requirements encourage potential developers to build in neighboring jurisdictions with less stringent drainage regulations. Ironically, the concerned community will in some cases have to accommodate the increased storm runoff from these areas.

The shortcomings of this local approach to drainage management could be alleviated if local governments were willing to cooperate with regional and state governments. The writers suggest two regional approaches to drainage management -- a Regional/Local approach and a State/Local approach.

Regional/Local - The Regional/Local approach to drainage programs is sensible. It allows impact evaluation on an entire basin rather than within jurisdictional confines. It recognizes the true hydrologic situation of storm runoff. The weakness of this approach is that the authority remains with each local government. At the present time regional councils are advisory only and have no real enforcement capacity. This role is indicative of the unwillingness of local governments to relinquish any of their authority to a regional entity. Reference (61) is an enlightening article on the nonacceptability of regional forums.

In the more progressive urban areas, local governments may begin to move toward more cooperative planning. The Regional Governments may begin to get stronger regulatory roles. Freilich's Model Subdivision Regulations (38) includes this kind of provision for regional entities.

His Section IV entitled "Requirements for Improvement, Reservation, and Design" requires in part that:

> ...all subdivision plats shall comply with...all pertinent standards contained within the planning guides published by the applicable Regional or Metropolitan Planning Commission or Metropolitan Council of Governments.

State/Local - Carrying the regional concept one step further, a state enforced-locally controlled drainage program would effect the needed comprehensive approach to drainage control. The marriage of state and local governments would work similarly to the Minnesota Floodplain Commission (7) and the Hawaiian State Land Use Commission (7). The Minnesota Floodplain Commission was created by the Minnesota Floodplain Management Act of 1973. They have the authority to coordinate state, local, and federal activities with regard to floodplains. Local ordinances and regulations must be reviewed for conformity with state goals.

The Hawaiian Land Use Commission was created in 1961 by the Hawaiian Land Use Act. Recognizing the value of agricultural and scenic lands, this Commission has divided the Islands into four zones: urban, rural, agricultural, and conservation. The local government can act independently on any of the land within the urban zones but all development within the other three must be reviewed by either the state Land Use Commission or the Department of Land and Natural Resources.

A state enforced-locally controlled system would be much stronger than the regional approach. It also has the following advantages over existing drainage ordinances:

1. It provides for overall basin management ignoring jurisdictional boundaries. This provision will afford a better interface with the federal floodplain regulations and will be almost mandatory when storm water quality regulation becomes a reality.

2. It will alleviate the problem of unequal development opportunities by forcing otherwise unwilling local governments to participate. This will assure all local governments that their efforts in drainage control will not be diminished by nonparticipating upstream communities.
3. It will relieve local governments of the many legal uncertainties associated with drainage programs.
4. It will provide a pool of state-wide expertise in drainage control from which local governments can draw.

This intergovernmental approach is not new. The majority of federal environmental regulation consists of state governments being mandated to carry out federal policy. Some examples include: The Federal Water Pollution Control Act, the Clean Air Act, etc. These programs have enjoyed tremendous implementation success because of their equal impact on every state. All states are mandated to comply with the programs thereby destroying the era of discretionary enforcement that prompted unequal state development potentials. The programs also have been effectively carried out because of the imaginary federal club over the states' heads -- if the states do not comply, the federal government can come into the states and administer the program. Like these federal/state programs, the strength of the proposed state/local drainage program lies in a similar provision that allows the state governments to take over the local program if the local governments fail to properly implement it.

A state enforced-locally controlled system of regulation is a difficult piece of legislation to pass. State legislators recognize the local government's strong desire to keep state, and federal intervention on the local level to a minimum. The success of the few existing state/local regulations was achieved because of an atypical desire for strong state control. For example, in 1972 the voters of California overwhelmingly approved the California Coastal Zone Conservation Act. This Act established the California Coastal Commission empowered with planning and regulating the entire coastal region of California. The voters recognized the valuable coastal resource and were determined to insure some kind of unified control. They were dissatisfied with the piecemeal approach offered by the existing local regulations.

Another example is the Hawaiian Land Use Act. The success of this strong state control over land use rests on two facts:

1. The desire to preserve the central valley and other prime agricultural land and to restrict the city of Honolulu within narrow urban limits to avoid the Los Angeles-type urban sprawl that many islanders foresaw.
2. The familiarity and acceptance of strong centralized territorial governmental control that existed during the many years preceding statehood in 1959.

Voter desires have not always been successful, however. The Colorado Land Use Commission was created to plan, direct, and control land use in this rapidly growing state. The commission's powers, however, were not strong in the beginning and have been gradually eroding away. State legislators, continually under pressure from their constituent local governments who are dissatisfied with actions of the Land Use Commission, have repeatedly tried, with success, to strip the Land Use Commission of all enforceable powers. For all practical purposes, it exists today as a mere advisory agency.

These examples suggest the following recommendations for implementing the proposed state/local system of drainage regulation:

1. Drainage management must be sold to the public. The importance of basin-wide management versus jurisdictional authority must be stressed. The general public must be made to recognize the inappropriateness of strict local control over drainage matters.
2. The effectiveness of state/local legislation will be a function of the authority given to the state agency. The creation of a state drainage control agency will do more harm than good if it does not have the strength to set guidelines and policies and to require local governments to enforce them.
3. The state/local legislation should be carefully drafted to insure against legal loopholes. Costly and time consuming court actions over the interpretation of the legislation will severely reduce the effectiveness of the program. It would probably be better to do nothing than to pass legislation riddled with legal flaws.

The writers are indifferent towards the two regional approaches. Both will accomplish consistent basin-wide drainage planning and management, and both can be imposed at the subdivision stage. In addition, they can be developed to keep the regional government or the state out of the day-to-day administration leaving each local government to set up its own specific processing mechanisms. This regulatory configuration is advocated by the American Law Institute in its Model Land Development Code (1) wherein they try to follow the principle that:

> ...policy should be established at the state level but enforcement of that policy should be handled by the local development agencies in deciding particular cases, subject to appeal to a state adjudicatory board.

In the next section the writers illustrate how the State/Local approach can be enacted. This approach is implemented through changes to the state subdivision enabling legislation. A Regional/Local approach can be implemented by tailoring the intergovernmental agreements to the recommended changes in the enabling legislation.

Proposed changes to state subdivision legislation - The Legislative Declaration and the Subdivision Requirements sections of the state subdivision enabling legislation need to be modified to enact a State/Local drainage management approach. The suggested modifications to these sections are described below and sample legislative language is included in Appendix C.

1. Legislative Declaration: The legislative declaration of the state subdivision enabling legislation cites some of the problems incident to land division, outlines state policy with regard to subdivisions within the state (granting regulatory control of the "design and improvement of subdivisions" to the legislative bodies of local governments), and enumerates specific purposes to which local subdivision regulations should be directed. In order to clarify the state's policy on urban drainage and flood control, the declarations should include language that:

a. discusses safety and fiscal impacts of development-induced changes to runoff response

b. specifies state policy in the area of drainage and flood control (granting different authorities to different agencies), and

c. expands the purposes of regulating subdivisions to include sound drainage planning and management.

2. Subdivision Requirements: This section of state land division statutes grants authority to local governments to impose reasonable conditions to subdivision approval. The statute addresses such items as water systems, sewer systems, roads, and parks. The statute divides the authorities into infrastructure that the local government shall require as established by state case law, and the infrastructure that a local government may require. In general, the sections relating to urban drainage and flood control have been quite general and leave local governments in a quandary as to the extent of their regulatory authority. To avoid confusions the drainage and flood control requirements section should be made more specific in relation to the stated purposes. The enabling legislation should specifically require local governments:

a. to recover the costs of accommodating development induced drainage impacts, and

b. to properly regulate floodplain areas in accordance with federal and state guidelines.

The enforcement of these two requirements will effect a realization of the intent of the Federal Flood Insurance Program by insuring that all basin residents internalize their drainage impacts.

In order to insure a regional approach to drainage management, this legislation (or intergovernmental agreements in the case of the Regional/Local concept) should also create an agency for directing and coordinating the drainage program. This agency shall be:

a. responsible for establishing uniform policies and guidelines regarding local drainage management. These guidelines shall stress consistent hydrologic/hydraulic computations, and equitable recovery of drainage facility costs.

b. responsible for insuring that local governments comply with these policies and guidelines.

c. empowered with the necessary authoirty to carry out the responsibilities listed in items a. and b. above. This authority can include the ability of the drainage management program commission to take over the local administration of the drainage management program if the local government is not satisfactorily executing it.

d. responsible for the collection of hydrologic data throughout the state, for updating the drainage management program policies and guidelines, and for assisting local governments in developing the necessary day-to-day administrative procedures to comply with the state drainage management program policies.

The writers wish to re-emphasize that the success of the drainage management program will be determined by the effectiveness of the Regulatory element. The effectiveness of the element will depend on the care with which the legislation was drafted. More importantly, it will depend on the acceptance of the element by the people who administer and who are subject to the drainage management program. As inferred in the case of the Colorado Land Use Commission, forcing a statewide planning approach on people who did not accept it has done more harm than good. The writers suggest that the drainage management program begin with a politically workable Regulatory element regardless of its ability to deal with basin-wide problems. The basin-wide approach can be adopted later as the drainage management program gains credibility, and as people begin to recognize the interjurisdictional nature of storm water runoff.

Chapter V

CONCLUSIONS AND RECOMMENDATIONS

In this report, the writers have made the following findings:

1) Local governments are generally unable to effectively control development-induced drainage impacts. Management programs do not exist or are poorly implemented due to uncertainties surrounding drainage management such as:

- Which technical evaluation technique should be used,
- What legal authority exists for cost apportionment,
- What management approach will be equitable yet administratively and politically workable.

2) There are a number of rainfall-runoff models that are available for estimating the change in hydrologic response due to development. They range from fairly simple conceptual models to detailed computer simulation algorithms. At the present time, neither of these model types appears to predict runoff response any better than the other. As more data and better algorithms become available, this may change. When a model can be shown to predict the runoff response more accurately, it should be used because of the sensitivity of project analysis to poor runoff prediction.

3) A dual liability exists for development-induced drainage impacts. Developers are responsible for their actual land alterations and municipal governments are responsible for their actions in approving these land alterations. This dual liability and the high cost of drainage facilities makes sharing of the cost to provide structures that mitigate these impacts appropriate. The method of cost sharing is

generally under legislative control but the method enacted must be reasonable to withstand judicial overrule.

4) The effectiveness of the drainage management program will depend on the regulatory mechanism in which it is packaged. The regulations must be within granted authorities, and more importantly the regulatory approach must be acceptable to the people who administer and who are subject to the regulations.

Based on these findings, they have developed a practical drainage management program for small to medium sized communities. The drainage management program is implemented through existing local subdivision regulations and has the following features:

1) Simple technical evaluation requirements. The drainage management program requires drainage facility planning and design to be in accordance with the design criteria manual maintained by the municipal engineer.

2) Equitable and administratively practical cost apportionment techniques. Facility costs and benefits (the reduction in average annual damages) are calculated from an Initial Study plan. The costs are divided into General Costs and Special Costs in proportion to the reduction in average annual flood damage liability that accrues to the community and to new developments. The General Costs are paid by the general fund and the Special Costs are paid by new developments.

3) Timely reimbursements for front-end construction money provided by developers, and adjustments to property owners for poor estimates of project cost.

4) Growth management provisions similar to a timed-development concept.

The writers acknowledge that this drainage management program approach enforced through local subdivision regulations, will still fall short of addressing comprehensive basin-wide planning and management because of its parochial nature. However, it is favored over any regional approach because of the socio-political problems with implementing regional programs. The writers recommend that the local government, after implementing the local program, should strive for one of these regional approaches. The local government, after gaining credibility through the local program, must impress upon the community the importance of basin-wide planning with regard to drainage and flood control.

ENDNOTES

1. Verbal converstion with Mr. Ben Urbonas of the Urban Drainage and Flood Control District, Denver, Colorado, January 1978
2. The South Lakewood Gulch basin in the city of Lakewood, Colorado was used for this example
3. Clark vs. Beauprez, 377 P2d 105 (1962)
4. Ibid
5. Hankins vs. Barland, 431 P2d 1007 (1967)
6. Ibid
7. Breiner vs. C & P Home Builders, Inc. 536 F2d 27 (1976)
8. City of Englewood vs. Linkenheil 362 P2d 186 (1961)
9. Ibid
10. Ibid
11. Welch vs. City of Kansas City, 465 P2d 951 (1970)
12. Ibid
13. Baldwin vs. City of Overland Park, 468 P2d 168 (1970)
14. Ibid
15. Ibid
16. Wilber Development Corporation vs. Les Rowland Contr. Inc. 523 P2d 186 (1974)
17. Ibid
18. Verbal conversation with Mr. Ben Urbonas of the Urban Drainage and Flood Control District, Denver, Colorado, February 1978
19. Verbal conversation with Mr. Ben Urbonas of the Urban Drainage and Flood Control District, Denver, Colorado, August 1978
20. City of Buena Park vs. Boyar, 8 Cal Rptr. 674 (1960)
21. Kelber vs. City of Upland, 318 P2d 561 (1957)

22. City of Buena Park vs. Boyar, 8 Cal Rptr. 674 (1960)
23. Duncan et al. vs. St. John Levee and Drainage District et al. 69 F2d 342 (1934)
24. Ibid
25. Kirst vs. Street Improvement District No. 120 109 SW 526 (1908)
26. Thibault et al. vs. McHaney et al., 177 SW 877 (1915)
27. Luckehe vs. Reclamation District No. 2054, 238 P 760 (1925)
28. Funkhouser et al. vs. Randolph et al., 122 NE 144 (1919)
29. Reclamation Board vs. Chambers, 189 P 479 (1920)
30. Hurley vs. Board of County Commissioners of the County of Douglas, 360 P2d 1110 (1961)
31. Board of County Commissioners of Sedgewick County vs. Robb, and City of Wichita vs. Robb, 199 P2d 530 (1948)
32. Ibid
33. Ibid
34. State ex. rel. Board of Supervisors of South Florida Conservancy District vs. Warren, Governor, et al. 57 S2d 337 (1951)
35. Ibid
36. Wood Bros. vs. City of Colorado Springs, 800 P2d 500 (1977)
37. Ibid
38. Ibid
39. Ibid
40. Ibid
41. Ibid
42. Baltimore County vs. Security Mortgage Corp., 755 A2d 755 (1961)
43. Verbal conversation with Mr. Moen, Engineering Section, City of Los Angeles, West Valley Office, California, November 1976

44. See for example reference 11, or "Phase Zoning: Regulation of the Tempo and Sequence of Land Development," 26 Stanford Law Review 585 (1974)

45. See for example the Lake Minnequa Master Storm Drainage and Financing Plan, City of Pueblo, Colorado by Sellards and Grigg, Inc. 1975; Los Angeles, Cal. Kelvin Avenue Drainage District, 1968; or the Los Angeles, Cal. Shoup Ave. and Sherman Way Drainage District, 1968

46. Euclid vs. Ambler Realty, 272 US365 (1926)

47. Ibid

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f) Dekalb, GA, County of

g) Fairfax, VA, County of

h) Ingham, MI, County of

i) Lakewood, CO, City of

j) Larimer, CO, County of

k) Los Angeles, CA, City of

l) Los Angeles, CA, County of

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APPENDIX A

LIST OF INVESTIGATION RESULTS

APPENDIX A
LIST OF INVESTIGATIVE RESULTS

LEGEND AND NOTES FOR: "LIST OF INVESTIGATIVE RESULTS"

$\underline{X}R(A,B)_T$ = The ratio of the storm runoff characteristic ($\underline{X}$) for a watershed with A% of its area being impervious and B% of its area being sewered to the same storm runoff characteristic for the same watershed under rural conditions (approximately 0% impervious area and 0% sewered area) for the T year storm event (or for the watershed unit hydrograph when T=UH).

SYMBOL	STORM RUNOFF CHARACTERISTIC
X=Q	Peak stormwater runoff rate
P	"Time-to-peak" (time from the beginning of stormwater runoff to the peak stormwater runoff rate)
L	"Lag time" (time from the centroid of excess rainfall to the centroid of direct stormwater runoff)
V	Volume of direct stormwater runoff

NOTES:

1. A blank (-) within the parentheses indicates that the investigator did not examine that parameter.
2. An asterisk (*) within the parentheses indicates that the storm runoff characteristic is relatively insensitive to the value of that parameter.
3. The investigators qualitative description of the watersheds are listed when percentage values were not given and could not be estimated.

HP = high probability storm event
LP = low probability storm event
RES = residential development
SF = single-family development
PUD = planned-unit development
DEV = developed area
PD = partially-developed area
PS = partially sewered
var = various

LIST OF INVESTIGATIVE RESULTS

YEAR	INVESTIGATOR	GEOGRAPHICAL AREA OF INVESTIGATION	AREA OF STUDY BASIN (mi)^2	EFFECTS OF URBANIZATION ON:		
				Q_p	t_p & t_L	VOL
1955	BIGWOOD & THOMAS (5)	Connecticut	4.1(min) 1545(max)	$QR(RES)_{2.33}=3.5-5.5$	-	-
1961	CARTER (13)	Washington, D.C.	3.9(min) 546(max)	$QR(12,PS)_{2.33}=1.8$ $QR(12,100)_{2.33}=2.6$ $QR(100,100)_{2.33}=5.5$	$LR(*,PS)_{var}<0.4$ $LR(*,100)_{var}<0.2$	-
1961	WAANANEN(103)	Northern NJ, MI, PA, & VA	varies	$QR(DEV,-)_{HP}=3-4$	-	-
1961	WIITALA(106)	Detroit, MI	36.5 22.9	$QR(25,100)_{2.33}=2.3-2.7$	$LR(*,100)_{var}=0.3$	$VR(25,100)_{var}\doteq 1$
1962	VAN SICKLE (99)	Houston, TX	38(min) 204(max)	$QR(DEV,100)_{UH}=2-5$	$PR(DEV,100)_{UH}\doteq 0.1$	-
1963	SAWYER(81)	Long Island, NY	31 10	$QR(DEV,-)_{2.33}>1$	-	-
1965	CRIPPEN (19,20)	Palo Alto, CA (Sharon Creek)	0.4	$QR(PD,-)_{UH}=1.4$	$PR(PD,-)_{UH}\doteq 1$ $LR(PD,-)_{UH}\doteq 0.7$	-
1965	JAMES(48)	Sacramento, CA (Morrison Creek)	72.7	$QR(30,30)_{2.33}=1.6$ $QR(30,30)_{100}=1.2$ $QR(100,100)_{2.33}=4.5$ $QR(100,100)_{100}=3.1$	$PR(100,100)_{var}<1$	$VR(100,100)_{var}=$ 5.9-125

LIST OF INVESTIGATIVE RESULTS (Cont'd)

YEAR	INVESTIGATOR	GEOGRAPHICAL AREA OF INVESTIGATION	AREA OF STUDY BASIN $(mi)^2$	EFFECTS OF URBANIZATION ON:		
				Q_p	t_p & t_L	VOL
1965	ESPEY(36)	Austin, TX (Waller Creek)	4.13	$QR(27,50)_{UH}=1.5$ $QR(50,100)_{UH}=2.1$	$PR(27,50)_{UH}\doteq0.5$ $PR(50,100)_{UH}\doteq0.4$	$VR(25,-)_{var}\doteq2$
1967	WILSON(107)	Jackson, MS	1(min) 10(max)	$QR(DEV,100)_{2.33}=4.5$ $QR(DEV,100)_{50}=3$	-	-
1968	ANDERSON(2)	Washington, D.C.	0.0034(min) 570(max)	$QR(20,100)_{2.33}=3-4$ $QR(100,100)_{2.33}=6-7.7$ $QR(1-100,100)_{100}=2.4-3$	$LR(*,75)_{var}<0.2$ $LR(*,100)_{var}\doteq0.1$	-
1968	ESPEY(36)	Houston, TX	varies	$QR(50,50)_{UH}=3$	$PR(50,50)_{UH}\doteq0.3$	-
1968	MARTENS(65)	Charlotte, NC & Central NC	0.86(min) 865(max)	$QR(22,100)_{2.33}=2.4$ $QR(100,100)_{2.33}=4.7$ $QR(1-100)_{50}=1.9$	$LR(*,100)_{var}<0.25$	-
1968	LEOPOLD(60)	Compilation of results by: CARTER, WIITALA, JAMES, ESPEY, ANDERSON, WILSON, MARTENS		$QR(20,20)_{2.33}=1.5$ $QR(20,100)_{2.33}=2.5$ $QR(100,100)_{2.33}\doteq6$	-	-
1969	LULL & SOPPER(62)	Northeastern US,NH,MA,CT,NJ	4.5(min) 96.8(max)	$QR(DEV,-)_{var}>1$	-	-

LIST OF INVESTIGATIVE RESULTS(Cont'd)

YEAR	INVESTIGATOR	GEOGRAPHICAL AREA OF INVESTIGATION	AREA OF STUDY BASIN $(mi)^2$	EFFECTS OF URBANIZATION ON:		
				Q_p	t_p & t_L	VOL
1969	SARMA(79)	Indiana	0.05(min) 19.3(max)	$QR(40,-)_{UH}=1.7-1.9$	-	-
1969	KINOSITA(55)	Tokyo,Japan (Syakuzii R.)	18.7	$QR(44,-)_{LP}=1.5$ $QR(100,-)_{LP}=2.5-4$	-	-
1969	SEABURN(84)	Long Island, NY (East Meadow Brook)	31	$QR(28,65)_{UH}=2.5$	-	$VR(28,65)=1.1-4.6$
1970	FEDDES(37)	Bryan,TX	1.39 1.98	$QR(24,-)_{UH}\doteq 2$	$PR(25,-)_{UH}=0.5$ $LR(25,-)_{var}=0.6$	$VR(25,-)_{var}>1$
1970	STALL(88)	E. Cen. IL (Boneyard Creek & Kaskaskia R.)	3.58 12.3	$QR(75,100)_2\doteq 8$ $QR(75,100)_{50}\doteq 4$	$PR(75,100)_{UH}\doteq 0.1$	-
1970	DA COSTA(21)	-	-	$QR(90,-)_{var}3-12$	$PR(DEV,100)_{var}<1$	-
1971	REIMER(77)	San Diego,CA (Los Coches Creek)	0.06(min) 15(max)	$QR(DEV,50)_{100}=1.5-2.7$ $QR(DEV,100)_{100}\doteq 2$	-	-
1972	RAO(74)	Indiana & TX	0.05(min) 19.3(max)	$QR(40,-)_{UH}=1.9$	$LR(40,-)_{var}\doteq 0.6$ $PR(40,-)_{UH}=0.4$	-
1973	JOHNSON(52)	Houston,TX	0.05(min) 358(max)	$QR(35,-)_2\doteq 9$ $QR(35,-)_{50}\doteq 5$	-	-

LIST OF INVESTIGATIVE RESULTS (Cont'd)

YEAR	INVESTIGATOR	GEOGRAPHICAL AREA OF INVESTIGATION	AREA OF STUDY BASIN $(mi)^2$	EFFECTS OF URBANIZATION ON: Q_p	t_p & t_L	VOL
1974	STANKOWSKI (89)	NJ	0.6(min) 779(max)	$QR(80,-)_2=3$ $QR(80,-)_{100}=1.8$	-	-
1974	McPHERSON (95)	Schwippe Valley Germany	19.5	$QR(DEV,-)_{var}=2$	-	-
1974	DEMPSTER(29)	Dallas, TX	-	$QR(40,-)_2=1.35$ $QR(40,-)_{50}=1.16$ $QR(100,-)_{50}=1.36$	-	-
1974	DURBIN(33)	Santa Ana Valley,CA	3.7(min) 83.4(max)	$QR(DEV,-)_2=3\text{-}6$ $QR(DEV,-)_{100}\doteq 1$	-	-
1975	BRAS(9)	Puerto Rico (Hypothetical Catchment)	0.2	$QR(50,100)_{10}=1.3\text{-}2$ $QR(50,100)_{50}=1.1\text{-}1.2$	$PR(50,100)_{10}\doteq 0.65$ $PR(50,100)_{50}\doteq 0.8$	-
1975	DOEHRING(32)	Southeastern New England	34(min) 219(max)	$QR(-,-)_{2.33}=1\text{-}1.6$ $QR(-,-)_{100}=1.2\text{-}2.3$	-	-
1975	McCUEN(66)	Baltimore,MD (Grayhaven Watershed)	0.04	$QR(SF,-)_{2.25}\doteq 2$ $QR(PUD,-)_{2\text{-}25}\doteq 5$	-	-
1976	LAZARO(57)	Unity,MD	72.8 34.2	$QR(DEV,-)>1$	-	-

LIST OF INVESTIGATIVE RESULTS (Cont'd)

YEAR	INVESTIGATOR	GEOGRAPHICAL AREA OF INVESTIGATION	AREA OF STUDY BASIN $(mi)^2$	EFFECTS OF INVESTIGATION ON: Q_p	t_p & t_L	VOL
1976	CECH(14)	Texas Coastal Region (Houston, Galveston, Texas City)	varies	$QR(DEV,PS)_2$=2-5 $QR(DEV,PS)_{LP}$= lesser effect	-	-

APPENDIX B

COMPARATIVE ANALYSIS DATA

APPENDIX B
COMPARATIVE ANALYSIS DATA

Table B-1. Measures of the Physically Based Models

Modeler (Year)	Basin Area(Acres) % Imper.	Storm Date	Estimated Rec. Int.(Tr)	Q_p obs. (cfs)	SWMM				UCUR			
					Q_p sim	Q_p ratio	RMOD	RSPEC	Q_p sim	Q_p ratio	RMOD	RSPEC
Papadakis (Sept.73)	Oakdale 12.9 46%	07/02/60-2	5	17.3	15.4	0.89	0.8963	0.9696	18.0	1.04	0.8704	0.9589
		07/07/64	2	9.6	-	-	-	-	9.0	0.94	0.8167	0.9030
	Bloody Run 2380 55%	11/09/70	2	105	67	0.64	0.0927	0.5996	85	0.81	0.6267	0.9425
		05/13/71	2	208	127	0.61	0.0394	0.5242	200	0.96	0.7339	0.9647
		08/25/71	5	330	543	1.65	0.4507	0.6237	330	1.00	0.8396	0.8828
Heeps (July 74)	Vine St. 173 36%	11/06/71	2	37.8	40.1	1.06	0.8992	0.9715	71.4	1.89	0.5191	0.7129
		12/24/71	2	21.2	43.9	2.07	0.3745	-0.2923	56.4	2.66	0.2944	-1.9942
	Yarralumla 1240 20%	12/20/71	2	293	296	1.01	0.6921	0.7768	407	1.39	0.5381	0.3746
		03/03/72	2	249	117	0.47	0.7387	0.9000	159	0.64	0.5796	-0.4864

Table B-1. Measures of the Physically Based Models (Cont'd)

Modeler (Year)	Basin Area(Acres) % Imper.	Storm Date	Estimated Rec. Int.(Tr)	Q_p obs. (cfs)	SWMM				UCUR			
					Q_p sim	Q_p ratio	RMOD	RSPEC	Q_p sim	Q_p ratio	RMOD	RSPEC
Watt (April 75)	Calvin Park 89.4 27%	07/25/72	5	38.1	40.9	1.07	0.9433	0.9524				
		08/09/72-1	2	8.2	8.9	1.09						
		08/09/72-2	2	18.7	24.7	1.32						
		08/14/72	2	12.3	13.2	1.07						
		08/18/72	2	6.0	5.6	0.93						
		08/23/72	2	19.0	19.1	1.01	0.9160	0.9898				
		06/01/73	2	9.4	7.5	0.80						
		06/12/73	2	11.4	11.5	1.01						
		07/26/73	2	18.7	24.4	1.30						
		08/01/73	5	38.6	45.6	1.18	0.4999	0.5791				
Marsalek (April 75)	Oakdale 12.9 46%	05/19/59[1]	2	7.25	9.11	1.26	-	0.978	10.19	1.12	-	0.801
		07/02/60-1	2	4.6	4.69	1.02		0.949	-	-	-	0.902
		07/26/60-1	2	2.5	3.18	1.27		0.887	-	-	-	-
		07/26/60-2	2	4.3	3.14	0.73		-	3.57	0.83		0.677
		09/18/60	2	5.1	6.17	1.21		0.857	6.30	1.23		0.645
		10/14/60	2	4.5	5.61	1.25		0.661	5.97	1.33		0.288
		07/02/62-1	5	10.1	8.21	0.81		0.911	9.40	0.93		0.914
		07/02/62-2	2	7.9	6.79	0.86		-	7.72	0.93		-
		04/17/63-1	2	4.6	6.18	1.34		0.811	-	-	-	-
		04/17/63-2	2	6.5	6.52	1.00		-	6.77	1.04		0.748
		04/19/63	5	11.6	12.69	1.09		0.923	14.60	1.26		0.782
		04/29/63-1	2	6.7	6.87	1.03		0.943	7.50	1.12		0.937
		-	2	5.75	4.80	0.84	-	-	4.54	0.79	-	-
		06/19/63	2	7.80	6.84	0.88	-	0.774	7.10	0.91	-	0.724
		08/2/63-1	2	4.85	5.75	1.19	-	-	5.71	1.17	-	-

Table B-1. Measures of the Physically Based Models (Cont'd)

Modeler (Year)	Basin Area(Acres) % Imper.	Storm Date	Estimated Rec. Int.(Tr)	Q_p obs. (cfs)	SWMM				UCUR			
					Q_p sim	Q_p ratio	RMOD	RSPEC	Q_p sim	Q_p ratio	RMOD	RSPEC
Marsalek (cont'd)* (April 75)	Oakdale (cont'd)	08/02/63-2	2	5.95	7.58	1.27	-	0.953	8.30	1.40	-	0.813
		09/22/64	2	4.45	6.09	1.37	-	0.961	6.15	1.38	-	0.773
	Calvin Park 89.4 27%	07/25/72-1	5	38.1	46.0	1.21	-	0.776	48.0	1.26	-	0.616
		07/25/72-2	2	26.6	32.7	1.22	-	-	38.6	1.45	-	-
		08/09/72-1	2	8.2	9.1	1.11	-	0.859	8.6	1.05	-	0.617
		08/09/72-2	2	18.7	28.6	1.53	-	0.512	28.6	1.53	-	0.232
		08/14/72-1	2	12.3	15.7	1.28	-	0.727	13.7	1.11	-	-
		08/14/72-2	2	13.2	14.8	1.12	-	-	12.5	0.95	-	-
		08/18/72-1	2	6.0	4.4	0.73	-	0.815	4.3	0.72	-	0.688
		08/18/72-2	2	3.4	4.7	1.38	-	-	4.2	1.24	-	-
		08/23/72	2	19.0	22.0	1.16	-	0.819	25.7	1.35	-	0.597
		06/08/73	2	9.4	7.0	0.75	-	0.335	10.9	1.06	-	-0.516
		07/12/73	2	9.0	12.2	1.36	-	0.131	15.1	1.68	-	-
		07/26/73	2	18.7	27.8	1.48	-	-0.363	26.2	1.40	-	-0.465
		08/01/73	5	38.6	47.2	1.22	-	0.193	45.6	1.18	-	0.173
	Gray Haven 23.3 52%	06/05/63	5	80.7	78.0	0.97		0.979				
		06/10/63	5	79.0	78.1	0.99		0.981				
		06/14/63-1	2	30.8	31.4	1.02		0.907				
		06/14/63-2	2	23.2	33.5	1.44		-				
		06/20/63-1	2	29.6	34.1	1.15		0.865				
		06/20/63-2	2	22.6	33.7	1.49		-				
		06/29/63	2	27.2	30.9	1.13		0.912				
		08/01/63	5	88.1	63.3	0.72		0.934				

*Q_p ratio and RSPEC taken from Ref. 64.

Table B-1. Measures of the Physically Based Models (Cont'd)

Modeler (Year)	Basin Area(Acres) % Imper.	Storm Date	Estimated Rec. Int.(Tr)	Q_p obs. (cfs)	SWMM				UCUR			
					Q_p sim	Q_p ratio	RMOD	RSPEC	Q_p sim	Q_p ratio	RMOD	RSPEC
Marsalek (cont'd)	Gray Haven (Cont'd)	08/14/63-1	2	34.7	38.5	0.11		0.962				
		08/14/63-2	2	16.8	21.6	1.29		-				
		08/14/63-3	2	17.1	19.1	1.12		-				
		08/18/64	2	19.6	16.1	0.82		0.745				
		08/02/65	2	30.3	34.7	1.15		0.936				
		08/12/66	2	19.3	15.1	0.78		0.933				
Chow (May 70)	Oakdale 12.9 46%	05/19/59	2	7.2	7.6	1.06	0.9488	0.9922	10.2	1.42	0.6531	0.8294
		07/02/60-2	5	17.5	15.6	0.89	0.9071	0.9628	18.2	1.04	0.8474	0.9640
		04/29/63-1	2	6.7	5.7	0.85	0.9434	0.9322	7.8	1.16	0.9013	0.9448
		07/07/64	2	9.6	-	-			8.8	0.92	0.8087	0.9071
Jennings (July 76)	Manitou Way 141 20%	06/22/71	2	26	41	1.58						
		07/08/71	2	55	72	1.31						
		09/27/71	2	39	33	0.85						
		11/01/71	2	22	30	1.36						
		08/11/71	2	41	57	1.39						
		08/14/72	2	34	32	0.94						
		08/19/72	2	46	24	0.52						
		08/23/72	2	40	31	0.78						
		08/25/72	2	62	56	0.90						
		09/17/72	2	18	19	1.06						
		09/20/72	2	38	25	0.66						
		04/30/73	2	27	19	0.70						
		07/09/73	2	22	-	-						
		08/08/73	2	32	31	0.97						
		08/30/76	2	19	29	1.53						

Table B-1. Measures of the Physically Based Models (Cont'd)

Modeler (Year)	Basin Area(Acres) % Imper.	Storm Date	Estimated Rec. Int.(Tr)	Q_p obs. (cfs)	SWMM				UCUR			
					Q_p sim	Q_p ratio	RMOD	RSPEC	Q_p sim	Q_p ratio	RMOD	RSPEC
Jennings (cont'd)	Manitou Way (cont'd)	04/28/75	2	63	68	1.08						
		06/14/75	2	64	17	0.27						
		06/24/75	5	92	109	1.18						
		07/03/75	5	109	116	1.06						
	Crane Creek 287 19%	05/15/65	2	39	49	1.26						
		06/24/65	2	103	135	1.31						
		06/25/65	2	65	43	0.66						
		07/24/65	2	161	183	1.14						
		08/12/65	2	147	206	1.40						
		08/20/65	2	29	61	2.10						
		09/11/65	5	253	145	0.57						
		09/22/65	2	20	72	3.60						
		10/06/65	2	66	141	2.14						
		01/04/66	2	56	130	2.32						
		01/28/66	2	40	-	-						
		02/01/66	2	20	28	1.4						
		02/26/66	2	22	15	0.68						
		03/03/66	2	137	88	0.64						
		04/20/66	2	154	170	1.10						
		04/26/66	2	112	-	-						
		05/23/66-1	5	270	-	-						
		05/23/66-2	5	244	183	0.75						

Table B-1. Measures of the Physically Based Models (Cont'd)

Modeler (Year)	Basin Area(Acres) % Imper.	Storm Date	Estimated Rec. Int.(Tr)	Q_p obs. (cfs)	SWMM				UCUR			
					Q_p sim	Q_p ratio	RMOD	RSPEC	Q_p sim	Q_p ratio	RMOD	RSPEC
Brandstetter (August 76)	Oakdale 12.9 46%	05/19/59	2	7.25	7.77	1.07	0.9144	0.9603				
		07/02/60-1	2	4.60	3.89	0.85	0.8121	0.9327				
		07/02/60-2	5	17.40	15.46	0.89						
		07/02/60-3		-	-							
		07/26/60-1	2	2.50	2.01	0.80	0.6815	0.9202				
		07/26/60-2	2	4.30	3.00	0.70						
		07/26/60-3	2	2.90	2.44	0.84						
		08/02/63-1	2	4.85	4.43	0.91	0.8457	0.9481				
		08/02/63-2	2	5.95	7.18	1.21						

Table B-2. Measures of the Conceptual Models

Modeler (Year)	Basin Area(Acres) % Imper.	Storm Date	Estimated Rec. Int.(Tr)	Q_p obs. (cfs)	Q_p sim	Q_p ratio	RMOD	RSPEC	Q_p sim	Q_p ratio	RMOD	RSPEC
						RRLM					QUURM	
Papadakis (Sept.73)	Oakdale 12.9 46%	07/02/60-2	5	17.3	14.2	0.82	0.8525	0.9284				
		07/07/64	2	9.6	11.3	1.18	0.8207	0.9417				
Heeps (July 74)	Vine St. 173 36%	11/06/71	2	37.8	34.4	0.91	0.3890	0.6781				
		12/24/71	2	21.2	37.1	1.75	0.5152	0.2472				
	Yarralumla 1240 20%	12/20/71	2	293	132	0.45	0.4496	0.7667				
		03/03/72	2	249	90	0.36	0.5283	0.7882				
Watt (April 75)	Calvin Park 89.4 27%	07/25/72	5	38.1					39.0	1.02	0.9760	0.9812
		08/09/72-1	2	8.2					9.8	1.20		
		08/09/72-2	2	18.7					23.5	1.26		
		08/14/72	2	12.3					12.0	0.98		
		08/18/72	2	6.0					6.2	1.03		
		08/23/72	2	19.0					19.8	1.04	0.9621	0.9789
		06/01/73	2	9.4					9.2	0.98		
		06/12/73	2	11.4					12.7	1.11		
		07/26/73	2	18.7					24.3	1.30		
		08/01/73	5	38.6					42.8	1.11	0.5895	0.6938

Table B-2. Measures of the Conceptual Models (Cont'd)

Modeler (Year)	Basin Area(Acres) % Imper.	Storm Date	Estimated Rec. Int.(Tr)	Q_p obs. (cfs)	Q_p sim	Q_p ratio	RMOD	RSPEC	Q_p sim	Q_p ratio	RMOD	RSPEC
Marsalek * (April 75)	Oakdale 12.9 46%					RRLM						
		05/19/59	2	7.25	7.98	1.10		0.961				
		07/02/60-1	2	4.6	5.27	1.15		0.841				
		07/26/60-1	2	2.5	3.18	1.27		0.828				
		07/26/60-2	2	4.3	2.71	0.63		-				
		09/18/60	2	5.1	5.70	1.12		0.804				
		10/14/60	2	4.5	5.19	1.15		0.647				
		07/02/62-1	5	10.1	6.41	0.64		0.818				
		07/02/62-2	2	7.9	5.59	0.71		-				
		04/17/63-1	2	4.6	4.87	1.06		0.810				
		04/17/63-2	2	6.5	6.13	0.94		-				
		04/19/63	5	11.6	9.88	0.85		0.907				
		04/29/63-1	2	6.7	5.17	0.77		0.887				
		-	2	5.75	4.18	0.73		-				
		06/19/63	2	7.80	5.20	0.68		0.825				
		08/02/63-1	2	4.85	4.85	1.00		0.956				
		08/02/63-2	2	5.95	6.48	1.09		-				
		09/22/64	2	4.45	4.72	1.06		0.933				
	Calvin Park 89.4 27%	07/25/72-1	5	38.1	42.2	1.11		0.966				
		07/25/72-2	2	26.6	28.9	1.09		-				
		08/09/72-1	2	8.2	10.9	1.33		0.829				
		08/09/72-2	2	18.7	25.3	1.35		0.865				
		08/14/72-1	2	12.3	14.1	1.14		0.917				
		08/14/72-2	2	13.2	-	-		-				
		08/18/72-1	2	6.0	9.2	1.53		0.759				
		08/18/72-2	2	3.4	4.8	1.42		-				

*Q_p ratio and RSPEC taken from Ref. 64.

Table B-2. Measures of the Conceptual Models (Cont'd)

Modeler (Year)	Basin Area(Acres) % Imper.	Storm Date	Estimated Rec. Int.(Tr)	Q_p obs. (cfs)	Q_p sim	Q_p ratio	RMOD	RSPEC	Q_p sim	Q_p ratio	RMOD	RSPEC
Marsalek (cont'd)	Calvin Park (cont'd)					RRLM						
		08/23/72	2	19.0	22.8	1.20		0.971				
		06/08/73	2	9.4	11.7	1.25		0.357				
		07/12/73	2	9.0	15.1	1.67		0.002				
		07/26/73	2	18.7	25.7	1.37		0.114				
		08/01/73	5	38.6	46.7	1.21		0.649				
	Gray Haven 23.3 52%	06/05/63	5	80.7	59.4	0.74		0.866				
		06/10/63	5	79.0	58.9	0.75		0.864				
		06/14/63-1	2	30.8	32.9	1.07		0.871				
		06/14/63-2	2	23.2	27.0	1.16		-				
		06/20/63-1	2	29.6	35.7	1.21		0.842				
		06/20/63-2	2	22.6	26.9	1.19		-				
		06/29/63	2	27.2	35.4	1.30		0.834				
		08/01/63	5	88.1	59.2	0.67		0.890				
		08/14/63-1	2	34.7	40.5	1.17		0.871				
		08/14/63-2	2	16.8	19.7	1.17		-				
		08/14/63-3	2	17.1	22.6	1.32		-				
		08/18/64	2	19.6	23.8	1.22		0.444				
		08/02/65	2	30.3	36.6	1.21		0.845				
		08/12/65	2	19.3	15.7	0.81		0.953				

Table B-2. Measures of the Conceptual Models (Cont'd)

Modeler (Year)	Basin Area(Acres) % Imper.	Storm Date	Estimated Sec. Int.(Tr)	Q_p obs. (cfs)	Q_p sim	Q_p ratio	RMOD	RSPEC	Q_p sim	Q_p ratio	RMOD	RSPEC
						CUHP				SCS		
Haan (July 75)	Clays Mill 890 32.3%	05/22/73	5	318	249	0.78	0.6068	0.7654	260	0.82	0.5394	0.5994
		04/22/72	5	386	763	1.98			735	1.90		
		07/24/73	2	230	264	1.15			286	1.24		
		09/26/71	2	238	330	1.39			341	1.43		
		09/25/71	2	217	262	1.21			240	1.11		
		06/28/72	2	210	129	0.61			140	0.67		
		06/05/73	2	205	140	0.68			146	0.71		
	Lansdowne 646 30%	09/25/71	5	300	190	0.63			201	0.67		
		09/26/71	2	233	154	0.66			155	0.67		
		04/22/72	2	289	524	1.81			510	1.76		
		06/28/72	2	188	125	0.66			133	0.71		
		08/09/72	2	243	253	1.04			254	1.05		
						RRLM				UNIT HYDROGRAPH		
Chow (May 76)	Oakdale 13 46%	05/19/59	2	7.2	7.3	1.01	0.9026	0.9706	6.9	0.96	0.9670	0.9637
		07/02/60-2	5	17.5	14.2	0.81	0.8684	0.9296	15.3	0.87	0.8435	0.9521
		04/29/63	2	6.7	4.4	0.66	0.5840	0.8855	6.0	0.90	0.8626	0.9240
		07/07/64	2	9.6	11.5	1.20	0.8360	0.9412	10.7	1.11	0.8247	0.9259
						BNW						
Branstetter (August 76)	Oakdale 13 46%	05/19/59	2	7.25	5.90	0.81	0.8514	0.9189				
		07/02/60-1	2	4.60	3.45	0.75	0.8278	0.9071				
		07/02/60-2	5	17.40	21.74	1.25						
		07/26/60-1	2	2.50	1.81	0.72	0.6960	0.9662				
		07/26/60-2	2	4.30	2.88	0.67						

Table B-2. Measures of the Conceptual Models (Cont'd)

Modeler (Year)	Basin Area(Acres) % Imper.	Storm Date	Estimated Rec. Int.(Tr)	Q_p obs. (cfs)	Q_p sim	Q_p ratio	RMOD	RSPEC	Q_p sim	Q_p ratio	RMOD	RSPEC
Branstetter (August 76)	Oakdale 13 46%	07/26/60-3	2	2.90	3.21	1.11	BNW 0.8335	0.8954				
		08/02/63-1	2	4.85	3.32	0.68						
		08/02/63-2	2	5.95	6.87	1.15						

APPENDIX C

SAMPLE LEGISLATION

APPENDIX C

SAMPLE ORDINANCE SECTIONS FOR LOCAL SUBDIVISION REGULATIONS AND STATE ENABLING LEGISLATION

The sample ordinance sections presented in this appendix illustrate how the philosophical approaches to drainage management proposed in this report might be put into law. The sections represent additions to or modifications of the drainage related sections of local subdivision ordinances and state subdivision statutes. The ordinance sections are not intended to be used verbatim, but rather to be used as a guide to state governments or local communities in preparing their own regulations. The legislative bodies must obtain such legal, engineering, and planning assistance as is necessary to tailor the proposed ordinance sections to the local situations.

The appendix is divided into two parts. The first part contains ordinance sections that can be used by local governments under the traditional state grant of authority for subdivision control. The sections rely upon the "broad" inherent subdivision powers granted to local governments by the state enabling legislation in the area of urban drainage and flood control. The second part of the appendix contains sample drainage-related sections of state enabling legislation for subdivision control.

I. Local Subdivision Ordinance Sections

21.05 Drainage and Storm Sewers

21.05.01 Definitions

(a) Drainage Basin:

An area of land - generally between 10 and 100 square miles - defined by physical boundaries such that all precipitation falling upon this area will drain by gravity toward a common watercourse such as a natural stream, river, or man-made channel and will ultimately exit the area at a specific point known as the outfall (also referred to as basin).

(b) Drainage Sub-basin:

An area of land - generally between 1 and 10 square miles - contained within a drainage basin. Each drainage sub-basin has its own physical characteristics and has all the qualities of a drainage basin. The drainage basin is divided into several drainage sub-basins in order to more carefully analyze each portion of the drainage basin (also referred to as sub-basin).

(c) Off-site Drainage Facilities:

Drainage facilities physically located outside of the subdivision in question, or the excess capacity portion of drainage facilities physically located within or adjacent to the subdivision in question. These facilities are not the sole responsibility of the owner/developer of the subdivision in question; the cost of these facilities shall be shared with the owner/developer and the (name of city or county).

(d) Off-site Drainage Fee (ODF):

The fee charged to the owner/developer of the subdivision in question for sharing in the cost of providing off-site drainage facilities. The ODF represents the owner's/developer's proportionate share of providing these facilities based on the land area and land use of the subdivision in question.

(e) Project Cost:

The cost of providing the drainage facilities for a particular basin or sub-basin as recommended under the Initial Drainage Study. The cost shall include the cost of installing the facilities; all right-of-way costs, all mapping and planning costs; design, inspection, and administration costs; and appropriate contingency costs.

(1) General Costs: That fraction of the project cost that is proportional to the project benefits that accrue to the general community. These general benefits shall include the reduction in the community's flood damage liability as computed from the basin or sub-basin damage-frequency curves as well as the non-quantifiable benefits that accrue to the community such as prevention of life loss, aesthetic improvements, improved public convenience, improved land values, alleviation of health hazards, and provision for recreational opportunities.

(2) Special Costs: That fraction of the project cost that is proportional to the project benefits that accrue to new developments. These special benefits are computed as the reduction in new development flood damage liability from the basin or sub-basin damage-frequency curves.

21.05.02 General Provisions

(a) Requirements:

No subdivision of land shall be approved in the (name of city or county) until the owner/developer has suitably guaranteed the provision for both on-site and off-site drainage and storm water runoff.

(1) On-site Drainage Facilities: The owner/developer of land to be subdivided shall provide drainage facilities within his development as determined by the city (or county) engineer to be necessary for the drainage and control of stream and surface waters within his development. These facilities shall in each case be large enough to accommodate potential upstream runoff from areas inside and outside of the city (or county) and of the subdivision in question without altering existing flood elevations as shown in the city's (or county's) Flood Hazard Boundary Map. The size of the facility shall be determined by the city (or county) engineer, who shall base his determination on the applicable basin and sub-basin plans, the (name of city or county) Master Land Use Plan and any other appropriate land use planning documents. The cost of constructing drainage facilities to accommodate potential upstream runoff from land other than that being subdivided shall be shared by the owner/developer and the city (or county) in accordance with Section 21.05.02(c).

(2) Off-site Drainage Facilities: The owner/developer of land to be subdivided shall contribute to the provision of off-site drainage facilities required to convey potential runoff from his development and all areas upstream of his development to such outfall or discharge point(s) as shall be indicated on the applicable drainage basin and sub-basin plans for the drainage basin and sub-basin

within which the devleopment is located. The proportionate contribution for off-site drainage facilities shall be determined by the (name of city or county) and shall be based on an estimate of the hydrologic impact of the development as outlined in Section 21.05.04. The city (or county) may require the owner/developer to pay an off-site drainage fee (ODF) as determined under Section 21.05.04 for the proposed subdivision, or it may require the construction of necessary off-site drainage facilities that traverse through, are adjacent to, or extend beyond the proposed subdivision in lieu thereof, or it may require some combination of fee payment and facility construction. The decision to require off-site construction in lieu of payment shall be based on the construction practicability, the need for the facility, and the ability of the city (or county) to share in the cost of construction as required. The cost of constructing off-site drainage facilities shall be shared by the owner/developer and the city (or county) in accordance with Section 21.05.02(c).

(3) Location: All on-site and off-site drainage facilities shall be located in street right-of-way where feasible, or in perpetual unobstructed easements of appropriate width. The city (or county) shall cooperate with and assist owners/developers subject to the provisions of this ordinance in such matters as the exercise of its power of eminent domain for obtaining easement rights for drainage facilities.

(b) Procedures:

(1) Plans and Specifications: Prior to final approval of a subdivision plat, detailed plans and specifications for the construction and installation of the on-site and off-site drainage facilities as required under this Section 21.05 shall be prepared in accordance

with the criteria set forth in Section 21.05.02(d) by a registered professional engineer retained by the owner/developer, and shall be approved by the city (or county) engineer. A copy of the hydrologic and hydraulic design calculations and the itemized estimate of the costs of constructing the planned facilities shall be submitted along with the plans. The city (or county) engineer shall not approve the plans and specifications unless they are in substantial conformance with the applicable basin and sub-basin drainage plans. However, if the plans and specifications for the proposed drainage facilities subject to adjustment under Section 21.05.02(c) are determined not to be the most economical alternative available, and the developer elects to provide a more expensive alternative, the city (or county) engineer shall approve the plans and specifications if the developer agrees to waive his eligibility for any credit in excess of the city's (or county's) estimate of the cost of the most economical alternative available.

(2) On-site Drainage Facility Guarantee: Prior to final approval of a subdivision plat, the on-site drainage facilities required under this Section 21.05 shall either be constructed by the owner/developer and accepted by the city (or county), or shall be suitably guaranteed by the execution of a performance bond as provided in Section (number of section in ordinance that discusses requirements for performance bonds).

(3) Off-site Drainage Facility Guarantee: Prior to final approval of a subdivision plat all off-site drainage fees applicable to the proposed subdivision as required under Section 21.05.04 and as adjusted under Section 21.05.02(c) shall be paid in full, and any

off-site drainage facilities required under this Section 21.05 shall either be constructed by the owner/developer and accepted by the city (or county), or shall be suitably guaranteed by the execution of a performance bond as provided in Section <u>(number of section in ordinance that discusses requirements for performance bonds)</u>.

(4) <u>Facility Acceptance</u>: Except as provided below, all drainage facilities and appurtenant structures constructed or provided under this Section 21.05 shall upon written acceptance by the <u>(name of city or county)</u> become the property of the city (or county) and the city (or county) thereafter shall be responsible for the operation and maintenance of same. The city (or county) may allow title of an off-site drainage facility that is designed for combined flood control and park purposes to remain with the owner/developer if the owner/developer establishes or agrees to establish a homeowners' association for the continued maintenance and operation of that facility. The organizational documents of such a homeowners' association shall allow the <u>(name of city or county)</u> to assume maintenance and/or operation of the on-site drainage facility should the homeowners' association fail to properly maintain and/or operate the facility, as determined by the city (or county) engineer, for flood control and/or other designated purposes. The documents shall further declare that all costs incident to such city (or county) maintenance and/or operation shall be the responsibility of the homeowners' association and shall become a lien on the property held by each homeowner in the association until paid.

(c) Adjustments:

(1) Planning and Construction Cost Adjustments: The planning and construction cost adjustment is the adjustment for differences between the off-site drainage fee (ODF) as computed under Section 21.05.04 and the sum of the planning fees required under Section 21.05.03(c.1) plus the cost of off-site drainage facilities either inside or outside of the subdivision constructed by the owner/developer. Off-site drainage facilities include facilities outside of the subdivision boundary, and excess capacity drainage facilities inside the subdivision boundary. The cost of these facilities shall be computed by adding the construction cost of the outside facilities to the cost of the excess portion of the inside facilities. The excess portion shall be computed by multiplying the cost of the excess capacity drainage facility by the ratio of inflow from areas upstream of the subdivision to the total flow accommodated by the facility. The city (or county) engineer can define "inflow" and "total flow" in terms of peak discharge rate, volume of discharge, or a combination of both depending on the function of the inside facilities. If the sum of the required planning fees plus the off-site drainage facility cost is less than the ODF, the owner/developer shall pay the difference prior to subdivision plat approval as required under this Section 21.05. If the sum of the required planning fees plus the off-site drainage facility cost is greater than the ODF, the owner/developer shall be entitled to the difference. The owner/developer may elect not to be reimbursed this difference and may direct the city (or county) to apply the sum of money he would be reimbursed to pay for ODF's for which he is liable in other subdivisions he is developing within the city (or

county); or, upon approval by the city (or county), the owner/developer may direct the city (or county) to apply the sum of money to pay for other facility costs for which he is liable within the city (or county). If the owner/developer elects to be reimbursed, the city (or county) shall, except as provided below, pay such difference to the owner/developer from the following sources and in the following order:

- i) First, from the available funds in the particular drainage basin fund in which the development is located;
- ii) Second, from available funds in other drainage basin funds;
- iii) Third, from the city (or county) general funds specifically earmarked for drainage construction reimbursement. If these three sources are not sufficient, then the city (or county) shall include money sufficient to complete the reimbursement in the next succeeding annual appropriation ordinance. For purposes of budgeting, the cut-off date for being included in the "next succeeding annual appropriation ordinance" shall be the first day of September.

The funds from which the money is drawn to reimburse the developer shall be paid back by the drainage basin fund in which the development is located as money is collected from other developers in that drainage basin. If the city (or county) determines that the subdivision will create a new flooding problem or aggravate an existing flooding problem without the installation of off-site drainage facilities, and further determines that the city (or county) is unable to guarantee sharing the cost of constructing these facilities with the owner/developer as prescribed above, the city (or county) shall deny approval of the subdivision unless the owner/developer agrees to an extension of the adjustment period that shall not exceed ten (10) years.

(2) Poor Estimate Adjustment: Upon completion and acceptance of entire basin and sub-basin facilities, the city (or county) engineer shall determine whether the base ODF calculated pursuant to Section 21.05.04 was overestimated or underestimated. In the event of an overestimate, the properties that contributed to ODF shall receive a credit against future public works assessments for the amount of overestimate in proportion to their contribution. The city (or county) shall bear the burden of ODF underestimation.

(d) Criteria:

The design and construction of required on-site and off-site drainage facilities shall be in accordance with sound engineering practices and shall be in accordance with the criteria contained in the (name of local or regional storm drainage criteria manual) as amended and applied by the city (or county) engineer. The city (or county) engineer is responsible for developing and maintaining the amended criteria and he shall endeavor to coordinate his efforts with other jurisdictions within the same drainage basin.

21.05.03 Drainage Basin Studies

(a) Basin and Sub-basin Plans:

As soon as possible after the adoption of this ordinance, the boundaries of the drainage basins and sub-basins within the city (or county) and surrounding the city (or county) shall be delineated upon a map or maps by the city (or county) engineer. There will also be shown upon said map or maps the area in said basins which have been platted, subdivided or developed and not subject to the provisions of this ordinance, and those areas therein which are presently not subdivided and subject to the provisions of this ordinance. The recommended drainage facilities shall be shown on said maps as studies for the individual sub-basins and basins are completed pursuant to Section 21.05.03(b) and adopted by the city (or county) council. The maps shall be adopted by the city (or county) by resolution after a public hearing and shall serve as official designations of the respective sub-basins and basins. The maps will be subject to revision from time to time to conform with and show existing conditions, the results of additional studies, and other information obtained. Major revisions shall be adopted by the city (or county) only after a public hearing has been held.

(b) Drainage Study Methodology:

(1) General: Pursuant to the Multiple Planning Process described in this section, the city (or county) engineer shall cause to be made engineering studies of drainage basins and sub-basins within the city (or county) and those surrounding the city (or county) which either extend into the city (or county) or which affect or may affect present or future city (or county) territory and drainage therein. The larger basin studies shall precede the individual sub-basin studies within that basin. The city (or county) shall in all ways and within the limits of its powers solicit the (names of adjoining jurisdictions) to cooperate in the drainage basin planning process and in carrying out the drainage plan in drainage basins and sub-basins that extend outside the city (or county) limits. The engineering studies will provide an interdisciplinary investigation of the drainage basins and sub-basins with the idea of

putting drainage facilities to multiple uses. Retention sites and green strips shall, when practicable, be designed for park and recreation as well as drainage and flood control uses. In the event that such sites and strips are so used for park and recreational purposes, the owner/developer making available and granting these areas for the aforesaid uses shall be credited for Park and Recreation fees payable under this subdivision ordinance (if such fees are required under this subdivision ordinance) to the extent of the appraised value of the land within the boundaries of each area.
The studies shall be based upon land uses and developments as projected by the (name of city or county) Comprehensive Plan. The studies will develop a plan which designates the necessary conduits, open channels, natural drainage courses, greenbelts, retention ponds, and other drainage facilities, and the necessary easements and rights-of-way for these facilities required to provide for the drainage and control of storm runoff within said sub-basins and basins. Every effort shall be made to promote economies in the proposed drainage schemes by the selection of materials, structure, and methods which minimize costs. Previous studies made by the city (or county) or others shall be considered in whole or in part where applicable. The studies shall include a current estimate of the cost of providing the recommended drainage facilities. The computation of such costs shall include the cost of installing the recommended drainage facilities; all right-of-way costs; all mapping and planning costs; design, inspection, and administration costs; and appropriate contingency costs. These studies shall be authorized

as finances become available and as allocated by the city (or county) Council except as provided in Section 21.05.03(c).

(2) Multiple Planning Process: The following three studies shall be prepared for each basin and sub-basin except as provided in Section 21.05.03(c).

i) Initial Drainage Study -- This study shall be made to determine one viable plan for drainage and flood control within the basin or sub-basin and to determine the base ODF for that basin or sub-basin in accordance with Section 21.05.04. The plan is viable if either the estimated costs of the plan are less than the estimated benefits from the plan, or there exist overriding sociopolitical considerations that warrant the construction of the plan regardless of the benefit to cost relationship. If a viable plan cannot be developed, the planning process for that basin or sub-basin shall be terminated.

ii) Alternative Plan Study -- The purpose of this study shall be to consistently investigate all feasible alternative drainage schemes so that the best drainage and flood control plan for the basin can be determined and justified. The investigations shall be presented in a report to the public for their review and comment.

iii) Final Plan Study -- The purpose of this study is to prepare the master drainage plan that has been identified as the best drainage scheme for the basin or sub-basin during the Alternative Plan Study.

(c) Modifications:

(1) Planning: In the event that a proposed development lies within a sub-basin and basin that has not been studied as provided in Section 21.05.03(b), the owner/developer shall in addition to other fees required by these subdivision regulations and this Section 21.05, pay to the city (or county) one hundred percent (100%) of the estimated cost as calculated by the city (or county) engineer of completing the drainage basin and sub-basin Initial Drainage Study for the basin and sub-basin in which the subdivision is located. The owner/developer shall be entitled to an adjustment for this planning fee as provided in Section 21.05.02(c).

(2) Construction: In the event that a proposed development lies within a sub-basin and basin that does not have a master drainage plan and the adoption of a master drainage plan for that sub-basin and basin is not scheduled for within six months from the time of subdivision application, the owner/developer shall design and construct all required on-site and off-site drainage facilities in accordance with the latest adopted drainage facility plan.

21.05.04 Off-Site Drainage Fee (ODF):

(a) Project Cost Calculation:

The cost estimate prepared in the Initial Drainage Study for the viable drainage plan for the sub-basin or basin shall be the "project cost" of the necessary sub-basin or basin drainage facilities.

(b) Division of Project Cost:

The "project costs" for the sub-basins calculated in the Initial Drainage Study for each shall be divided into Special Costs and General Costs in proportion to the reduction of flood damage liability that accrues to new development and that accrues to existing development. The Special Costs shall be financed by the owners/developers of subdivisions requesting approval after adoption of this ordinance and the General Costs shall be financed through the city (or county) general fund. The method of division shall be based on the relationship between the computed reduction in average annual damages for new developments, and the computed reduction in average annual damages for existing development plus the minimum monetary equivalent of non-quantifiable considerations to make the project benefits equal the project cost. The exact method for dividing the project costs using the damage-frequency plots of the Initial Drainage Study shall be detailed in the amended criteria maintained by the city (or county) engineer.

(c) Fees:

The projected amount and type of new development shall be used to allocate the Special Costs of the sub-basin and basin Initial Drainage Study plans. The base ODF for a particular basin or sub-basin shall be computed by dividing the Special Costs of that basin or sub-basin by the sum of the projected development acreage times its development factor as specified in the following table:

Land Use	Development Factors*
Single-family Residential	1.0
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.	.
List of other city (or county) zone classifications	.
.	.
Commercial/Industrial	2.0

*Note: The Land Use/Development Factor Table is based on the relative percentages of imperviousness for each zoning classification and should be developed by the city (or county) engineer.

This base ODF shall be set for each sub-basin and basin by resolution of the city (or county) Council. The ODF for a particular development shall be determined by multiplying the applicable basin and sub-basin base ODF's by the appropriate Development Factor and then by the total gross acreage of that particular development including portions dedicated to the city (or county).

(d) Revision:

The city (or county) shall reestablish the basin and sub-basin base ODF's in accordance with changes in construction and other costs at its first regular meeting in <u>(month of first annual meeting)</u> of each year.

(e) Sub-basin and Basin Funds:

All ODF's paid to the city (or county) or other revenue received by the city (or county) for the construction of drainage facilities under this ordinance shall be placed into the applicable basin fund in which the development is located. The money collected in each fund shall be used for the provision of drainage facilities within that basin except as provided in this Section 21.05.02(c).

II. State Enabling Legislation Sections

3100. Legislative Declaration

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3100.10 Urban Drainage and Flood Control

The hydrologic impacts of land divisions can be critical to the general health, safety, and welfare of the citizens of this state and to the fiscal integrity of local communities in this state. The powers of land division set forth in this article are granted to all counties and municipalities for the following drainage-related purposes (these purposes will be in addition to general purposes stated earlier in the legislation):

(a) To encourage rational land use planning by requiring drainage basin-wide land management that complements federal flood plain management programs, and state and regional urban drainage and flood control programs.

(b) To avoid approval of land divisions that would, when acting alone or in combination with other existing and anticipated developments, create a danger to the health, safety, or welfare of the citizens of this state due to flood waters, or would necessitate an inordinate expenditure of public funds for flood water protection.

(c) To encourage equitable contribution for urban drainage and flood control facilities including preserved flood plains and structural flood control works.

3200. Subdivision Requirements

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3200.10 Urban Drainage and Flood Control

(a) General. The flow of storm water is generally not confined within one jurisdiction. Land development in one jurisdiction may seriously affect the hydrologic response of a river that traverses many other communities by increasing the volume and peak runoff rate of stormwater runoff. A drainage basin-wide land management approach is necessary to account for these multi-jurisdictional impacts.

(b) State Drainage and Flood Control Commission. There is hereby created a State Drainage and Flood Control Commission to be composed of (list of appointed or elected officials). The number and stature of these officials will vary from state to state. The intent is to create a commission that is concerned with each local government within the state, without creating a large bureaucracy). This commission shall be responsible for carrying out the drainage-related purposes of this act.

(c) Duties of the Commission. The specific duties of the commission shall include:

(1) The establishment and maintenance of a data monitoring network for the collection of representative rainfall and runoff information. The emphasis of this data collection effort should be placed in areas identified by the commission as urbanizing or soon to be urbanizing.

(2) Assisting all local land division approval agencies in the development of technical review standards. This development shall take into account the resources (financial, personnel, data, and expertise) of the local governments within a drainage basin planning area, and acceptable engineering methods previously applied in that planning area. All efforts shall be taken to expedite the development of practical and acceptable technical review standards. It shall be the policy of the commission to develop review procedures

that are readily usable with the intention of updating them as more data, personnel, finances, and greater expertise become available.

(3) Assisting all local land division approval agencies in the development of land management regulations that conform to and are consistent with federal flood plain management programs and drainage basin-wide or regional management programs.

(4) Assisting all local land division approval agencies in the development of mechanisms for equitable apportionment of the costs of drainage and flood control facilities required by land alterations. The cost recovery mechanisms shall recognize the differential drainage and flood control benefits in terms of land use, extent, and location that accrue to different properties within a drainage basin and shall treat each accordingly so far as administratively practicable.

(5) The establishment of drainage basins throughout the state and the preparation of an Initial Drainage Study on each basin in the priority established by the commission. The purposes of the Initial Drainage Study are: a) to develop a feasible cost effective drainage basin plan, b) to establish the 100 year flood plain from this plan assuming the anticipated ultimate development of the basin, and c) to estimate the total cost of implementing this plan including planning, design and construction, ROW and relocation costs. The cost estimate from this Initial Drainage Study shall be the basis for approtioning drainage and flood control facility costs as required under item 4. If a developer wants to subdivide in a drainage basin planning area that has not yet been studied, the commission

may require him to do the basin study at his expense or the commission may share in the cost of the study.

(6) The establishment of guidelines for master drainage planning in addition to the Initial Drainage Study. It is recommended that the Master Drainage Planning be broken into two phases -- a phase where alternatives are developed and examined by the public, and a phase that fully develops the recommended alternative.

(d) Enforcement. Local land division approval agencies are to begin working with the commissions within 30 days after the passage of this act. A subdivision ordinance that includes provisions for drainage and flood control technical review and cost recovery to the satisfaction of the commission must be adopted within 12 months after the passage of this act. Twelve months (12) after the passage of this act the commission is authorized and shall stop all land division approvals within a particular jurisdiction until subdivision regulations are developed to the satisfaction of the commission and are adopted by the local agency with regulatory control over that jurisdiction. All amendments to local subdivision ordinances shall be reviewed and approved by the commission before they become effective.

(e) Resources. The commission shall create a modest staff responsible for monitoring the data collection system, developing and updating technical review procedures, monitoring local government implementation of commission directives, and clerical assistance.

Each county shall be assessed for the operating funds required by the commission in proportion to the benefit each derives. The operating funds are to include staff support and expenses for Initial Drainage Studies and Master Drainage Planning.